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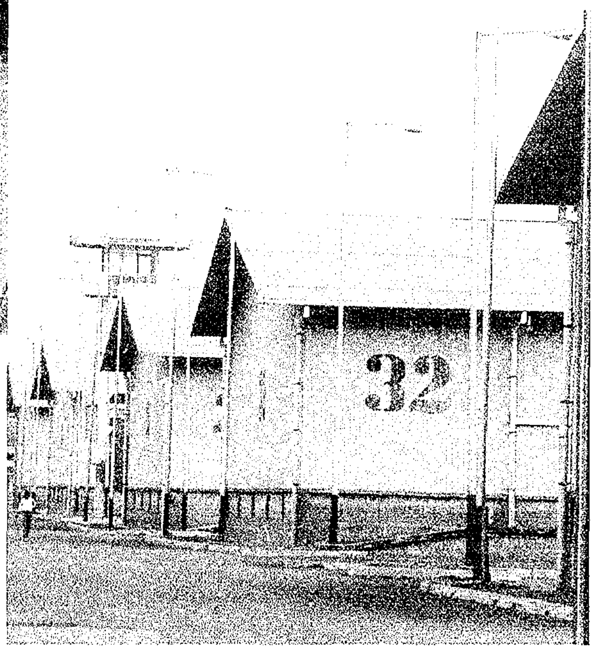
DEMONSTRATION PROJECT:

ALTERNATIVES TO THE USE OF METHYL BROMIDE IN STORED PRODUCTS IN INDONESIA

FINAL REPORT



THE NATIONAL LOGISTICS AGENCY (BULOG)
DEPARTMENT OF PLANT PESTS AND DISEASES, IPB
PT. SUCOFINDO (INDONESIA)
MARCH, 2001

EXECUTIVE SUMMARY

Indonesia as other developing countries still place agriculture as the backbone of the national economy and therefore agricultural development is one of the first priority in the national development. It is generally known that in the era of globalisation and liberalisation, the opportunity to win international market for agricultural products is widely open, as far as the country is able to meet several pre-requisites. Among those pre-requisites, quality of products plays a key role in determining the competitiveness of the marketed products in international market. Therefore it is a must that quality improvement of agricultural products be placed as one of the top priority in agricultural development, particularly on the post-harvest sector.

Recognising that exported commodity for international market and also consumers demand in domestic market, has to comply with agreed standard, various methods to maintain quality of products have been implemented. Methyl bromide has been known as fumigant capable of controlling storage pests, as well as treatment for pre-shipment of export commodity. However, with finding that methyl bromide is categorised as ozone depleting substance, attempts to find alternative technology has become of importance task. With schedule to phase-out methyl bromide as stipulated in Montreal Protocol, the alternative technology has become even more important to Indonesia as well as other countries.

Along this line a Demonstration Project on the Alternative Technology to methyl bromide was carried-out in Indonesia as an efforts to introduce alternatives technology to relevant parties, including government institutions, researchers, and more importantly private sectors involved in quality maintenance, export commodities and many others.

The demonstration project on alternative technology to methyl bromide was carried out in the year of 2000. The activities conducted were technical and financial analysis of fumigation, workshops and training, and integrated storage pest management (ISPM) survey. Fumigations on rice commodities were done once at Bulog's Tambun (West Java) warehouse and twice at Dolog's Buduran (East Java) warehouses. On coffee and wood commodities, fumigation trials

using methyl bromide and Eco_2Fume (liquefied phosphine in CO_2) were conducted three times in Lampung. The technical analyses conducted were evaluation of time-course change in fumigation concentration during the fumigation period and determination of efficacy of fumigation against target pests (*Sitophilus* and *Tribolium*), analysis of rice physical properties, monitoring of insect population in rice stacks, and pesticide residue analysis.

In the fumigation trial on rice, four methods were evaluated: (1) fumigation with cylinderized phosphine (Eco_2Fume) + contact insecticide spraying; (2) fumigation with methyl bromide + contact insecticide spraying; (3) fumigation with Eco_2Fume + cotton sheet covering + contact insecticide spraying; and (4) fumigation with phosphine in tablet formulation + contact insecticide spraying. In all treatments, even distribution and the expected level of fumigants were achieved between 18 and 24 hours from the start of fumigation. The achievement of the expected concentration of fumigants was responsible for the complete kill (100% mortality) of the test insects (*T. castaneum* and *S. zeamais*) in all treatments.

The use of cylinderized phosphine could distribute phosphine gas evenly within 24 hours and thereafter the concentration of phosphine could be kept above or at about the targeted dose (300 ppm) during the whole fumigation period (5 days) given that the plastic covering over the rice stacks were soundly air-tight. At such dose, the treatment could give a complete kill in the test insects. In the phosphine (AlP) tablet treatment, the concentration of phosphine released was much higher than the targeted dose. Thus, it can be concluded that the use of Eco_2Fume is more efficient than that of phosphine tablet. In the methyl bromide treatment, at 24 hours onwards the concentration of fumigant in the rice stacks was also much higher than that necessary to kill the test insects.

At Tambun, fumigation was done only once because the insect population, as monitored by bait traps, did not reach the control threshold after four months, whereas at Buduran, the insect population reached the control threshold after the same period of time; therefore, re-fumigation was conducted at Buduran 4 months after the first fumigation.

Comparison of the rice quality data from Tambun and Buduran led to the suggestion that initial conditions of the commodity to be stored are essential for the storage management. Implementation of other components of integrated storage management could reduce the need of frequent fumigation.

Cotton sheet covering treated with an appropriate contact insecticide could act as an effective barrier against insect infestation after fumigation. This method, however, could only be used to a limited extent because of its potential to promote fungal growth. None of the fumigation treatments could inhibit the growth of storage fungi. Among the four treatments, the worst condition — with regard to the fungal contaminants — was found in the Eco_2Fume + cotton sheet treatment. Probably the cotton sheet covering made the air within the rice stacks become more humid and this condition was more favourable for the growth and development of storage fungi.

In the fumigation trial with coffee, the concentration of phosphine could also be kept above or at about the targeted dose (300 ppm) during the whole fumigation period, but in that with wood, the concentration of phosphine could drop below 300 ppm in just 2-3 days. Inconsistencies of results with wood fumigation, with regard to phosphine concentration, might be due to the leakage in containers and/or absorption of the fumigant by wood material. Nonetheless, both in coffee and wood, mortality of the test insects reached 100%.

Results of pesticides residue analysis showed that the levels of methyl bromide residue in rice and coffee were below the acceptable limit. Likewise, the amount of fenitrothion residue in rice was also below the maximum residue limit.

The financial analysis showed that the least cost analysis can be used as a guidance to choose the most feasible alternative technology. The treatment with methyl bromide for rice was the least cost method. The second least method is phosphine in tablet, then followed by Eco2Fume. The most expensive fumigation treatment is Eco_2Fume with cotton covering. Irrespective of the cost of Eco_2Fume, the treatment with Eco_2Fume without cotton sheet covering is cheaper than that with the cotton sheet covering.

Workshops on alternative technology to methyl bromide were conducted twice, the first on April 25-27, 2000 and the second on November 7-9, 2000, both at BIOTROP, Bogor. In the first and second workshop, there were 40 and 30 participants, respectively, who came from various institutions including the Plant Quarantine Office, Bulog, Dolog, universities, research institutes, private companies, and NGOs. In the first workshop, presentations about ISPM and fumigation technique were given, and the presentations were enlightened with discussion. In the second workshop, topics of presentations and discussion included technical and financial analysis, survey to Bulog's warehouses in West Java, quality control and storage pest management, as well as preshipment and quarantine aspects. The instructors came from Bulog, universities, and private companies.

The training on alternative technology to methyl bromide was conducted in Jakarta and Bogor on August 25-29, 2000. There were 25 participants attended the training and they came from the Plant Quarantine Office, Dolog, universities, and private sectors. In the training, besides presentations in the classroom, the participants were also given a chance to do a demonstration of warehouse and shipping container fumigation and to do identification of important storage insects and pathogens. The instructors came from Bulog, universities, and private companies.

Survey on ISPM was conducted in two locations,. i.e. Bandung and Karawang. Eight BULOG's warehouse complexes or 36 warehouses were inspected. The general condition of warehouses, warehouse management, and storage pest management were evaluated. Generally, the warehouse condition is good, mainly at BULOG's new type warehouses. These warehouses are still feasible for storing commodities. One important problem is that several warehouses have few leaks and many leaks in their roof. This needs to be seriously addressed because water falling to the staples of stored commodity would decrease the quality of products. Training in warehouse management is needed particularly that related to administration, hygiene, and pest monitoring.

In adopting ISPM as an alternative to methyl bromide, several steps need to be implemented. These include understanding of various factors that cause quality deterioration starting with sound initial conditions of products; understanding of physical factors of environment; understanding the species, characteristics, and status of storage pests through routine monitoring program; and integration of various control methods by considering economic feasibility, food safety and environment conservation. By integrating all of those factors, the use of chemicals is only complementary to the whole system. On the other hand, considering negative effects of pesticides to the environment and food safety, it is worth to seriously consider the use of botanical pesticides and mineral ingredients as an alternative technology which is technically and economically feasible as well as environment friendly.

In order to improve understanding of integrated pest management in storage environment, the role of training is very important. In the context of disseminating various information and experiences in IPM as a part of alternative technology to methyl bromide, seminars, workshops or other methods are appropriate for a socialize the technology. Socialization is very important so that the people have a better understanding on methyl bromide phase out, and alternative technology to methyl bromide could be appropriately implemented.

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INTRODUCTION

Agriculture is still considered the most important sector in Indonesia economy, therefore in the national development is placed as one of the number priority. In the last two decades agricultural development has been driven towards fostering agribusiness and agro-industry, as a part of integrated rural development program, not only intended to strengthen food security at household level but more importantly to increase value-added of agricultural products as a mean to increase farmers income. Various programs have been launched to improve quality of agricultural products through improvement in post-harvest, since in the global market competition has become so fierce. Thus, it is obvious that all agricultural products for export have to meet quality standards as set-out by international organisation or institution in the importing countries. It is clear, therefore, that there are issues beyond agricultural production systems which certainly affect the contribution of agriculture in Indonesia national development.

Recognising agricultural products requires a well-established systems of the production-consumption chain, an integrated approach starting from pre-harvest to consumption should be planned properly. And in this respect efforts have been carried-out to maintain the quality of agricultural products in the post-harvest sector such as in processing and storage. However, losses due to pests and quality deterioration particularly during storage are still considered excessively high.

Methyl bromide (MeBr) is one of the most commonly fumigant used to control storage pests and pre-shipment treatment of export commodities. The total consumption of MeBr in the world has been estimated as much as 76,000 tons annually, whereas in Asia including Israel and Middle east MeBr uses approximately 24% of the world In Indonesia this fumigant is used primarily for storage treatment or quarantine treatment, since Indonesian Pesticide Committee considered MeBr is not allowed for soil treatment. Total consumption of methyl bromide in Indonesia is around 275 tons per year, which is relatively small as compared to other countries in North America.

Methyl bromide is the most popular fumigant due to its effectiveness, short exposure period, easy to handle , not too complicated and relatively cheap. Aside from these advantages, methyl bromide has been considered as ozone depleting substance since scientific evidence recently indicated that bromine released from MeBr has much stronger ozone depleting potential than chlorine from CFC's per molecular basis. Due to its destruction potential to ozone layer this fumigant has to be phased-out as scheduled by signatories of the Montreal Protocol in 1997. Therefore it is obvious that technology alternative to methyl bromide as fumigant has to be found-out.

In December 1999 BULOG was awarded a contract by the United Nations Industrial Development Organisation (UNIDO) to conduct a demonstration project on alternatives to the use of methyl bromide in stored commodities such as rice, coffee and wood products. The initiation of these activities have been started since February 1999 under the co-ordination of the Office of State Minister for Environment. Since then preparation for conducting the demonstration project has been carried-out by BULOG in co-operation with UNIDO Representative Office in Jakarta, Department of Plant Pests and Diseases, Faculty of Agriculture, Bogor Agricultural University (IPB), PT. Sucofindo (one of the leading fumigation company in Indonesia).

Detail works of the demonstration project has been described in the **Protocols for Conduction of the Demonstration Activities** basically covering three main activities which are: fumigation of rice with fumigant alternatives (cylinderized phosphine) the use of physical barriers to improve Integrated Storage Management, fumigation of export commodities (coffee and woods) in the containers, and dissemination of the results of the demonstration through workshop, training and publication. Economic and technical analyses will be conducted to verify the advantage and /or disadvantage of the new technology as compared to the methyl bromide fumigation technique including analysis to strengthen the existing BULOG Integrated Storage Management.

To implement the demonstration project three sites were selected, namely: **Tambun** (30 km east of Jakarta), **Surabaya** for stored rice and **Lampung** for export commodities which were coffee and woods. In addition to the fields works, two one-day-workshop and one three-day-training will be conducted in SEAMEO-BIOTROP, Bogor in collaboration with the Department of Plant Pests and Diseases, Faculty of Agriculture, Bogor Agricultural University (IPB).

BULOG has been working closely with two other institutions, IPB and Sucofindo to execute the demonstration project and to formalise the co-operation, separate contract with IPB and Sucofindo have been signed, using BULOG-UNIDO contract as a model. IPB responsible for conducting economic and technical analyses and dissemination the results of this project, whereas Sucofindo carried-out fumigation of coffee and woods in shipping containers. BULOG in addition to its overall responsibility of the project, also carried-out fumigation of rice in two locations, Tambun and Surabaya. Therefore to implement the demonstration project there are three separate contracts : BULOG - UNIDO, BULOG- IPB and BULOG - Sucofindo. It should be pointed-out, however, BULOG as main contractor has the overall responsibility for execution of the demonstration project as described in the Contract between BULOG and UNIDO.

MATERIALS AND METHODS

a. Materials.

Two storages each with capacity of 3.500 metric tons were made available by BULOG as location of the project, one storage in Tambun (Jakarta) and one in Buduran (15 km south of Surabaya). Rice reasonably well-milled approximately 1,600 m. t was stored in each locations and divided into 8 stacks of 50 kg -polypropylene- bag This stack (around 200 m. t) was actually slightly smaller than the normal size of BULOG's stack, but smaller stack now becomes new standard stack of BULOG under new policy which is to minimise the quantity of the stock to reduce cost of operation. Under new government policy reform, BULOG has to operate with commercial credit line. In the past this para-statal organisation used to receive special credit with lower interest rate as compared to commercial credit provided by banks.

Rice used for the demonstration project was medium -quality, imported from the USA with 5% broken kernels (stored in Tambun) and 25% broken kernels imported from China stored in Buduran, Surabaya.

b. Method.

Treatment. Treatments were slightly modified from the protocols to reflect actual BULOG's operation . With this modifications there were **4 (four)** treatment which were :**rice fumigated with cylinderized phosphine (ECO2FUME), fumigation with ECO2FUME plus cotton sheet as physical protection, fumigation with phosphine tablets and fumigation with CH3Br.** Each treatment has two replicates meaning there were two stacks for each treatment.

Prior to receive the rice, storage was cleaned and repaired to minimise cracks and crevices which normally considered potential source of insect infestation. Clean storage then sprayed using contact insecticide with active ingredient fenitrothion at the rate of 0.75 cc/m2, intended to control residual insects and provide protection against incoming insects from the surrounding areas.

Surface spraying on the peripheral of the stacks was intended to control insects crawling on the surface of the stacks and spraying was repeated routinely at four weeks interval. Cotton sheet was also sprayed using similar contact insecticide to give a good protection against incoming insects at the beginning of the treatment and subsequently after four weeks spraying was only conducted at the edge of the sheet which directly contact with the floor of the storage.

Treatment for export commodities (coffee and woods) was slightly difference than rice, since fumigation were conducted in shipping containers (made of steel) with and without aeration windows. Four containers 33 cubic feet each were used for this treatment, two containers filled with approximately 18 m. t coffee medium quality (grade number 5) with 9 % moisture contents. Another four containers with the same capacity were filled with wooden pallets about three-fourth of the container. Four containers (two containers of coffee and two containers of woods) treated with cylinderized phosphine and another four containers were fumigated with methyl bromide. Fumigation was planned to be repeated at interval of three months, .until end of observation period which was eight month. More detail description of export commodity treatment are described in other sub-section.

Sampling and sample analyses. Samples of rice from stacks treated with methyl bromide and cylinderized phosphine were drawn from five sacks of each side of the stack using spear sampling (50 cm long, diameter approximately 3 cm). The five bags selected randomly, and sampling was repeated at monthly interval from the same sacks, until observation was terminated which were 12 months.

Samples drawn from each stack were collected for quality analysis based on measurement of moisture content, milling degree, percentage of broken kernels, yellow and chalky kernels. Number of insects (both live and dead insects) were count to determine the degree of insect infestation. In addition to check the possibility of pesticides residue, samples of the rice also sent for methyl bromide and fenitrothion residues analysis and mycology test, to check fungal infection.

The pesticides residue and mycology analyses were carried-out only at the beginning and the end of observation period. Physical analyses were conducted at BULOG laboratory in Tambun, whereas fenitrothion and mycology tests were done at SEAMEO-BIOTROP, Bogor and bromine residue test was carried-out at National Atomic Energy Agency in Jakarta.

In addition to spear sampling, to monitor the insects population in stacks treated with cylinderized phosphine covered with cotton sheet and stacks fumigated with phosphine tablets, bait-traps were placed in three places of each side of the stack; therefore total number of bait traps per stack was 12. The bait-traps were observed at 30 days interval to figure out species of insects found and to monitor population of the insects. Bait trap was made of perforated plastic mesh filled with brown rice which had relatively high percentage of broken kernels, intended to attract insect to harbour in the trap. The number of insects trapped in each trap was counted to predict the level of insect infeastation in each stack.

Sheeting of the stack. Good quality gas tight PVC sheets (its size approximately 25 m x 25 m) without holes was used to cover stack, since the size of the stack was ssmaller than the plastic sheet, the rest of the plastic was rolled and folded at the corner. To ensure there would be no gas escaping from the enclosure, a heavy weight iron chain was used, functioning as 'sand snake' during fumigation process.

Specially made cotton sheet enclosures were used to cover two stacks of milled rice in each location (Surabaya and Jakarta), with the main objective as physical barrier to prevent insect re-infestation. The physical protection was intended to improve Integrated Storage Pest Management which is now being implemented by BULOG. Prior to place on the stack the cotton sheet was sprayed with contact insecticide (fenitrothion) to provide pesticide residue in the cotton sheet to control incoming insects that could become a source of new infestation to the stack. The size of cotton enclosure was suited to the stack and its dimension was (14 x 7 x 6) meter per sheet. and it made with double sewing to ensure its strength for multiple uses.

Bioassay and measuring gas concentration. To evaluate the effectiveness of fumigations bioassay using a 50 g of milled rice infested with 25 *Sitophilus zeamais*, and another 50 g of milled rice infested with 25 *Tribolium castaneum*. Both insect tests six tubes of each species were placed near gas concentration monitoring tubes; therefore in each stacks there were 12 bioassay tubes in place prior to fumigation. After fumigation, bioassay tubes were removed and examined for insect mortality. The number of live and dead adult insects were recorded and compared with untreated control. Evaluation of effectiveness of fumigation were continued by examining bioassay tubes until four weeks after fumigation. The results of this examination will ensure that fumigation have controlled insects of pre-adult stages (egg, larvae, and pupae). The number of adults emerged in the control samples provided an indication of the level of infestation by pre-adults at the time of fumigation.

Gas concentration was measured using a gas monitoring tubing line, placed in top. middle and bottom levels adjacent to the corner of each stack. And also another half way along the side of the stack, that made six monitoring points per stack A phosphine meter was connected directly to the monitoring tubing line and reading was carried out one hour after fumigation and repeated after six hours during the working hours. A methyl bromide meter was used to measure gas concentration one hour after fumigation and measurement was repeated six hours after released of the methyl bromide gas, but again only during the working hours.

Dosage rate and exposure period. Fumigation with pressurised phosphine (ECO2FUME) was conducted at the rate which produced at least 200 part per million phosphine throughout the exposure period minimum four days. Fumigation using phosphine tablets was also conducted (in two stacks) and the rate was 2 tablets per metric ton, and exposure period of minimum four days. Methyl bromide fumigation was conducted with dosage rate of 21 g/m3 and 48 hours fumigation period. During fumigation physical conditions such as temperature and relative humidity inside the storage was monitored using thermo-hygrometer

Economic and technical analysis. To verify the feasibility of alternatives technology to methyl bromide, a technical and economic analysis would be carried out, based on various parameters. On technical analysis the advantage and disadvantage of each alternative technology would be assessed based on quality changes of the rice during storage period, complexity of its application and implementation procedures as compared to methyl bromide as a 'control'.

Financial Analysis

This financial analysis was performed based on data collected during the demonstration project on alternative technology to methyl bromide. The unit costs were derived from every treatment used in the demonstration. The four treatments applied were:

A. Cylinderized liquefied phosphine in CO_2 (Eco_2Fume) without cotton sheet covering.
B. Methyl bromide.
C. Eco_2Fume with cotton sheet covering
D. Phosphine (aluminium phosphide) in tablet formulation.

Data on the unit cost of all components in each fumigation treatment were taken. These include the price of fumigant materials (Eco_2Fume, methyl bromide, and AlP tablet), fumigant dispensing equipment and supplies, plastic fumigation sheet, cotton sheet for treatment C, residual contact insecticide, and labour cost. The depreciation cost was used for equipment that can be used more than once.

Assessment on the cost for implementing technology alternative to methyl bromide would be used to find its economic feasibility as compared to methyl bromide. If possible a monthly market test would be conducted to check the relationship between quality changes of the treated rice and its value in the market. Market test would give an indication of quality deterioration in relation to the price of the treated rice in the market. Moreover, as a part of technical analysis, assessment on the current implementation of Integrated Storage Management in several storage in West Java would be conducted to allow improvement to increase efficiency and practicability of this system in the field.

Dissemination and publication. Two workshops and one training course on the improved technology would be conducted, as an effort , to disseminate the results of the demonstration project. The participants were decision makers, practitioner, researchers and others who involve in the use of fumigation techniques as a tool to maintain grain quality and insect control, would participate in these activities, so they would familiar with application of the alternative technology to methyl bromide.

Workshops and Training

The workshops were conducted twice, the first on April 25-27, 2000 and the second on November 7-9, 2000, both at BIOTROP, Bogor. In the first and second workshop, there were 40 and 30 participants, respectively, who came from various institutions including the Plant Quarantine Office, Bulog, Dolog, universities, research institutes, private companies, and NGOs. In the first workshop, presentations about ISPM and fumigation technique were given, and the presentations were enlightened with discussion. In the second workshop, topics of presentations and discussion included technical and financial analysis, survey to Bulog's warehouses in West Java, quality control and storage pest management, as well as preshipment and quarantine aspects. The instructors came from Bulog, universities, and private companies.

The training on alternative technology to methyl bromide was conducted in Jakarta and Bogor on August 25-29, 2000. There were 25 participants attended the training and they came from the Plant Quarantine Office, Dolog, universities, and private sectors. In the training, besides presentations in the classroom, the participants were also given a chance to do a demonstration of warehouse and shipping container fumigation and to do identification of important storage insects and pathogens. The instructors came from Bulog, universities, and private companies.

Integrated Storage Management Survey

The survey was conducted in two locations under the authority of West Java Dolog (*Depot Logistik* = Logistic Warehouse), i.e. Bandung and Karawang. Three warehouse complexes (GBB = *gedung baru Bulog*, BULOG's new type of warehouse) in Bandung, i.e. at Gedebage, Cimindi, and Paseh complexes, and five warehouse complexes in Karawang, i.e. at Jatisari, Cilamaya, Cibitung, Purwasari, and Rengasdengklok complexes, were inspected. The survey was carried out by interviewing warehouse employees using a structured questionnaire and by direct inspection of warehouses. Three aspects were evaluated in this survey, i.e. the general condition of warehouses, warehouse management and storage pest management.

A manual of improved integrated storage management and also a manual of application of cylinderized phosphine in storage will be published and sent to relevant government organisations, researchers and pest control companies to make them aware and familiar with the new technology.

RESULTS AND DISCUSSION

Technical Analysis

Time-Course Changes in Fumigant Concentration
Rice

Fumigation was conducted only once at Tambun since the insect population did not reach the control threshold level after 3 months, i.e. less than one insect was caught per trap (Appendix Table 17) and only 0 to 1.5 insect larvae were found in rice samples (Appendix Table 15). At Buduran, however, re-fumigation was conducted 4 months after the first fumigation since the insect population exceeded the control threshold level after 3 months, i.e. on the average about 21 insect individuals were caught per trap in treatment D (Celphos 56 T) (Appendix Table 18) and up to 21 insect larvae were found in rice samples (Appendix Table 16).

Fumigant concentrations over time at different measurement points for various treatments are shown in Figures 1 to 6 and Appendix Tables 1 to 11. Results of the bioassay showed that all fumigation treatments could kill all test insects (adults *T. castaneum* and *S. zeamais*) in the bioassay tubes placed on treated rice stacks.

The data on gas concentration suggest that in most cases the fumigants had not diffused evenly and at most sampling points the concentration of fumigants had not reached the expected level (300 ppm) at 1 hour after fumigation. One hour after fumigation, both at Tambun and Buduran, in the treatment with cylinderized phosphine (Eco$_2$Fume), the concentrations of phosphine at about the position of release, i.e. the lower level (bottom corners and sides), were much higher than those at the other sampling points (Figures 1, 3 and 5, and Appendix Tables 1, 2, 5, 6 and 9). In the treatment with AlP tablet (Celphos 56 T), the concentrations of phosphine at nearly all sampling points were still low and had not reached the expected level (Figures 2B, 4B and 6B, and Appendix Tables 4, 8 and 11). Reaction between AlP fumigant tablet and air moisture is needed to release phosphine from the tablet.

In all cases, even distribution and the expected level of fumigants were achieved between 18 and 24 hours from the start of fumigation. The achievement of the expected concentration of fumigants was responsible for the complete kill (100% mortality) of the test insects (*T. castaneum* and *S. zeamais*) in all fumigation treatments. The most stable level of fumigant concentration was seen in the treatment with cylinderized phosphine, both at Tambun and Buduran as well as in the treatment without or with cotton sheet. This suggests that CO_2 in the Eco$_2$Fume contributed to the even distribution of phosphine. In the treatments with Eco$_2$Fume at Tambun, since 24 hours after fumigation until the end of fumigation period, the concentrations of phosphine were not markedly different among sampling points and could be kept above the expected level (Figure 1 and Appendix Tables 1 and 2). The same tendency was also observed during the first fumigation trial at Buduran, but in general the concentrations of phosphine decreased to below 300 ppm beyond 4 days after fumigation (Figure 3 and Appendix Tables 5 and 6). Probably the placement of plastic covering sheet at Buduran was not as tight as that at Tambun. The condition was even worse during the second fumigation at Buduran, where the concentrations of phosphine dropped to below 300 ppm in less than 3 days (Figure 5 and Appendix Table 9). Thus, air-tightness of the plastic covering sheet and the absence of cracks on the floor beneath the rice stacks constitute prerequisites for the success of fumigation with Eco_2Fume. Otherwise, higher rates of fumigation would be needed to maintain phosphine concentrations above the expected level during the whole fumigation period.

At Tambun, the concentration of phosphine in the treatment with Eco_2Fume + cotton sheet was generally lower than that in the treatment with Eco_2Fume without cotton sheet. This phenomenon, however, was not observed at Buduran. Thus, under certain conditions the cotton sheet may interfere with fumigant distribution in the rice stacks. Nonetheless, at Tambun the final fumigation concentration in the Eco_2Fume + cotton sheet treatment reached the targeted dose (Figure 1B and Appendix Table 2).

At Tambun and Buduran (first fumigation), the concentration of methyl bromide reached the highest level (exceeding the reading limit of the Cosmos MeBr meter) within 20 hours from the start of fumigation, but gradually decreased after 24 hours onwards (Figures 2A and 4A). During the second fumigation at Buduran, the concentration of methyl bromide even had exceeded the reading limit of the Cosmos MeBr meter only within 1 hour from the start of fumigation (Figure 6A). The concentration of phosphine in the treatment with AlP tablet fluctuated rather markedly until about 85-90 hours from the start of fumigation (Figures 2B, 4B and 6B). The fluctuation was very likely to be due to subsequent varied releases of phosphine from the tablet which were much affected by moisture in the air. In the AlP tablet treatment, the final concentration of phosphine was much higher than that in the Eco_2Fume treatments. This suggests that the use of Eco_2Fume is more efficient than that of phosphine in tablet formulation.

In conclusion, the use of cylinderized phosphine could distribute phosphine gas evenly within 24 hours and thereafter the concentration of phosphine could be kept above or at about the targeted dose (300 ppm) during the whole fumigation period (5 days) given that the plastic covering over the rice stacks were soundly air-tight. At such dose, the treatment could give a complete kill in the test insects.

Coffee and Wood

In all fumigation trials, the concentration of methyl bromide both in coffee and wood containers were above 5000 ppm until 48 hours from the start of fumigation, and this was beyond the measuring capacity of the Cosmo MeBr meter and overly higher than the recommended dose of MeBr fumigation, i.e. 300 ppm (the data are not presented in the form of tables or figures since the MeBr reading showed the figure of 5000 at all measurement points during the whole fumigation period [48 hours]).

Unlike methyl bromide, the concentration of phosphine (from the Eco_2Fume treatment) decreased markedly within 18 hours from the start of fumigation (Figures 7 – 9). The concentrations of phosphine at 1 hour after fumigation generally exceeded the reading limit of the Bedfont meter (2000 ppm), and at 18 hours after fumigation the concentrations of phosphine generally decreased to about 600 ppm both in coffee and wood containers (Appendix Tables 12 – 14). In the three fumigations of coffee, the concentrations of phosphine could be maintained above or at about the targeted dose (300 ppm) until 96 hours from the start of fumigation. In the trial with wood, however, such conditions were achieved only in the second fumigation. In the first fumigation of wood, the concentrations of phosphine even dropped to below 300 ppm after 2 days and thereafter the concentrations decreased further (Appendix Table 12). In the third fumigation of wood, the concentrations of phosphine dropped to below 300 ppm after 3 days (Appendix Table 14). Inconsistencies of results with wood fumigation, with regard to phosphine concentration, might be due to container leakage and/or absorption of the fumigant by wood material.

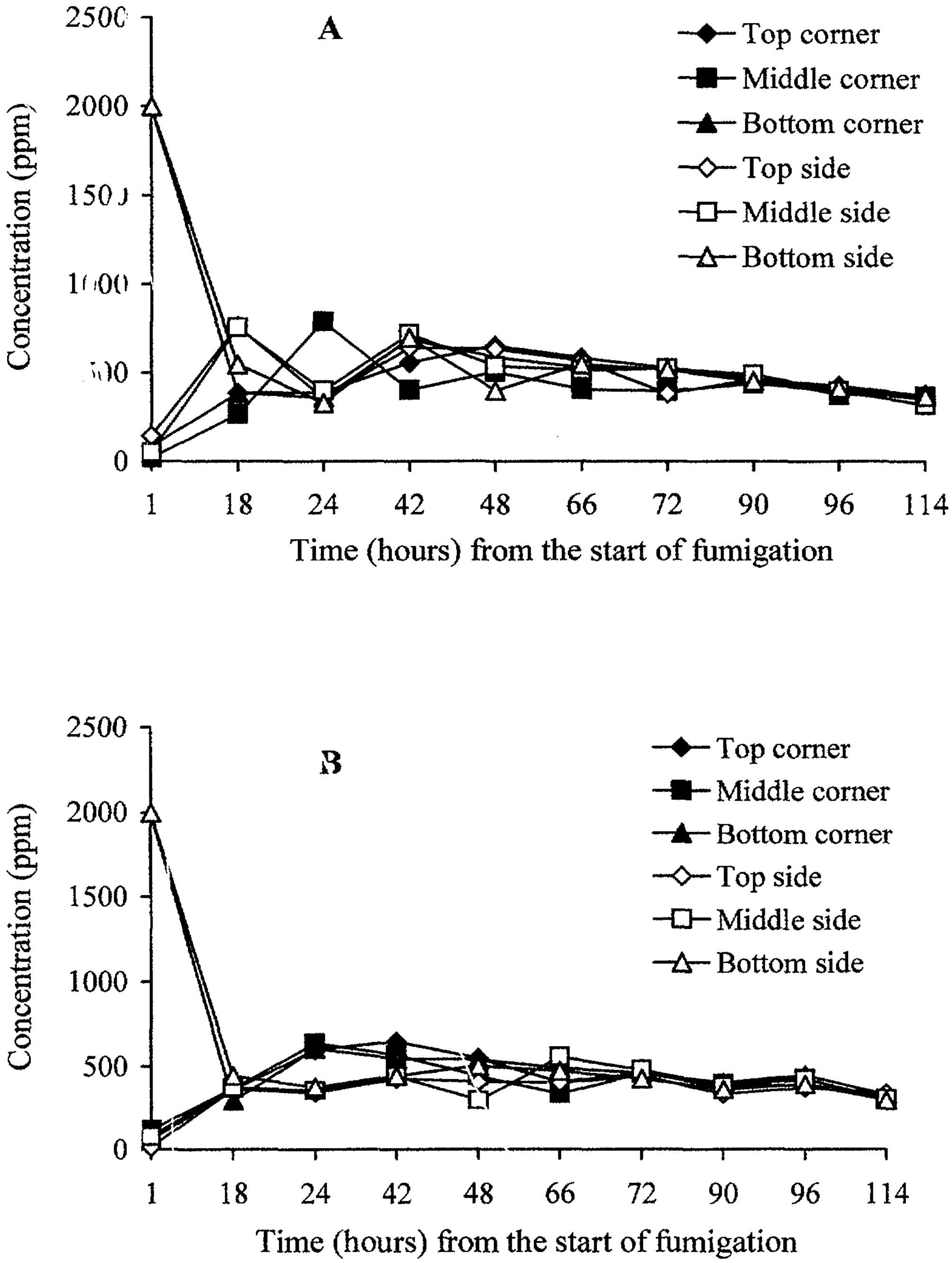


Figure 1. Time-course change in phosphine concentration at different points of rice stacks in the treatment with cylinderized phosphine Eco_2Fume (A) and Eco_2Fume + cotton sheet (B)) at Tambun Research Center.

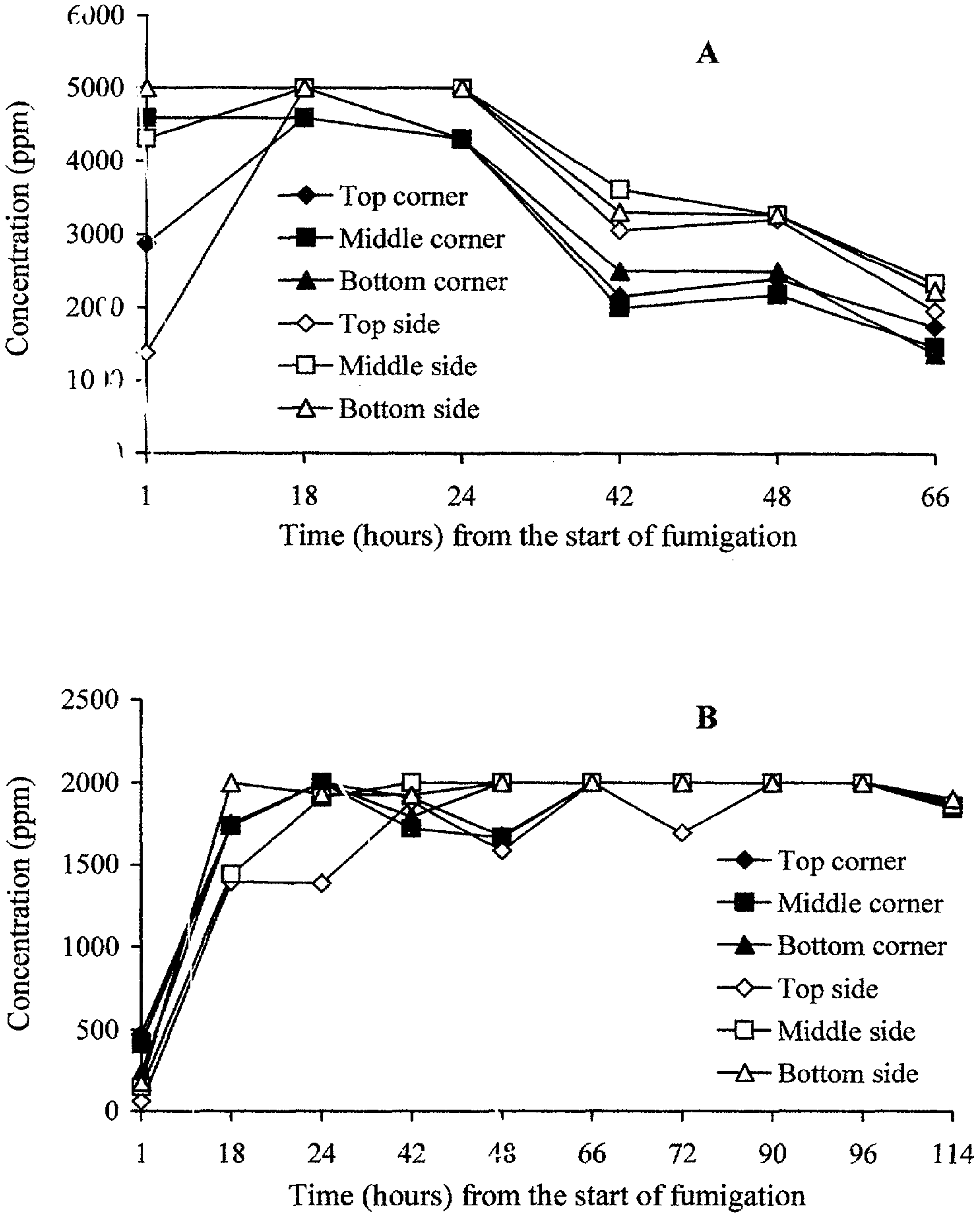


Figure 2. Time-course change in fumigant concentration at different points of rice stacks in the treatment with MeBr (A) and phospine tablet Celphos 56 T (B) at Tambun Research Center.

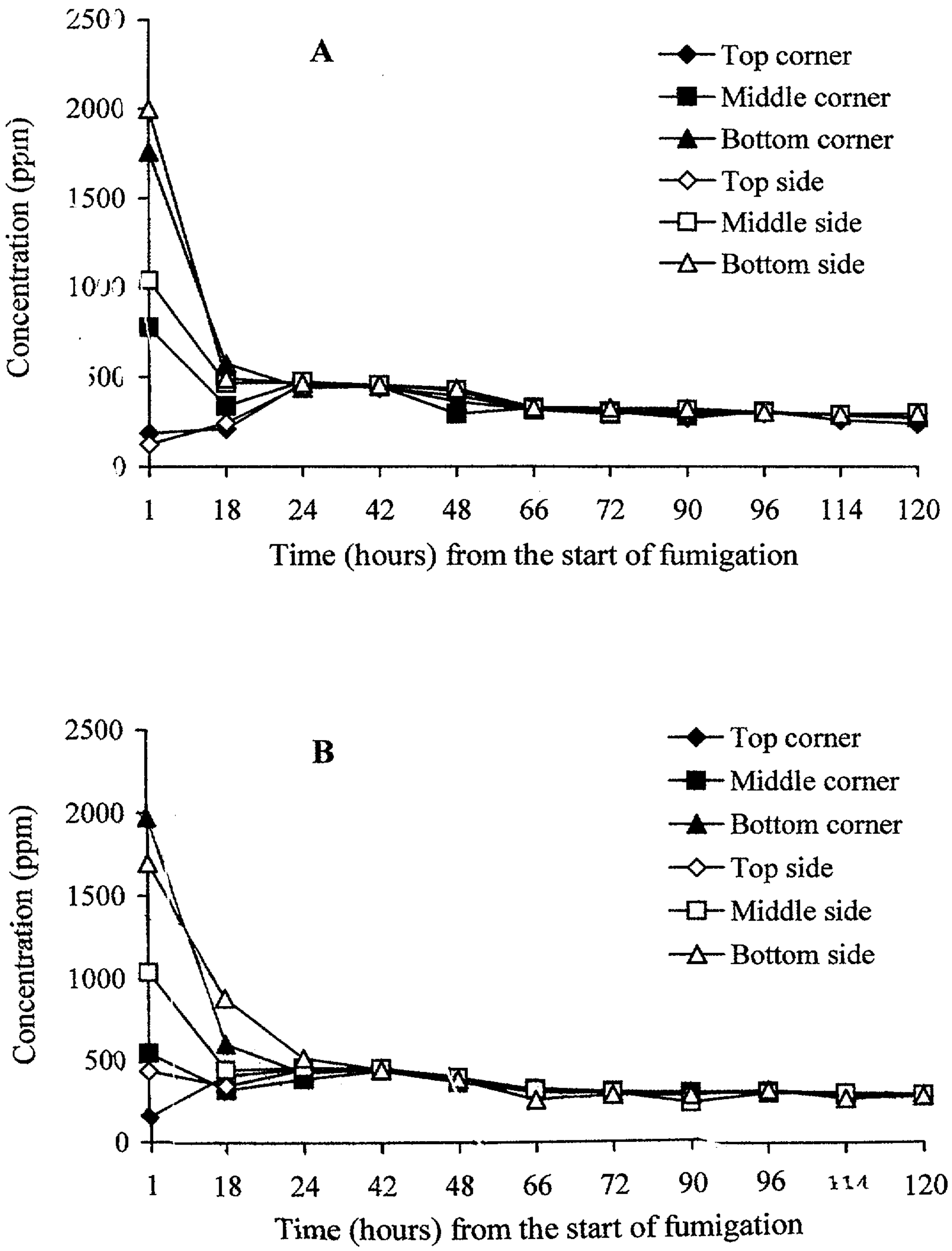
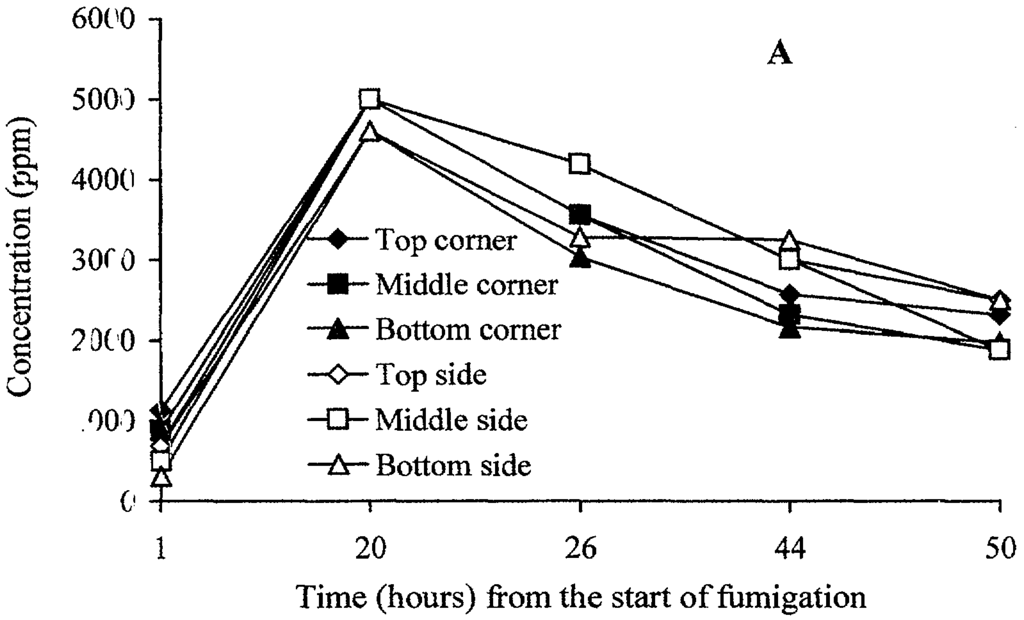


Figure 3. Time-course change in phosphine concentration at different points of rice stacks in the treatment with cylinderized phosphine Eco_2Fume (A) and Eco_2Fume + cotton sheet (B)) at Dolog's Buduran Warehouse, Surabaya, East Java (first fumigation).



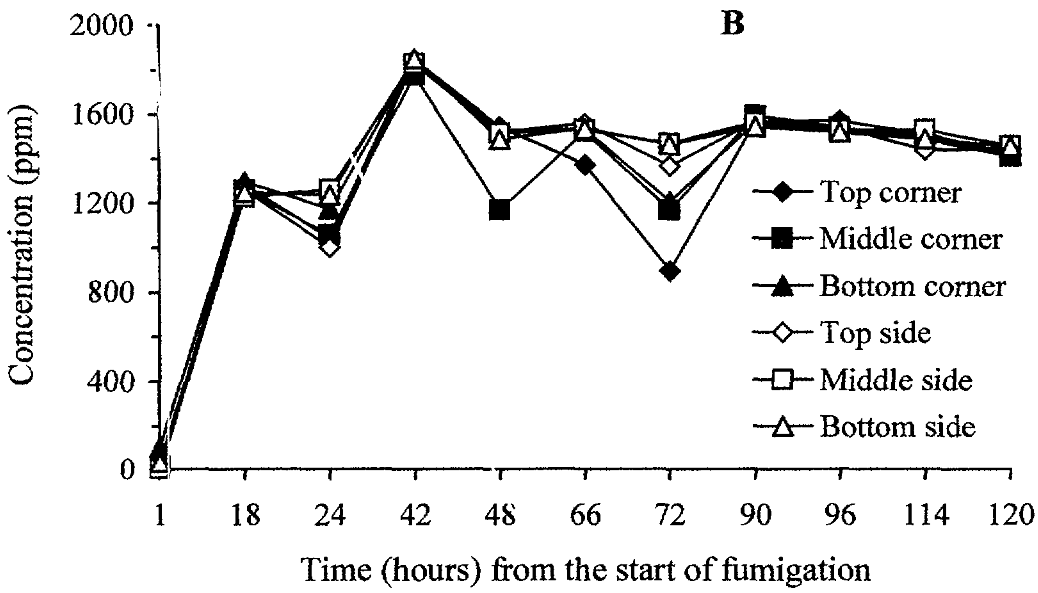


Figure 4. Time-course change in fumigant concentration at different points of rice stacks in the treatment with MeBr (A) and phospine tablet Celphos 56 T (B) at Dolog's Buduran Warehouse, Surabaya, East Java (first fumigation).

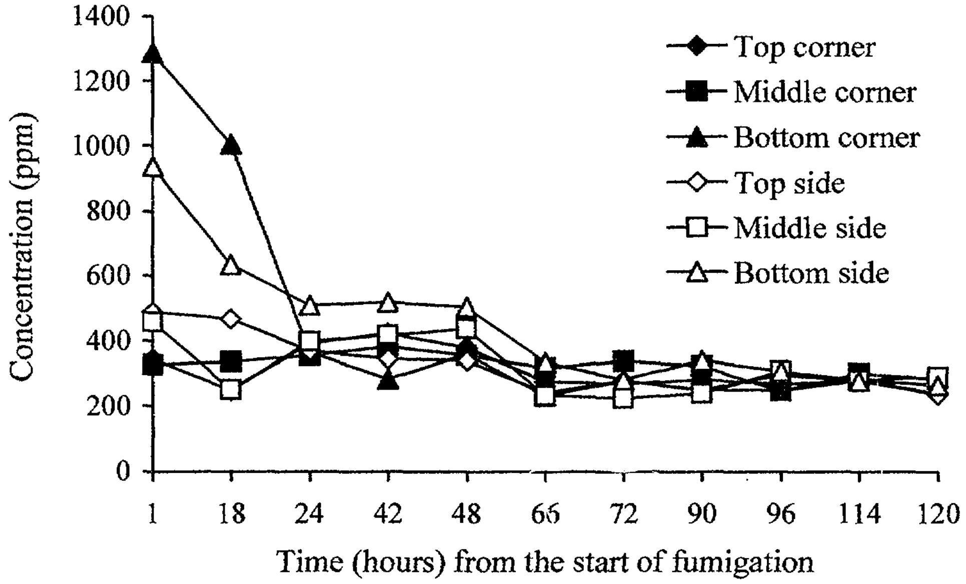


Figure 5. Time-course change in phosphine concentration at different points of rice stacks in the treatment with cylinderized phosphine Eco_2Fume at Dolog's Buduran Warehouse, Surabaya, East Java (second fumigation).

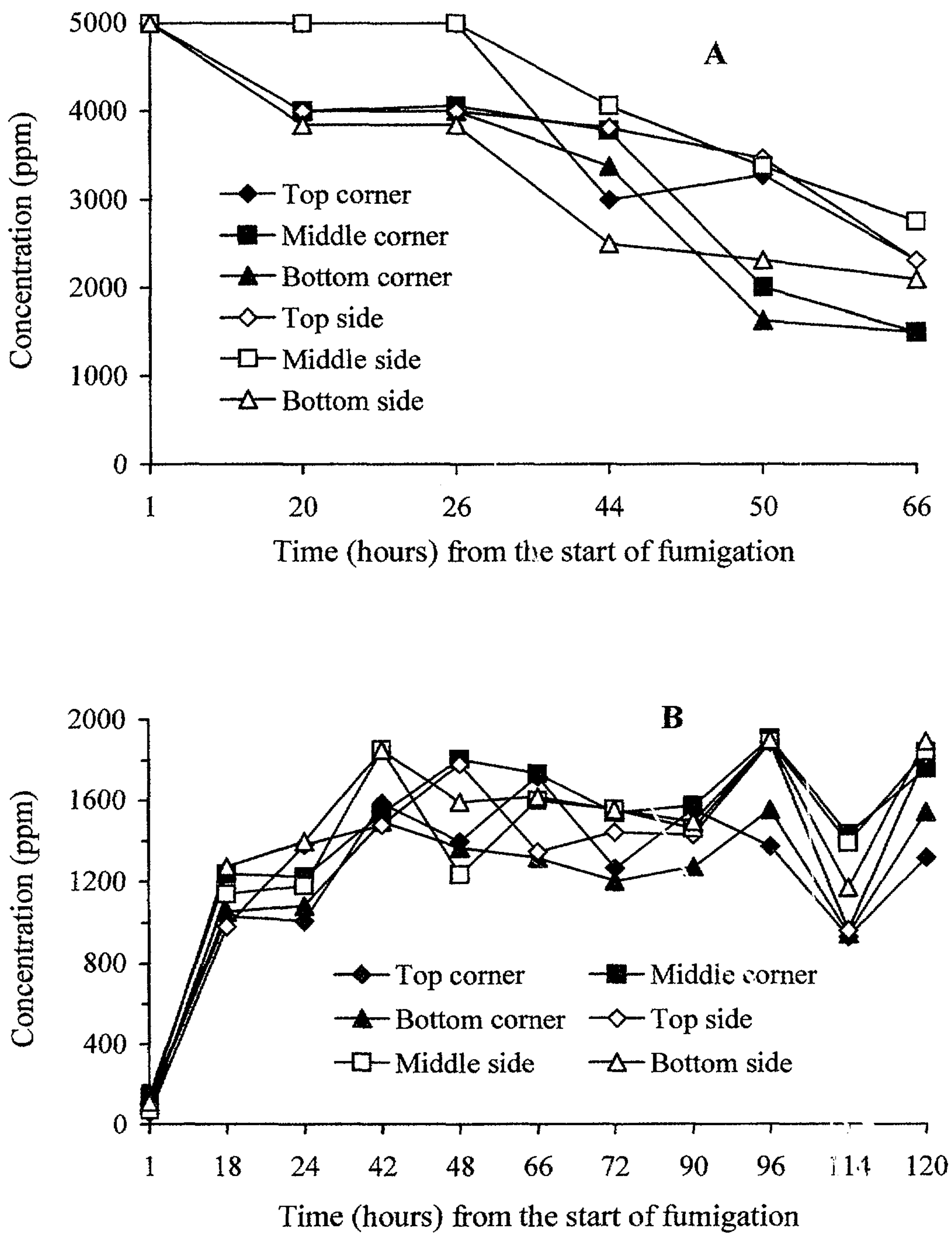


Figure 6. Time-course change in fumigant concentration at different points of rice stacks in the treatment with MeBr (A) and phospine tablet Celphos 56 T (B) at Dolog's Buduran Warehouse, Surabaya, East Java (second fumigation).

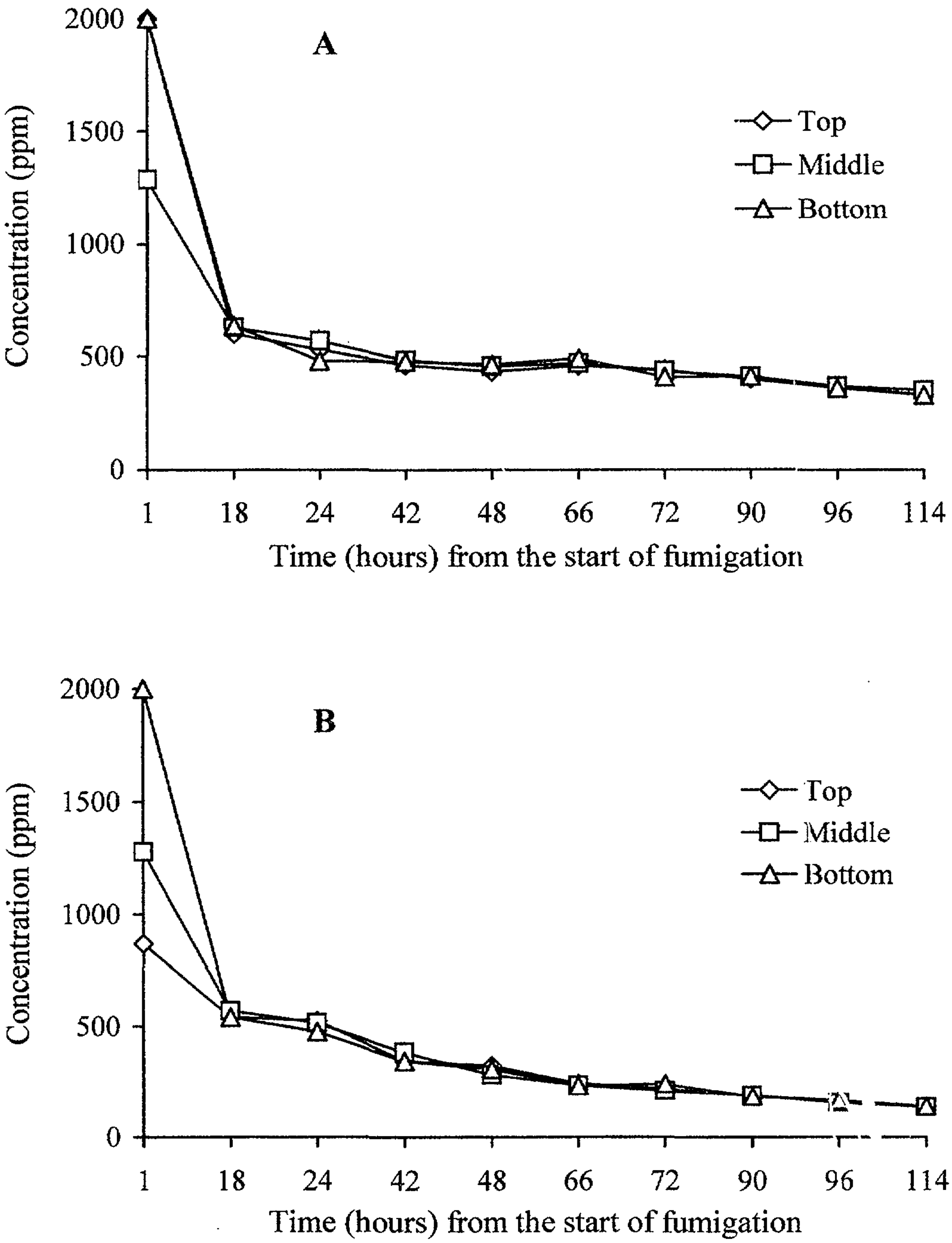
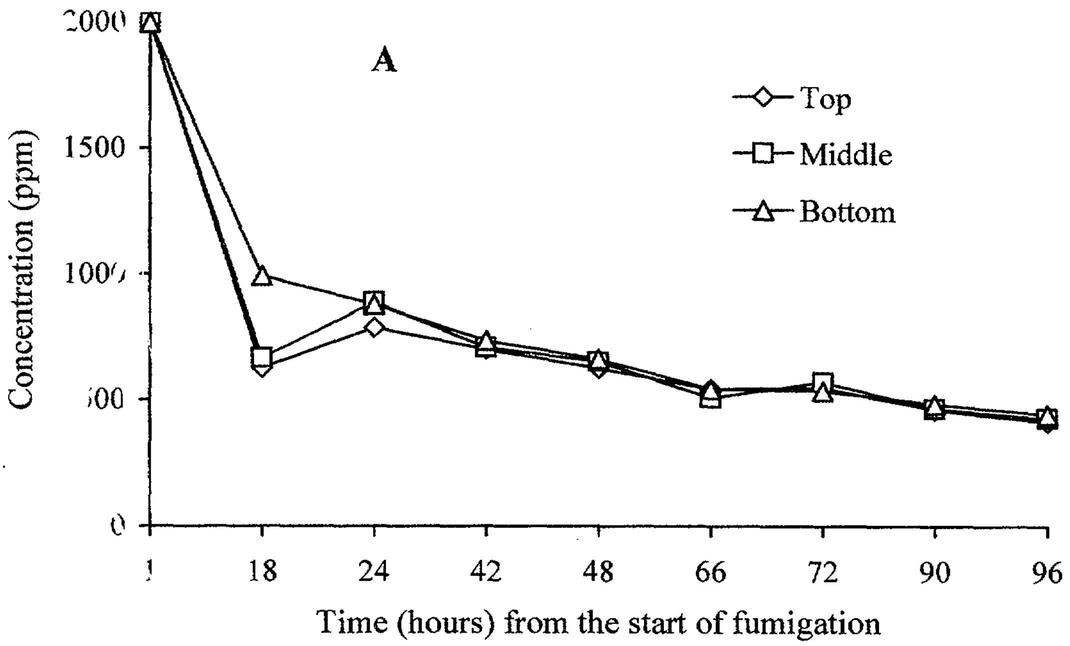


Figure 7. Time-course change in fumigant concentrations at different points of coffee container (A) and wood container (B) in the treatment with cylinderized phosphine Eco_2Fume in Lampung (first fumigation).



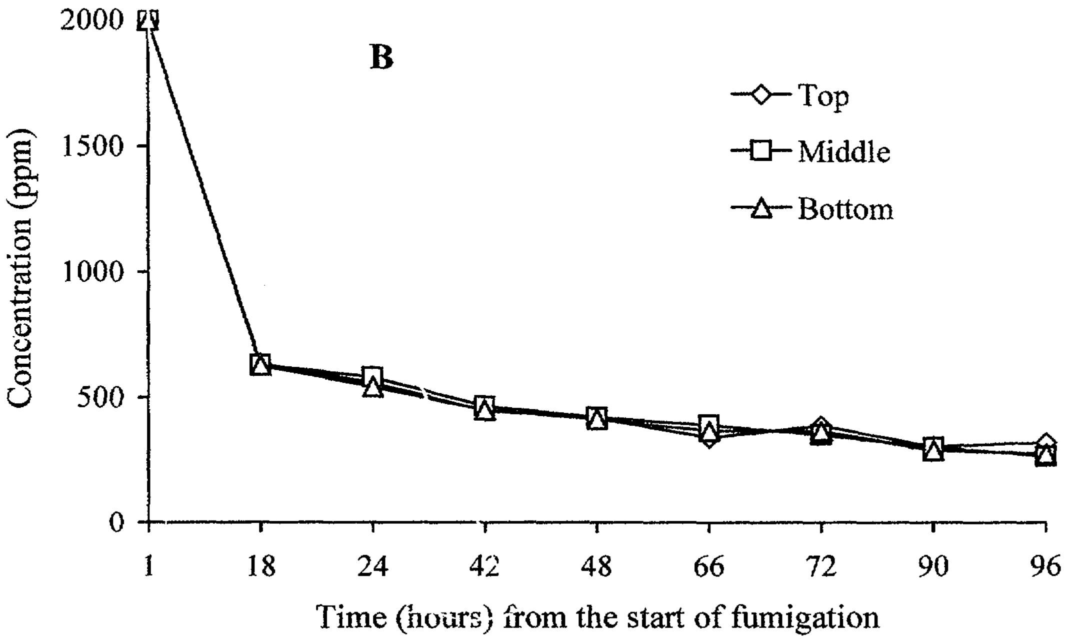


Figure 8. Time-course change in fumigant concentrations at different points of coffee container (A) and wood container (B) in the treatment with cylinderized phosphine Eco_2Fume in Lampung (second fumigation).

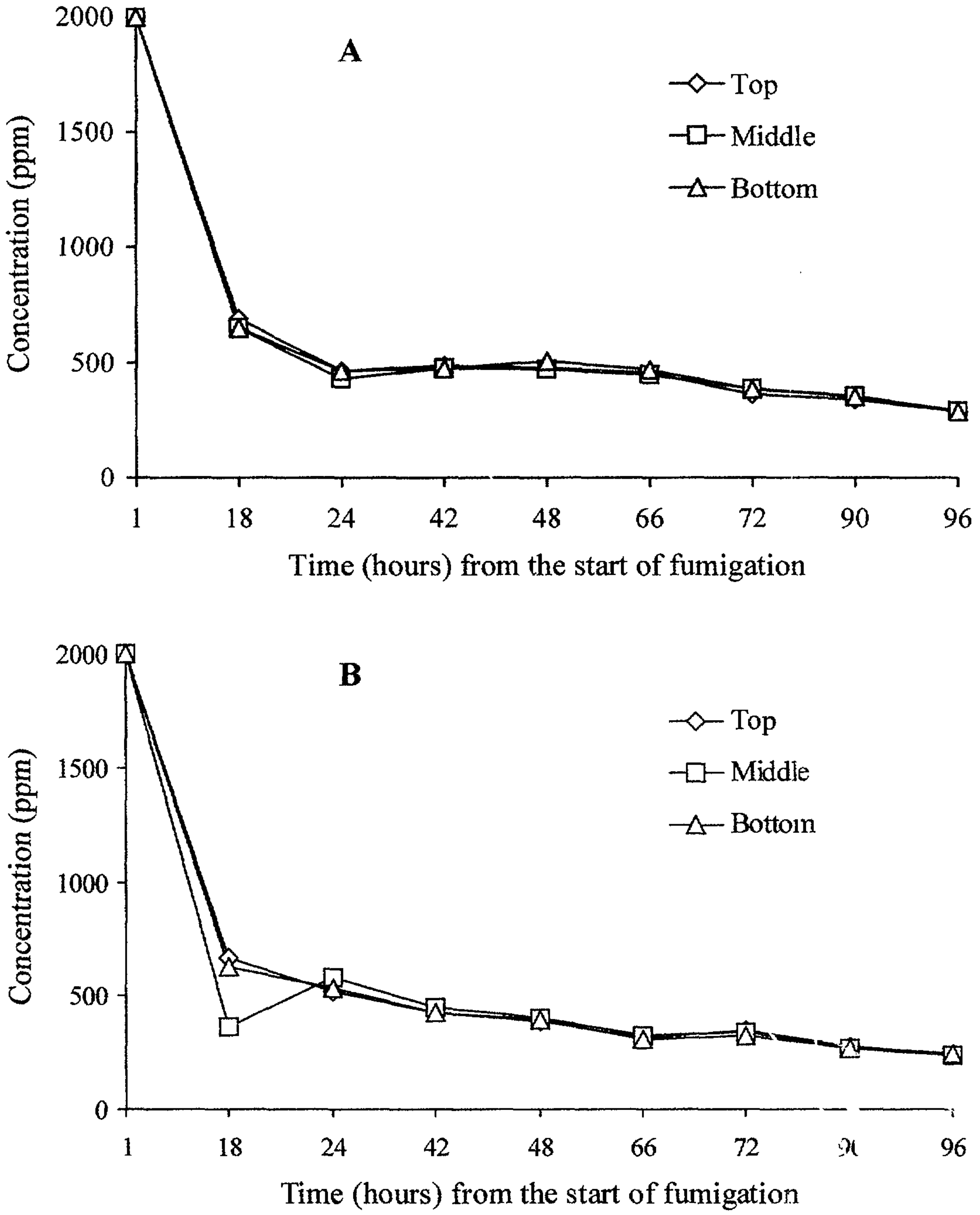


Figure 9. Time-course change in fumigant concentrations at different points of coffee container (A) and wood container (B) in the treatment with cylinderized phosphine Eco_2Fume in Lampung (third fumigation).

Rice Quality Analysis

The standard physical properties of rice analyzed were the presence of insects, moisture content, percentage of small broken grains, percentage of broken grains, percentage of head rice, percentage of yellow/damaged kernels, percentage of chalky/green kernels, percentage of foreign matters, the presence of paddy, and percentage of red kernels (Figures 10 - 15 and Appendix Tables 15 and 16).

In the trial at Tambun, the above-mentioned physical properties of rice in all treatments at 1 – 3 months after fumigation were more or less the same as the initial conditions (before fumigation), except for the percentages of small broken grains, yellow/damaged kernels and red kernels which show slight increases (Figures 10 – 12 and Appendix Tables 15). These might reflect physiological deterioration of rice commodity in the storage or deterioration caused by low infestation of insects or other organisms. In most cases, the moisture content of rice commodity was slightly higher than the acceptable level (14%) as determined by Bulog, and in a few instances was within the acceptable level. Variations in the other physical properties at different times of sampling might merely be due to sampling error and all might reflect the initial conditions of the rice commodity before being stored and fumigated. This is consistent with the fact that only one fumigation was needed at Tambun. Three months after fumigation, on the average only 0 to 1.5 larvae were found in the rice samples.

With regard to some physical properties, notably the percentages of broken grains and head rice, the initial conditions of rice commodity at Buduran were poorer than those at Tambun. Moreover, in all cases the moisture content of rice at Buduran was above the acceptable level (Appendix Table 16). Changes in physical properties over time were generally not consistent, except for the percentage of yellow/damaged kernels which showed an increasing trend. This might be due to, at least in part, an increase in insect infestation. At 3 months after the first fumigation, on the average up to 25 larvae could be found in samples from rice stacks treated with Eco_2Fume. After comparing the rice quality data from Tambun and Buduran, it can be suggested that initial conditions of the commodity to be stored are essential for storage management.

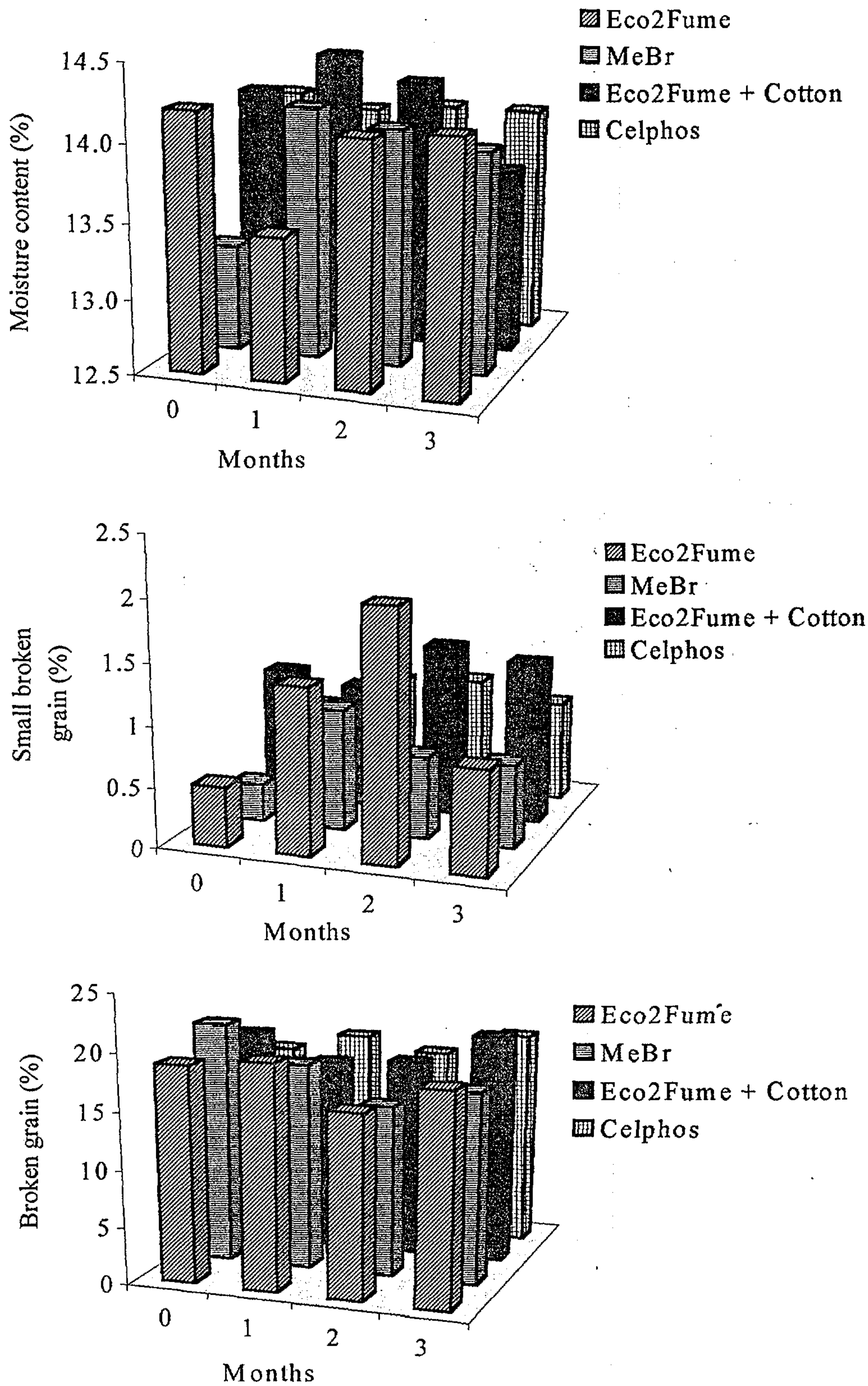


Figure 10. From top to bottom: moisture content of rice, percentage of small broken grains and percentage of broken grains before and after fumigation at Tambun Research Center Warehouse

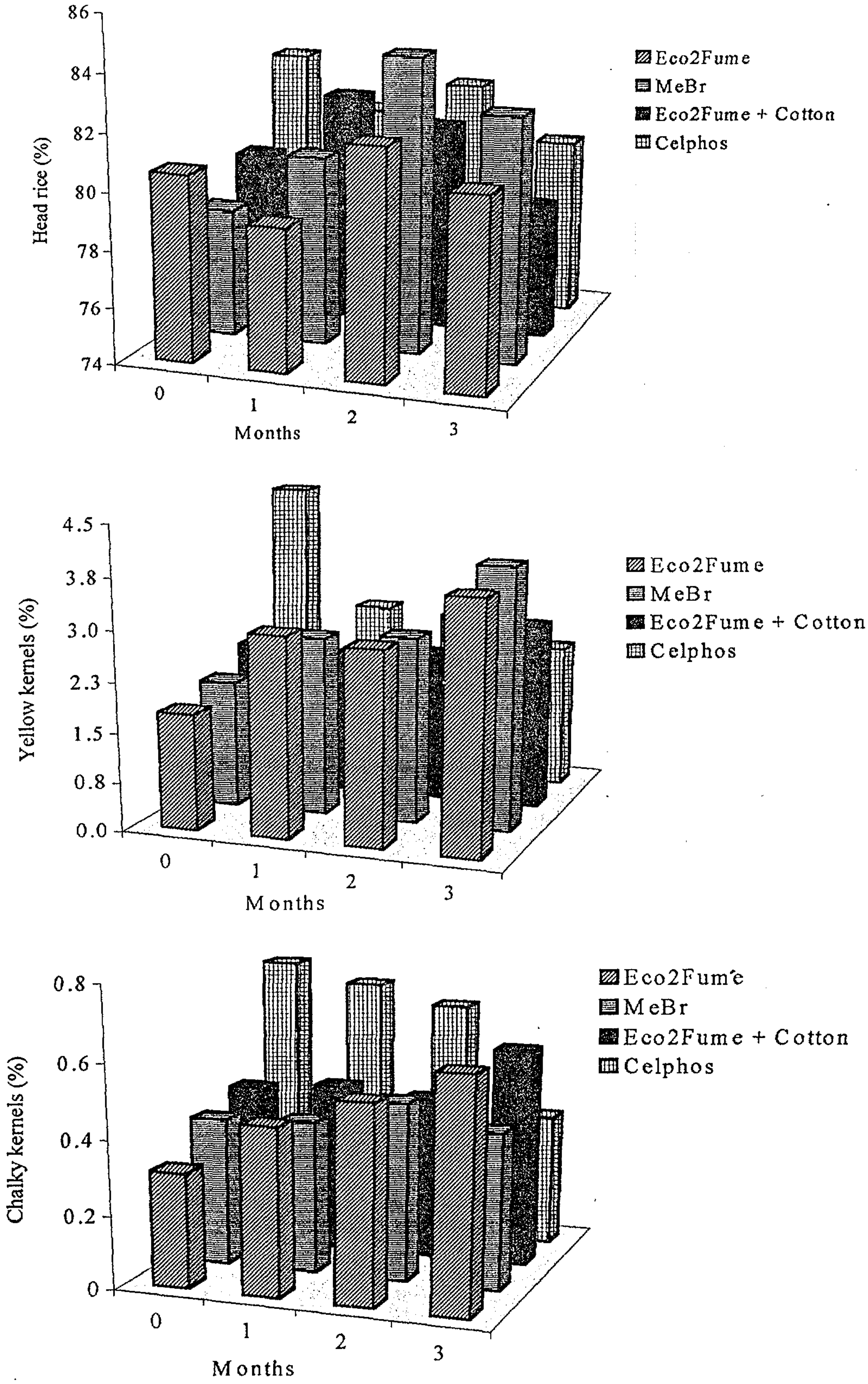


Figure 11. From top to bottom: percentage of head rice, yellow/damaged kernels and chalky/green kernels before and after fumigation at Tambun Research Center Warehouse

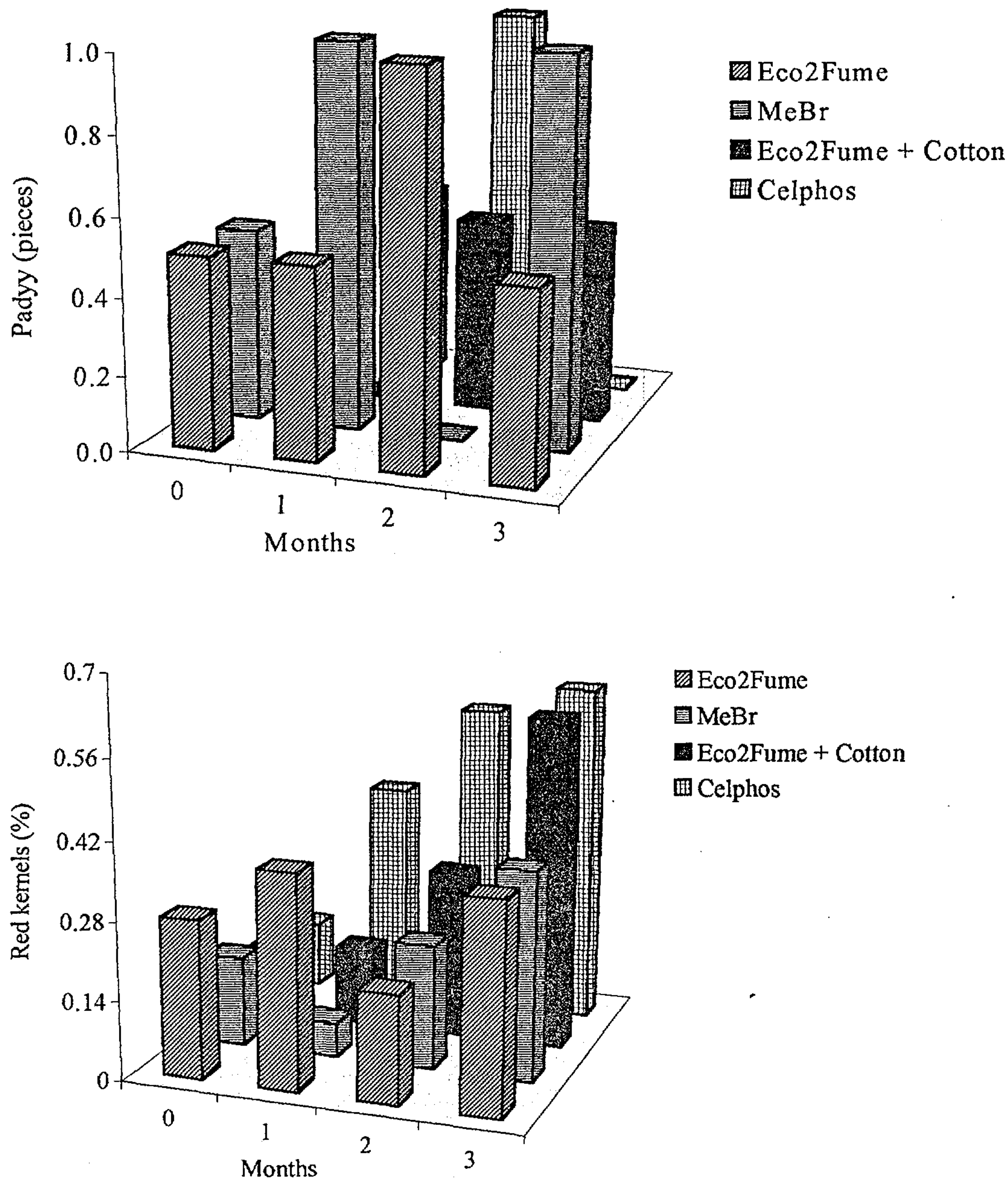


Figure 12. The presence of paddy (top) and percentage of red kernels (bottom) before and after fumigation at Tambun Research Center Warehouse

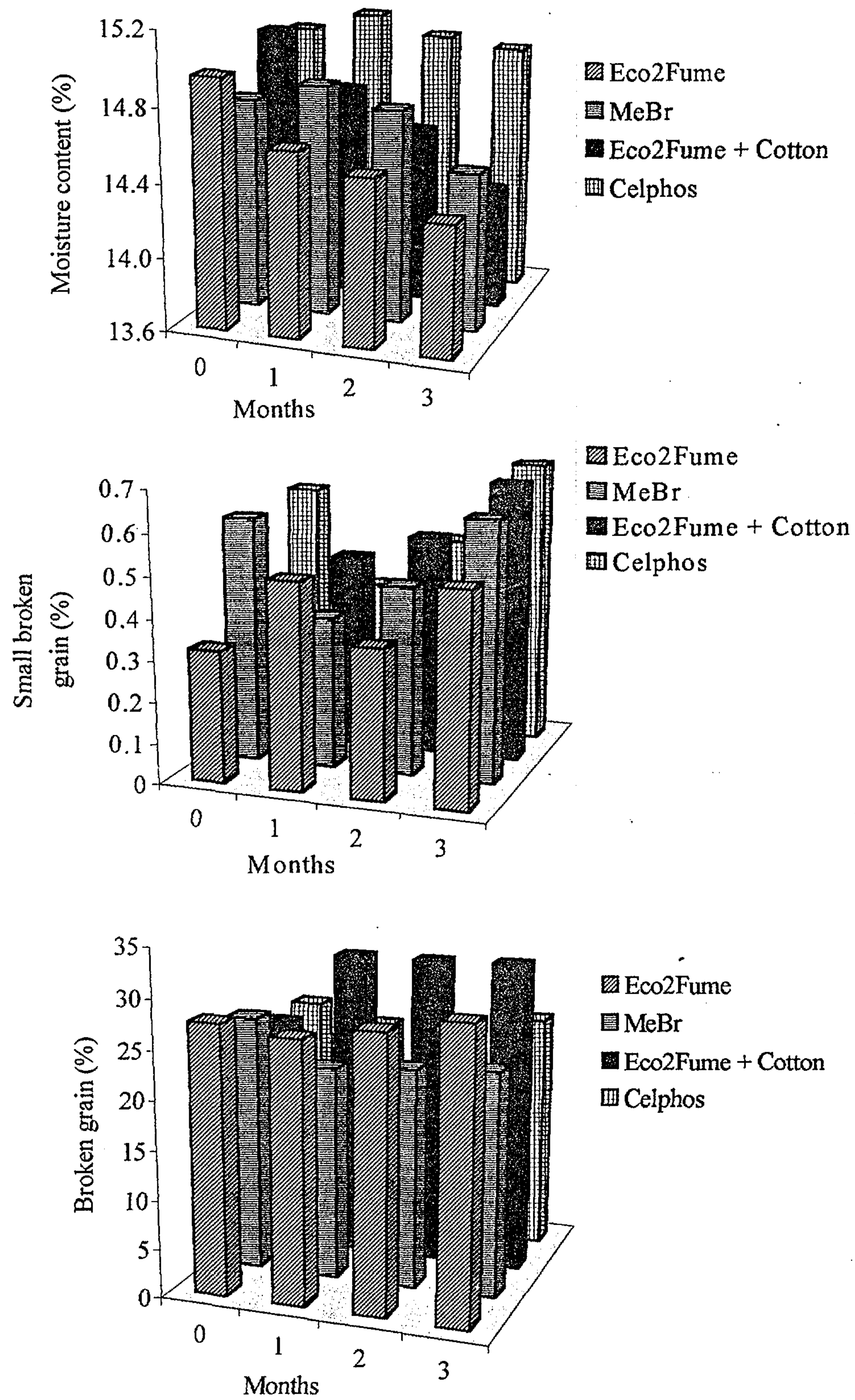


Figure 13. From top to bottom: moisture content of rice, percentage of small broken grains and percentage of broken grains before and after fumigation at Dolog's Buduran Warehouse

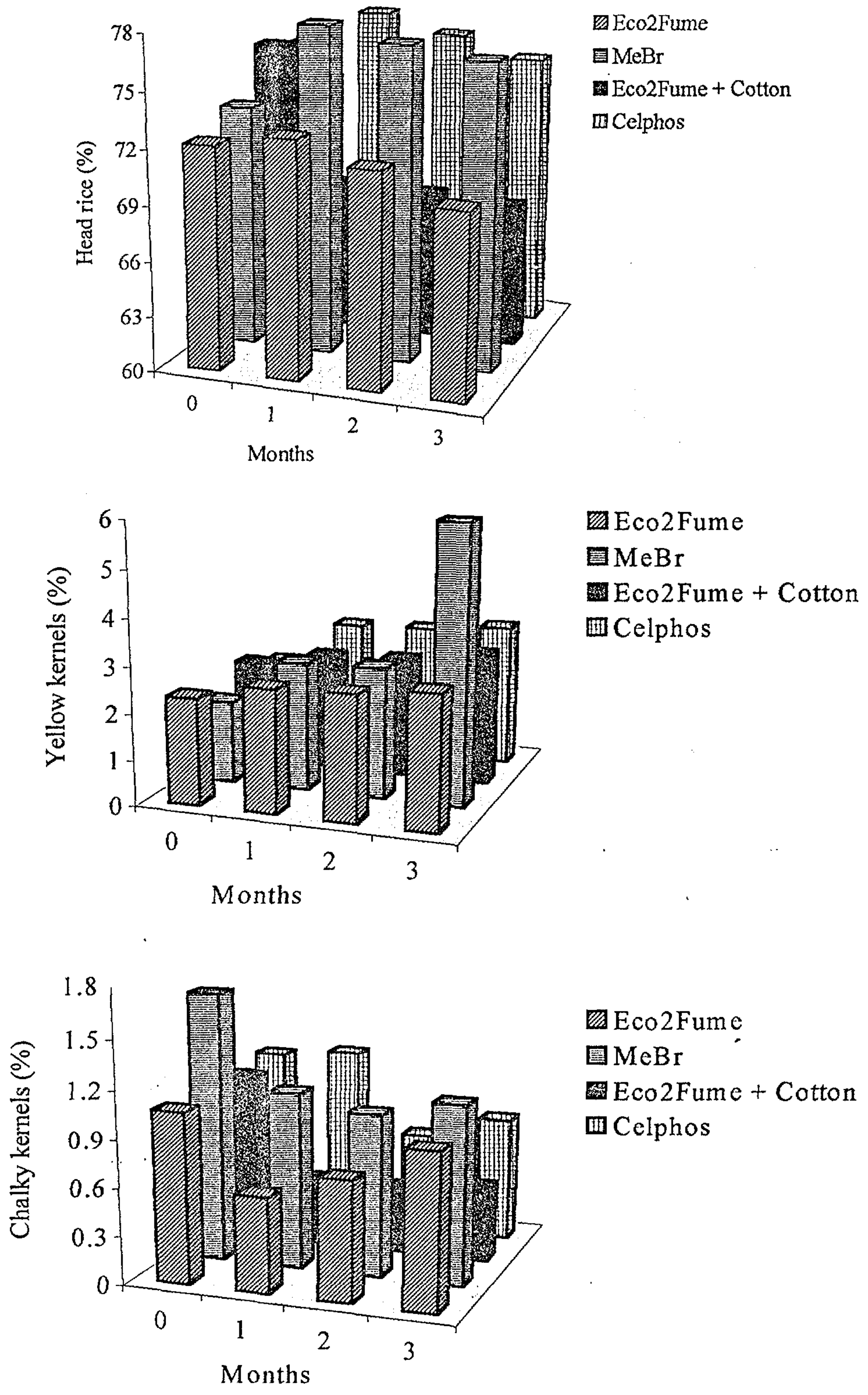


Figure 14. From top to bottom: percentage of head rice, yellow/damaged kernels and chalky/green kernels before and after fumigation at Dolog's Buduran Warehouse

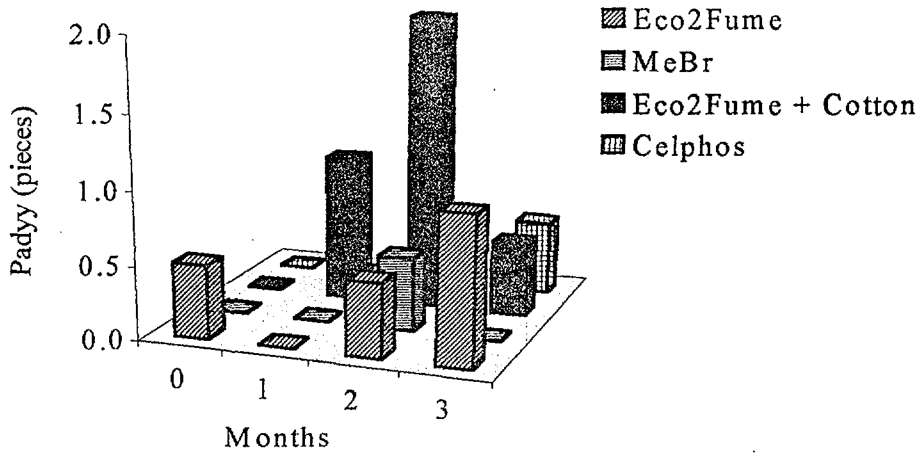


Figure 15. The presence of paddy before and after fumigation at Dolog's Buduran Warehouse

Growth of Total Insect Population in Rice Storage

The growth of the total insect population over time at Tambun and Buduran warehouses as monitored using bait traps placed on the rice stacks is shown in Figure 16 and Appendix Tables 17 and 18. At Tambun, there was no insect caught in the bait traps at 1 and 2 months after fumigation, and at 3 months after fumigation, only very few insects were caught in the bait traps on the rice stacks treated with methyl bromide whereas in the other treatments there was still no insect found. Even after 4 months, the number of insects trapped was still relatively low and still there was no insect found in the Eco_2Fume + cotton sheet treatment. Thus, fumigation was not necessary to be repeated in the fourth month. The total insect population began to increase steadily since 5 months after fumigation, except in the the Eco_2Fume + cotton sheet treatment where no insect was found until 8 months after fumigation and only very few insects were found in the ninth month (Figure 16 and Appendix Table 17).

At Buduran, there was no insect found in all fumigation treatments at 1 month after fumigation. The presence of insects could be detected since the second month except in the Eco_2Fume + cotton sheet treatment where no insect was found until the third month and relatively low number insects were caught in the fourth month. In the other three treatments, the total insect population increased markedly in the third and fourth month (Figure 16 and Appendix Table).

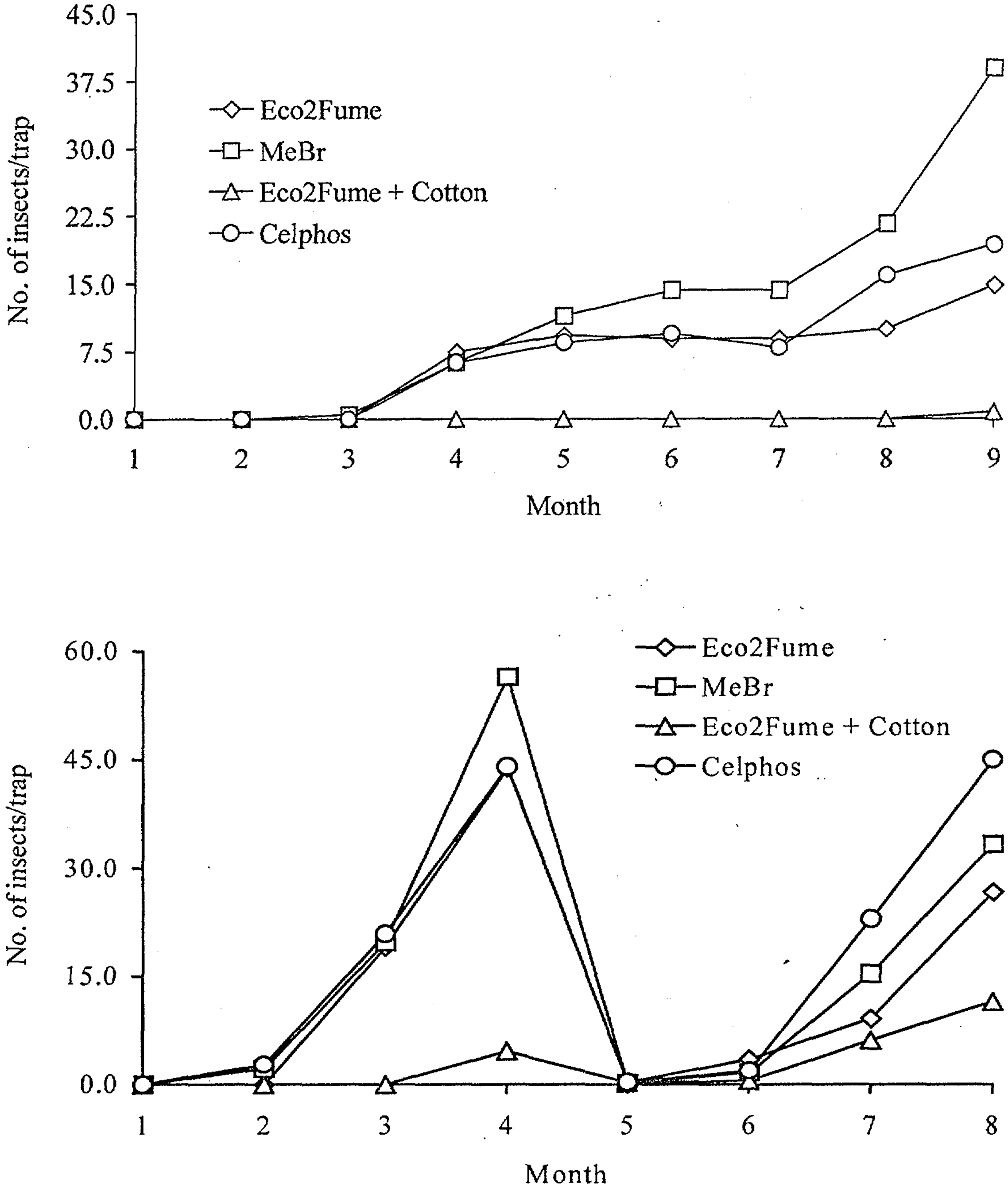


Figure 16. Growth of total insect population in Bulog's Tambun Research Center Warehouse (top) and Dolog's Buduran Warehouse (bottom) as affected by fumigation treatments. At Buduran, the second fumigation was conducted at 4 months after the first fumigation, whereas at Tambun fumigation was conducted only once.

18). At Buduram re-fumigation was conducted at the fourth month (on June 20 and 23, 2001). After re-fumigation, the total insect population dropped to near zero, and overall, increased markedly again after 3 months. Like at Tambun, the lowest insect population was found in the Eco_2Fume + cotton sheet treatment. Thus, the cotton covering sheet treated with an appropriate contact insecticide acted as an effective barrier against insect infestation after fumigation. In addition to technical effectiveness, the use of such cotton covering sheet must also consider economic feasibility.

The difference in insect population growth at Tambun and Buduran might be due to the difference in the initial conditions of the rice commodity used in the study, conditions of warehouses and their surrounding areas, and storage management practices. As described earlier, the initial conditions of the rice commodity used in the trial at Tambun were generally better than those at Buduran. The warehouse at Tambun used in this study is a research warehouse whereas that at Buduran is essentially a "commercial" warehouse which can easily be infested by insects from incoming stocks in the surrounding warehouses. Environmental conditions, e.g. temperature and air moisture, at Tambun were probably more favourable for insect growth and development than those at Buduran. Moreover, at Tambun sanitation practices were probably conducted more frequently and thoroughly than those at Buduran. Thus, implementation of other components of integrated storage management could reduce the need of fumigation.

Residue Analysis

Analysis of methyl bromide residue in rice and coffee samples was conducted by BATAN (National Atomic Energy Agency) and that of fenitrothion residue in rice samples was carried out by BIOTROP. For rice, two samples each were taken from Tambun and Buduran for both methyl bromide and fenitrothion residue analysis. For coffee, residue analysis was done only for the presence of methyl bromide before and after the fumigation trial.

The results showed that there was no methyl bromide residue (limit of detection: 0.3 ppm) detected in rice samples from Tambun. In rice samples from Buduran, methyl bromide residue was detected at amounts of 0.3 and 1.09 ppm (from two samples). In coffee from Lampung, the amount of methyl bromide residue detected increased from 1.01 ppm before fumigation to 6.01 ppm after fumigation.

The amounts of fenitrothion residue detected in two rice samples from Tambun were 0.0088 and 0.0021 ppm and those in rice samples from Buduran were 0.0073 and 0.0054 ppm. These residue levels were much below the maximum residue limit for rice as jointly determined by the Ministry of Health and the Ministry of Agriculture.

Postharvest Fungal Infestation

There were contrasting data of fungal contaminants in rice samples from Tambun and Buduran. No fungal colonies developed from rice samples taken from Tambun, whereas a total of 12 species of storage fungi could be cultivated from Buduran's rice samples (Table 2). This difference in fungal contaminants was consistent with that in physical properties of the rice commodity at Tambun and Buduran as described earlier.

In all fumigation treatments, the dilution method gave more fungal species than the plating method. Overall, the highest number of species was found in the Eco_2Fume + cotton sheet treatment (9 species), followed by AlP tablet and methyl bromide treatments (8 species each), and the lowest was in the Eco_2Fume treatment (7 species) (Table 2). Two species, *Aspergillus candidus* and *Eurotium* (=*Aspergillus*) *chevalieri*, were found in all treatments both with the dilution and plating method. These fungi could produce toxins that are hazardous to human health. *A. flavus*, *E. rubrum* and *Penicilium citrinum* could be cultured from rice samples of all treatments with the dilution method, but they were found only in some treatments when cultured with the plating method. On the contrary, *A. versicolor* was the only species that could be grown from rice samples of all treatments with the plating method, but it was detected only in some treatments when cultured with the dilution method.

The above data indicate that none of the fumigation treatments could inhibit the growth of storage fungi. Among the four treatments — with regard to the fungal contaminants — the worst condition was found in the Eco_2Fume + cotton sheet treatment. Probably the cotton sheet covering made the air within the rice stacks become more humid and this condition was more favourable for the growth and development of storage fungi. Thus, the cotton sheet covering, albeit very effective in preventing insect infestation after fumigation as described earlier, may find very limited use since it can promote fungal growth.

Table 2. Fungal contaminants in rice samples from Buduran

Treatment	Species of fungi (ave. no. of colonies/g)[a]	
	Dilution method	Plating method
Eco₂Fume	*Aspergillus candidus* (8.5) *A. flavus* (1.5) *A. niger* (1.5) *E. chevalieri* (3.0) *E. rubrum* (1.5) *Penicilium citrinum* (3.5)	*A. candidus* (3.0) *A. versicolor* (1.0) *Eurotium chevalieri* (2.0) *P. citrinum* (1.0)
Methyl bromide	*A. candidus* (13.5) *A. flavus* (5.0) *Cladosporium cladosporioides* (1.5) *E. chevalieri* (1.5) *E. rubrum* (3.5) *Paecilomyces variotii* (3.5) *P. citrinum* (343.5)	*A. candidus* (4.0) *A. versicolor* (2.0) *E. chevalieri* (6.0) *E. rubrum* (1.0)
Eco_2Fume + cotton sheet	*A. candidus* (63.5) *A. flavus* (1.5) *A. versicolor* (1.5) *C. cladosporioides* (3.5) *E. chevalieri* (1.5) *E. rubrum* (1.5) *Endomyces fibuliger* (3.5) *Mucor circinelloides* (1.5) *P. citrinum* (13.0)	*A. candidus* (13.0) *A. versicolor* (3.0) *C. cladosporioides* (1.0) *E. chevalieri* (8.0) *E. rubrum* (2.0)
AlP tablet	*A. candidus* (48.0) *A. flavus* (1.5) *A. versicolor* (12.0) *E. chevalieri* (8.5) *E. rubrum* (1.5) *En. fibuliger* (3.0) *Fusarium moniliforme* (5.0) *P. citrinum* (80.0)	*A. candidus* (4.0) *A. versicolor* (2.0) *E. chevalieri* (1.0)

[a] Average of two replications (from two rice stacks).

Financial Analysis

The financial analysis was done by comparing costs of the four demonstrated treatments. Under the assumptions that all the four methods give effective results for ISPM, the method with the lowest cost is considered the best method if it is looked from the economic point of view. Among the four kinds of treatments, application of Eco2Fume with cotton sheet covering required the highest amount of labor whereas the treatment with phosphine (AlP) tablets was the most practical one. Every activity has its own consequences in term of cost. However, it does not mean that the method with the least amount of activities incurred the lowest cost. For example, the treatment with AlP tablets has the least activities but it has a component such as cost for Celphos fumigant tablet which is most costly. Therefore, a detailed financial analysis of all costs for the application of a particular technology needs to be done accurately.

Table 3 shows the detailed activities and the average cost of fumigation methods from two locations of trial, i.e. from Tambun (West Java) and Buduran (East Java). Table 4 shows the recapitulation of the average cost of fumigation per ton of rice. Table 5 represents cost of fumigation treatment for a container of wood and a container of coffee.

The treatment with methyl bromide for rice was the least cost method. The second least method is phosphine in tablet, then followed by Eco2Fume. The most expensive fumigation treatment is Eco_2Fume with cotton covering. The difference between the least cost treatment with the second least cost was relatively high, i.e. about Rp 158 per ton or equal to US $ 0.02 per ton. Meanwhile between phosphine tablet and Eco_2Fume only US $ 0.01 per ton. Therefore, if methyl bromide would be fully abandoned, the possible recommended treatment for rice is phosphine tablet or Eco_2Fume. Despite the cost of Eco_2Fume is higher than phosphine tablet, in the long run if the demand of phosphine tablet is increasing (due to the shift of demand from methyl bromide to phosphine tablet), the cost of phosphine tablet tends to increase significantly. It can be concluded, Eco_2Fume will be the alternative technology for replacing the methyl bromide along with phosphine tablet. The locally made dispenser and CO_2 gas could bring about the lower price of Eco_2Fume treatment.

Though the cost of Eco_2Fume with cotton sheet covering is the highest, expensive but it could reduce the necessity for re-fumigation. Furthermore, all four fumigation methods used in this study still required surface spraying with contact insecticides every two weeks. The cost of this spraying was Rp 25.00 per ton, while in Suhadi's study (1999) the cost of spraying was Rp 191.40 per ton.

The fumigation for other products such as wood and coffee was implemented before these two commodities were shipped for export. The cost of fumigation for these two commodities is presented in Table 5. The use of methyl bromide for fumigation per container for wood and coffee was more expensive then the use of Eco_2Fume. This is because the cost of Sobrom fumigant is much more expensive than Eco_2Fume + CO_2.

The conclusion that can be made here is that there is an indication that the least cost analysis can be used as a guidance to choose the most feasible technology, but it is still necessary to have more accurate data or information particularly related to the price of every component of activity for each method being applied.

Table 3. The cost of fumigation for every 400 ton of rice in 2 staples during demonstration in Surabaya and in Tambun, February, 2000

Fumigant treatment	Item of costs	Cost for two staples	Unit cost	Cost per Ton	
Eco_2Fume	1 Eco_2Fume	10.8 kg		150	
	2 CO_2	200 g			
	3 Dispenser	1		428	
	4 Alumunium pipe	5 m	200,000	125	
	5 Plastic tube	8 m	7,000	14	
	6 Fumigation labor	1 mds	20,000	50	
	7 Plastic sheet	2 pieces	4,379,450	1,095	
	8 Covering/opening the plastic cover	10 mds	10,000	125	
	10 Contact pesticide (indogran 500 EC)	0.306 lt	70.175 / lt	54	
	11 Spraying	1 md	10,000	25	
			TOTAL	**2,066**	**0.28 $**
Eco_2Fume + cotton covering	1 Eco_2Fume	10.8 kg		150	
	2 CO_2	200 g			
	3 Dispencer	1		428	
	4 Alumunium pipe	5 m	200,000	125	
	5 Plastic sheet	8 m	7,000	14	
	6 Fumigation labor	1 md	20,000	50	
	7 Plastic cover	2 pieces	4,379,450	1,095	
	8 Cotton fabric	2 pieces	3,593,750	898	
	10 Spraying the cotton fabric	1 md	10,000	25	
	11 Covering/opening the plastic cover	5 md	10,000	125	
	12 Contact pesticide (indogran 599 EC)	0.0057 lt	70.175 / lt	10	
	13 Spraying	1 md	10,000	25	
			TOTAL	**2,945**	**0.39 $**
Metil bromida	1 Sobrom (MeBr)	8.4 kg	50,000	525	
	2 Plastic pipe for conveying fumigant	2 rolls	40,000	20	
	3 Fixing pipe and fumigation	1 md	20,000	50	
	4 Plastic for covering fumigant	2 pieces	4,379,450	1,095	
	5 Covering/opeing plastic covering	10 mds	10,000	125	
	6 Contacted pesticide (indogram 500 EC) for treatment after fumigation	0.29	70.175 / lt	-	
	7 Spraying	1 md	10,000	25	
			TOTAL	**1,840**	**0.25 $**
Fostin in capsul	1 Celphos (AlP) tablets	800 capsul	699 / capsul	699	
	2 Fumigation labor	1 md	20,000	50	
	3 Plastic sheet	2 pieces	4,379,450	1,095	
	4 Covering/opening plastic covering	10 md	10,000	1 25	
	5 Contacted pesticide (indogram 500 EC) for treatment after fumigation	0.303 lt	70.175 / lt	-	
	6 Spraying	1 md	10,000	25	
			TOTAL	**1,994**	**0.27 $**

Table 4. The cost of fumigation for every 400 ton of rice in 2 staples during demonstration in Surabaya and in Tambun, February, 2000

No	Fumigation treatment	Cost per ton in $	Total cost in Rp.
1	Eco2Fume	0.28	2,066
2	Eco2Fume + Cotton Covering	0.39	3,945
3	Metil Bromida	0.25	1,840
4	Fosfin in tablet	0.27	1,994

Assumptions:
plastic sheet is used 10 times, cotton sheets is used 10 times, and dispenser is used 20 times.

Table 5. The cost of fumigation for 33 m^3 of wood or for 33 m^3 of coffee (For a container treatment) during demonstration in Lampung, February, 2000

Treatments		Materials	Units	Unit cost	Total costs	
Eco_2Fume	1	Fumigant Eco 2 Fume	990 gr	11,074	10,963	
	2	CO_2	200 g	-		
	3	Dispencer	1		8,560	
	4	Al Pipe	5 m	200,000	2,500	
	5	Plastic Pipe	8 m	7,000	280	
	6	Fumigation Labor	1 md	20,000	10,000	
				TOTAL	**32,303**	**4.31** $
Methyl bromide	1	Sobrom Fumigation	1056 gr	50,000	52,800	
	2	Plastic pipe for convrying fumigant	2 rolls	40,000	280	
	3	Fixing pipe and fumgation	1 md	20,000	10,000	
				TOTAL	**63,080**	**8.41** $

Assumption:
rate of methyl bromide 32 g/m^3, Eco_2Fume 30 g/m^3, disepenser is used 20 times, US $ 1.00 = Rp. 7,500.00

Workshop and Training

Summary Workshop

Trade globalization has led to the necessity to comply with various requirements as stipulated in World Trade Organization (WTO) agreements, such as those related to Sanitary and Phytosanitary (SPS) Measures and Tariff Barrier to Trade (TBT). Thus, export agricultural and food commodities from Indonesia must meet such requirements in order to capture world market opportunities. Available data, however, indicate that there are still many export agricultural products from Indonesia which are rejected in foreign markets (automatic detention or automatic holding orders in the USA and Australia) because the products did not meet safety requirements or because of other reasons.

In attempts to comply with regulations in target countries of export, the use of methyl bromide in pest control measures by fumigation gradually has to be phased out in accordance with the schedule as stipulated in the Montreal Protocol. Thus, attempts to develop alternative technology to methyl bromide are becoming very important not only to Indonesia but also to other countries in the world.

Realizing that methyl bromide is an important part of management in maintaining the quality of stored commodities from infestation of stored-products pests, the implementation of Demonstration Project on Alternative Technology to Methyl Bromide – financially supported by UNIDO – is one of the avenues to introduce the alternative technology to various sectors involved in the maintenance of product quality, both government institutions and private sectors.

There are many alternative methods that have been developed by investigators in many countries, but only some of them that are promising enough to replace methyl bromide. Among fumigants that may be used as alternatives to methyl bromide are carbon disulfide, sulfuryl fluoride, methyl iodida, methyl phosphine, and mixture of phosphine and carbon dioxide. There are some alternative methods that use existing fumigants with improved application technology such as Siroflo. Non-fumigation technology that can be implemented as alternatives to methyl bromide includes physical control (heating, cooling, or use of barrier such as cotton sheet to cover stacks of products), modified atmosphere, irradiation, hermetic storage, and integrated storage pest management (ISPM).

In the adopting ISPM as an alternative to methyl bromide, several steps need to be implemented. These include understanding of various factors that cause the decrease of product quality beginning with the emphasis on achieving sound initial conditions of products; understanding of physical factors of environment; understanding of kinds, characteristics, and status of storage pests through continual monitoring program; and integration of various control methods by considering economic feasibility, food safety and environment conservation. By integrating all commodity management methods, the use of chemicals is only supplementary to the whole system. On the other hand, by considering negative side effects of pesticides to the environment and food safety, it is worth to seriously consider the use of botanical pesticides and mineral ingredients as an alternative technology which is technically and economically feasible as well as environment friendly.

In efforts to improve understanding of integrated pest management in storage environment, the role of training is very important. In this respect, the use of computerized teaching materials in the training of ISPM as a part of integrated commodity management can make understanding of training materials easier and faster compared to conventional training methods. In the context of disseminating various information and experiences in IPM as a part of alternative technology to methyl bromide, seminars, workshops or other methods are appropriate places to socialize the technology. Socialization is very important so that the people have sound understanding about methyl bromide phase out, and alternative technology to methyl bromide could be appropriately implemented by related sectors. In this way, unpleasant experience related to withdrawal of persistent insecticides such as DDT, endrin, etc., could be avoided.

Integrated Stored Product Management Survey

One of the important components to the success of ISPM implementation is the conditions of warehouse where agricultural products are stored. Thus, evaluation of the warehouse condition is necessary before implementing the ISPM.

General Condition of Warehouses

Overall, 36 units of warehouses (32 GBBs, and 4 GSPs (*gudang semi permanen*, semipermanent warehouses) were inspected in

Bandung and Karawang (Table 5). Generally, GBBs were built in 1980s, except at GBB Cimindi and Jatisari which were built in 1970s.

Table 5. Location, address, type of warehouse, and number of employees of BULOG's warehouses in Bandung and Karawang

No.	Name of warehouse	Address	Type and capacity (ton)	No. of unit (units)	No. of employees	Year of completion
1.	Cimindi	Jl. Leuwih Gajah, Cimahi Bandung	GBB/14,000	4 GBBs	13	1976
2.	.Cilamaya	Jl. Cilamaya No. 19 Karawang	GBB/4,000 GSP/2000	2 GBBs 2 GSPs	4	1983
3.	Rengas-dengklok	Jl. Rengas-dengklok Karawang	GBB/1,0500	3 GBBs	3	1984
4.	Cibitung	Jl. Cibitung Karawang	GBB/2,8000	8 GBBs	6	1981
5.	Jatisari	Jl. Raya Kali Asin, KRG	GBB/7,000 GSP/2,000	2 GBBs 2 GSPs	7	1976 1986
6.	Purwasari	Jl. Cikamjali Karawang	GBB/24,500	7 GBBs	11	1984
7.	Paseh	Jl. Paseh Sumedang	GBB/2,000	1 GBB	5	1982
8.	Gedebage	Jl. Gedebage Bandung	GBB/17,500	5 GBB	10	1983

Physical Condition of Warehouses

There were eleven aspects examined to evaluate the physical conditions of warehouse the: floors, floor joints, walls, doors, ventilation, bird proofing, roof, roof color, lighting, position of warehouse, and drainage condition.

The floor condition at GBB Rengasdengklok, Cibitung, Purwasari, and Gedebage could be considered good. Meanwhile, there were few cracks in the floor at GBB Cimindi (50%), Cilamaya (25%), Jatisari (50%), and Paseh (100%). A considerable number of cracks were found at GBB Cimindi (50%) and Cilamaya (50%) (Fig.17).

Almost all GBBs showed tight floor joint condition except GBB Paseh and Rengasdengklok which showed cracked (100%) and cemented (100%) conditions, respectively (Fig. 18).

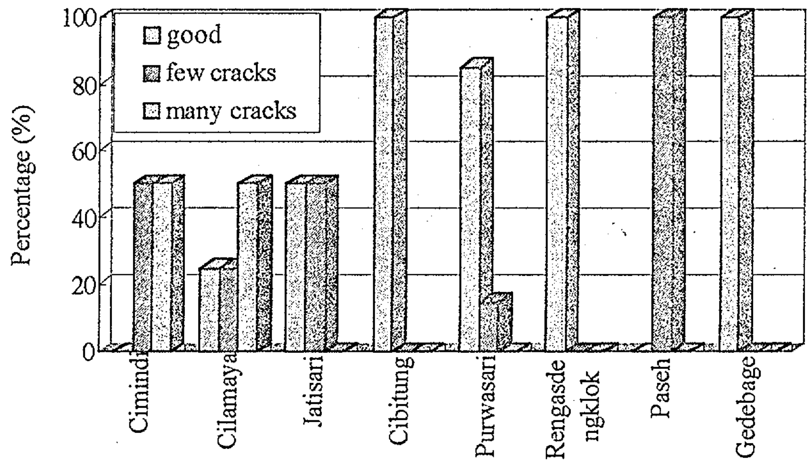


Figure 17. Floor condition at eight BULOG's warehouse complexes

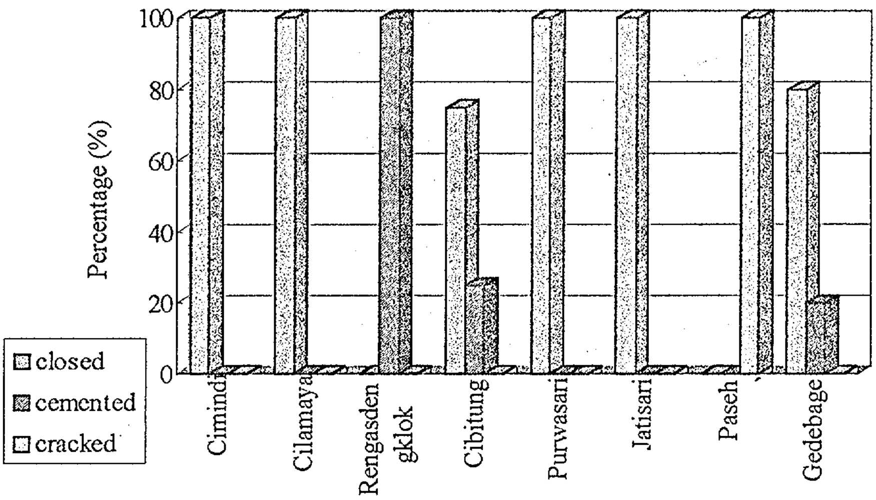


Figure 18. Floor joint condition at eight BULOG's warehouse complexes

Good wall condition was found at GBBs Cimindi (75%), Rengasdengklok, Paseh and Gedebage (100%). Few cracks were found at GBBs Cimindi (25%), Cibitung (50%), and Purwasari (57.1%); while many cracks were found at GBBs Cilamaya (50%9 and Jatisari (50%).

All GBBs have doors equipped with rodent proofing except warehouses of GSP types. Although, employees or workers sometimes found dead rats in warehouses, generally after routine fumigation, they thought that rats are not is not an important pests at all locations surveyed. They have never placed rodent baits for preventing rat infestation.

One important thing concerning commodity maintenance in warehouse is aeration. Thus, good ventilation of warehouse is necessary. Almost all warehouses surveyed have good ventilation installation, particularly the new warehouse types (GBBs), whereas warehouses of GSP types at Cilamaya (50%) and Purwasari (66.7%) lacked good ventilation (Fig. 19). Nevertheless, the warehouse doors were opened daily from 8:00 to 17:00 to provide sufficient air circulation in the warehouse.

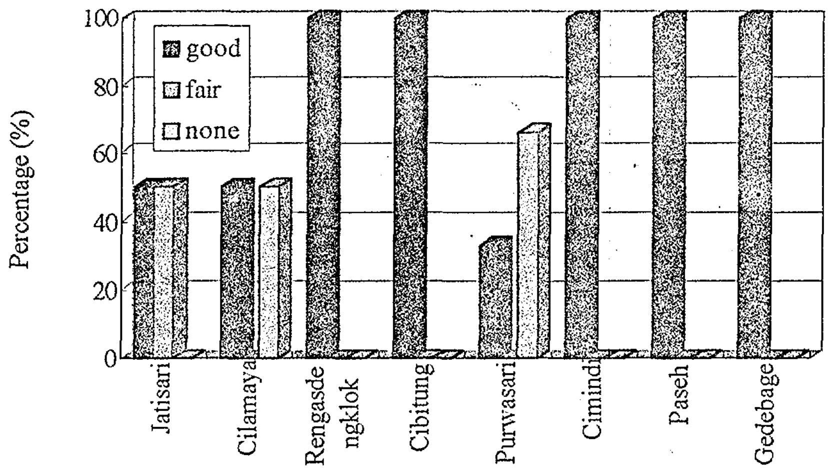


Figure 19. Ventilation condition at eight BULOG's warehouse complexes

The position of warehouse also plays an important role in keeping the quality of commidity stored. The position of warehouse are almost 86% east-west and only 14% is north-south (GBB Cilamaya and Gedebage). The source of light is TL lighting installed in warehouses. The condition of lighting is fair (80%-100%), but at GBB Cilamaya it was poor (75%).

Bird proofings have been installed on all warehouses except at GBB Rengasdengklok. However, birds were still able to enter and go out of warehouses through the holes because the wall covers are made up of corrugated iron sheets. Also, bird proofing at several warehouses has broken. This causes problem for several warehouses because the warehouses became dirty with rice or unhusked paddy.

Since all GBBs were built almost 20 years ago, the roof of at several warehouses showed some damage with few or many leaks. Few leaks were identified at GBB Cimindi (25%), Paseh and Rengasdengklok (100%), Jatisari (50%), and Purwasari (43%); while many leaks were found at GBB Rengasdengklok (50%) (Fig. 20). Warehouses with few and many leaks were repaired by using management fund. Warehouse employees have proposed the budget for repairing the warehouses to Bulog's Central Office but there was no response or the response came late. Since there were few or many leaks, several roofs showed a change of the color to red (GBB Cilamaya) or other colors (GBB Rengasdengklok).

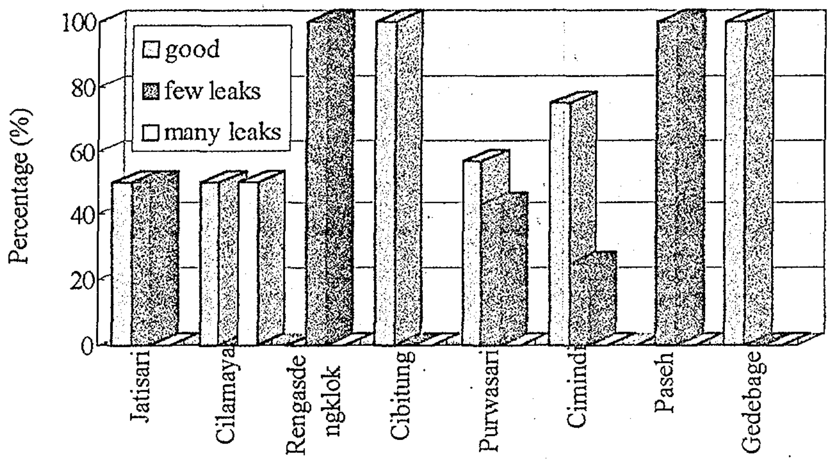


Figure 20. Roof condition at eight BULOG's warehouse complexes.

GBB Cimindi, Cibitung, Jatisari, Purwasari, and Paseh have good drainage system; while GBB Cilamaya (50%), Rengasdengklok (100%), and Gedebage (100%) have poor drainagé system (Fig. 21). At Gedebage, since the location of warehouse is lower than the outside, under condition of heavy rain, the location of warehouse would be flooded. Therefore, in front of warehouses at GBB Gedebage an additional dike was built to prevent flooding water. The average height of the warehouse wall is 1-1.2 m above ground. Several warehouses at GBB Cibitung and Jatisari have walls of 0.5 m and 0.25 m, respectively. At GBB Cilamaya, warehouses of GSP types have walls of 0.1 m high.

Generally, commodities stored were rice and unhusked rice. Sometimes sugar (GBB Purwasari) and soybean (GBB Gedebage) were also stored. The source of rice is domestic supply for direct or regional movement and import supply from Vietnam, Thailand, China, USA, and Pakistan (Table 6). All commodities were stored for more than 3 months. Several warehouses sometimes kept the commodities for only 1-3 months (GBB Cibitung and Paseh) and less than one month (GBB Purwasari). All import rice was stored for more than 3 months.

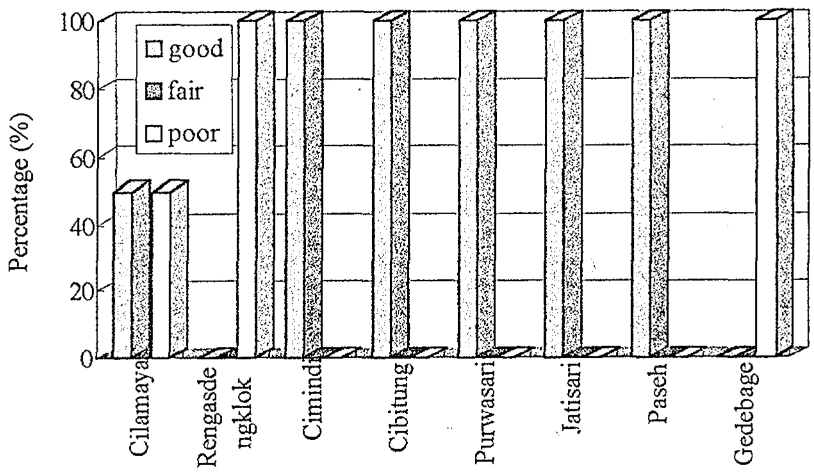


Figure 21. Drainage condition at eight BULOG's warehouse complexes

The amount of commodities stored was generally below the capacity of the warehouses (Table 7.) rendering inefficient warehouse management. In rice/unhusked rice stocking activity, on the average 5% of total the rice/unhusked rice was rejected because of unacceptable level of broken, moisture content, and rice quality (*sosoh* degree).

Table 6. Sources of commodity stored in eight BULOG's warehouses

No.	Name	Domestic			Import
		Direct	Regional movement	National movement	
1	GBB Cimindi	✓	-	-	Vietnam, Thailand, Pakistan,USA
2	GBB Cilamaya	✓	-	-	-
3	GBB Rengasdengklok	-	✓	-	USA
4	GBB Cibitung	✓	-	-	China
5	GBB Jati Sari	✓	-	-	China, USA
6	GBB Purwasari	✓	-	-	China
7	GBB Gudang Paseh	✓	-	-	China, USA
8	GBB Gede Bage	✓	✓	-	Thailand, China, USA

Table 7. Total commodities (tons) stored in BULOG's warehouses in the last 3 years (1998-2000)

No	Name	Rice	Paddy	Sugar	Soybean	Total
1	GBB Cimindi	8,443.95	451,30	-	-	8,895.25
2	GBB Cilamaya	4,000.10	-	-	-	4,000.10
3	GBB Rengasdengklok	4,422.65	8,162.94	-	-	12,585.59
4	GBB Cibitung	42,137.34	-	-	-	42,137.34
5	GBB Jatisari	31,286.84	-	-	-	31,286.84
6	GBB Purwasari	82,575.89	15,801.96	1,193.04	3,994.34	103,565.23
7	GBB Paseh	2,442.92	2,109.66	-	-	4,552.59
8	GBB Gedebage	4,262.10	2,322.29	-	128,69	6,713.09

Warehouse Equipment

In daily activity, each warehouse/GBB is equipped with various warehouse equipments such as flonder, fire extinguisher, ladder, conveyor, vacuum cleaner, forklift, sand barrel, balance, and cleaning equipment. The main equpments available at all warehouses are flonder, balance and cleaning equipment. Interestingly, several warehouses (GBB Cimindi, Cibitung, Purwasari, and Gedebage) have conveyors but the workers have never used them because of inconveniency and high electricity consumption. Also, they heve never used forklift and ladder because of inconveniency. There are many extinguishers but they have never used them and also they did not know whether the extinguishers are in good condition do not. Only GBB Cimindi has sand barrel, other GBBs have not. Historically, all warehouses/GBBs were equipped with sandbarrel, but later the function of sandbarrels has been converted as garbage bins.

Good Storage Practices

All warehouse managers mentioned that the warehouses were cleaned and sprayed prior to the acceptance of commodities. The cleaning and sweeping were conducted daily (at GBB Cimindi, Cilamaya, Cibitung, Jatisari, Paseh and Gedebage) or three times a week (at GBB Rengasdengklok) and once a week (at GBB Purwasari). The intensity of cleaning and sweeping activities was dependent on worker availability. The number of persons in every cleaning activity varied: 2 persons (GBB Cimindi, Cilamaya, Rengasdengklok, Cibitung, Jatisari, and Paseh), 3 persons (GBB Gedebage), or 4 persons (GBB Purwasari). Nevertheless, the warehouse managers mentioned that the cleaning activity in warehouses and their surroundings has a fixed schedule each month, except at GBB Purwasari. The employee mentioned that the inspection done for checking the leak, staple cleanliness, and staple ruin were conducted every day (at GBB Cimindi, Cilamaya, Jatisari, Purwasari, Paseh), or once a week (at GBB Rengasdengklok, Cibitung, and Gedebage).

At all GBBs, the spilled commodity was stored separately from the good stock and also was sprayed along with the good stock but at GBB Purwasari, the spilled commodity was sprayed, only occassionally.

Generally, the vegetation in the complex was dense except at GBB Rengasdengklok and Paseh, while the vegetation outside the complex was rare at all GBBs.

Maximum staple height for gunnybag was 24-25 layers (6 meter), while at GBB Cilamaya the maximum staple height was 30 layers. For plastic bag, GBB Jatisari put a maximum staple height of 30 layers, and at other GBBs were 25-27 layers. The narrowest distance of main alley was at GBB Paseh (1 m) and Cilamaya (1,1 m). At these warehouses, the capacity of storage were low so that the employees placed the commodity in tight spacing. The average an of main alley at GBB Cimindi, Gedebage, Jatisari, and Purwasari was 2 m, while at GBB Rengasdengklok and Cibitung was 2.67 m and 3 m, respectively. The width of across alleys varied among warehouses. GBB Cimindi has an average cross alley 0.35 m (the narrowest among all GBBs), GBB Purwasari and Paseh 0.5 m, Jatisari 0.75 m, and Rengasdengklok and Cibitung 0.84 m. In addition, all warehouses have fire alley of less than 1 m. The narrowest was at GBB Cimindi (0.3 m).

In the observation of commodities stored, all warehouse managers conducted visual observation on the spot fortnightly, together with the sampling activity. However, at GBB Paseh, the warehouse managers conducted observation weekly. Employees at GBB Cibitung, Jatisari, Purwasari, Paseh, and Gedebage gave a high priority to the warehouse hygienes, while the warehouse managers at GBB Cimindi, Cilamaya and Rengasdengklok gave a modest priority.

Fumigation Practice

Generally, fumigation activity was conducted by the division of pest quality control of Dolog. The employees mentioned that the fumigation has been conducted well and the fumigation has never failed. The fumigation was conducted by trained staffs.

In respect to the kinds of fumigant, GBB Rengasdengklok and Paseh mentioned that they preferred to use phosphine, but others preferred methyl bromide.

Surface Spraying

Like the fumigation practice, all employees also mentioned that surface spraying is needed because surface spraying was effective and gave good results. The surface spraying was conducted by adequately trained staff. All employees mentioned that before spraying the warehouse and stock commodity spilled commodity were removed. With regard to spraying areas around warehouses, all warehouse managers at all GBBs, except at GBB Gedebage, mentioned they did so. They mentioned some important things regarding spraying areas around the warehouse.

Pest Management

All warehouse managers mentioned that storage hygiene is very important to achieve good pest control. Storage hygiene means not only the cleanliness of the warehouse, but also the quality of commodity to be stored. Other reasons were rotation of commodity, punctuality in fumigation activity, and improvement of their employee's skill. The warehouse managers at GBB Cibitung, Cilamaya, and Rengasdengklok have never participated in training courses in the past few years. Almost all warehouse managers mentioned that training courses will improve and support their activity.

Concluding Remarks

Generally, the warehouse conditions are good, mainly at BULOG's new type warehouses (GBB). These warehouses are still feasible for storing commodities. One important problem is that several warehouses have few leaks and many leaks in their roof. This needs to be seriously addressed because water falling to the staples will decrease the quality of products. Training in warehouse management is needed particularly in administration, hygiene, and pest monitoring.

CONCLUSION AND RECOMMENDATIONS

1. The demonstration project on alternative technology to methyl bromide was carried out in the year 0f 2000. The activities conducted were technical and financial analysis of fumigation, workshops and training , and integrated storage pest management (ISPM) survey. The technical analyses conducted were evaluation of time-course change in fumigation concentration against target pests (Sitophilus and Tribolium), analysis of rice physical properties, monitoring of insect population in rice stacks, and pesticide residue analysis.
2. In the fumigation trial on rice, in all treatments even distribution and the expected level of fumigants were achieved between 18 and 24 hours from the start of fumigation. The achievement of the expected concentration of fumigants was responsible for the complete kill (100% mortality) of the test insects (*T. castaneum* and *S. zeamais*) in all treatments.
3. The use of cylinderized phosphine (Eco_2Fume) could distribute phosphine gas evenly within 24 hours and thereafter the concentration of phosphine could be kept above or at about the targeted dose (300 ppm) during the whole fumigation period (5 days) given that the plastic covering over the rice stacks were soundly air-tight. At such dose, the treatment could give a complete kill in the test insects. In the phosphine (AlP) tablet treatment, the concentration of phosphine released was much higher than the targeted dose. Thus, it can be concluded that the use of Eco_2Fume is more efficient than that of phosphine tablet. In the methyl bromide treatment, at 24 hours onwards the concentration of fumigant in the rice stacks was also much higher than that necessary to kill the test insects.
4. At Tambun, fumigation was done only once because the insect population, as monitored by bait traps, did not reach the control threshold after four months, whereas at Buduran, the insect population reached the control threshold after the same period of time; therefore, re-fumigation was conducted at Buduran 4 months after the first fumigation.
5. Comparison of the rice quality data from Tambun and Buduran led to the suggestion that initial conditions of the commodity to be stored are essential for the storage management. Implementation of other components of integrated storage management could reduce the need of frequent fumigation.

6. Cotton sheet covering treated with an appropriate contact insecticide could act as an effective barrier against insect infestation after fumigation. This method, however, could only be used to a limited extent because of its potential to promote fungal growth. None of the fumigation treatments could inhibit the growth of storage fungi. Among the four treatments, the worst condition — with regard to the fungal contaminants — was found in the Eco_2Fume + cotton sheet treatment. Probably the cotton sheet covering made the air within the rice stacks become more humid and this condition was more favourable for the growth and development of storage fungi.
7. In the fumigation trial with coffee, the concentration of phosphine could also be kept above or at about the targeted dose (300 ppm) during the whole fumigation period, but in that with wood, the concentration of phosphine could drop below 300 ppm in just 2-3 days. Inconsistencies of results with wood fumigation, with regard to phosphine concentration, might be due to the leakage in containers and/or absorption of the fumigant by wood material. Nonetheless, both in coffee and wood, mortality of the test insects reached 100%.
8. The financial analysis showed that the least cost analysis can be used as a guidance to choose the most feasible alternative technology. The treatment with phosphine tablet was the least cost method and the second least method was the methyl bromide treatment. Irrespective of the cost of Eco_2Fume, the treatment with Eco_2Fume without cotton sheet covering is cheaper than that with the cotton sheet covering.
9. Generally, the conditions of Bulog's warehouses in Bandung and Karawang are good, mainly at Bulog's new type warehouses. These warehouses are still feasible for storing commodities. One important problem is that several warehouses have few leaks and many leaks in their roof. This needs to be seriously addressed because water falling to the staples of stored commodity would decrease the quality of products. Training in warehouse management is needed particularly that related to administration, hygiene, and pest monitoring.
10. In adopting ISPM as an alternative to methyl bromide, several steps need to be implemented. These include understanding of various factors that cause the decrease of product quality beginning with the emphasis on achieving sound initial conditions of products; understanding of physical factors of environment;

understanding of kinds, characteristics, and status of storage pests through continual monitoring program; and integration of various control methods by considering economic feasibility, food safety and environment conservation. By integrating all commodity management methods, the use of chemicals is only supplementary to the whole system. On the other hand, by considering negative side effects of pesticides to the environment and food safety, it is worth to seriously consider the use of botanical pesticides and mineral ingredients as an alternative technology which is technically and economically feasible as well as environment friendly.

11. As an effort to improve understanding of integrated pest management in storage environment, the role of training is very important. In the context of disseminating various information and experiences in IPM as a part of alternative technology to methyl bromide, seminars, workshops or other methods are appropriate places to socialize the technology. Socialization is very important so that the people have sound understanding about methyl bromide phase out, and alternative technology to methyl bromide could be appropriately implemented by related sectors. In this way, unpleasant experience related to withdrawal of persistent insecticides such as DDT, endrin, etc., could be avoided.

APPENDICES

Appendix Table 1. Concentration of phosphine in treatment A (Eco_2Fume) at different measurement points during a 5-day fumigation period at Tambun Research Center Warehouse

Gas sampling position	Average PH_3 concentration (ppm) ± SD at indicated hours from the start of fumigation[a]									
	1	18	24	42	48	66	72	90	96	114
Stack corner										
Top	84.0 ± 55.2	385.5 ± 60.1	388.0 ± 73.5	557.0 ± 168.3	649.0 ± 72.1	583.0 ± 77.8	525.5 ± 147.8	470.0 ± 63.6	400.5 ± 79.9	347.5 ± 87.0
Middle	18.5 ± 4.9	263.0 ± 141.4	786.0 ± 575.6	403.0 ± 49.5	502.0 ± 91.9	405.0 ± 107.5	396.0 ± 21.2	439.0 ± 94.8	393.5 ± 33.2	364.5 ± 64.3
Bottom	2000.0 ± 0	383.5 ± 51.6	358.5 ± 40.3	684.5 ± 375.5	586.0 ± 46.7	525.5 ± 31.8	521.0 ± 117.4	470.5 ± 55.9	376.5 ± 129.4	377.5 ± 74.2
Stack side										
Top	142.5 ± 78.5	761.0 ± 561.4	356.0 ± 14.1	638.0 ± 295.6	634.0 ± 52.3	565.5 ± 64.3	382.5 ± 61.5	460.5 ± 115.3	426.5 ± 33.2	368.5 ± 62.9
Middle	49.5 ± 19.1	752.5 ± 608.8	397.0 ± 77.8	715.5 ± 422.1	536.5 ± 222.7	511.0 ± 14.1	523.0 ± 151.3	487.0 ± 141.4	394.0 ± 99.0	318.0 ± 82.0
Bottom	2000.0 ± 0	546.5 ± 266.6	326.5 ± 19.1	696.0 ± 258.8	398.5 ± 132.2	546.0 ± 46.7	516.5 ± 136.5	453.0 ± 86.3	411.5 ± 47.4	365.5 ± 62.9

[a] Average of two replications

Appendix Table 2. Concentration of phosphine in treatment C (Eco_2Fume + cotton sheet) at different measurement points during a 5-day fumigation period at Tambun Research Center Warehouse

Gas sampling position	Average PH_3 concentration (ppm) ± SD at indicated hours from the start of fumigation[a]									
	1	18	24	42	48	66	72	90	96	114
Stack corner										
Top	54.0 ± 19.8	360.0 ± 127.3	598.0 ± 186.7	645.5 ± 176.1	551.5 ± 259.5	404.5 ± 17.7	459.0 ± 161.2	373.0 ± 94.8	391.5 ± 65.8	319.5 ± 13.4
Middle	116.0 ± 97.6	368.5 ± 136.5	635.0 ± 224.9	566.0 ± 130.1	444.0 ± 117.4	331.0 ± 26.9	464.0 ± 147.1	397.5 ± 64.3	425.5 ± 92.6	296.5 ± 123.7
Bottom	2000.0 ± 0	290.5 ± 27.6	605.0 ± 178.2	545.5 ± 109.6	543.0 ± 267.3	490.5 ± 167.6	461.5 ± 145.0	403.0 ± 120.2	449.5 ± 128.0	330.5 ± 128.0
Stack side										
Top	13.5 ± 2.1	361.5 ± 156.3	338.5 ± 178.9	429.5 ± 384.0	410.5 ± 143.5	402.5 ± 34.6	445.5 ± 248.2	332.0 ± 111.7	370.0 ± 141.4	339.0 ± 154.1
Middle	77.5 ± 88.4	369.5 ± 150.6	352.0 ± 118.8	445.0 ± 391.7	293.0 ± 121.6	555.5 ± 147.8	476.5 ± 195.9	381.0 ± 108.9	423.0 ± 120.2	303.0 ± 91.9
Bottom	2000.0 ± 0	443.0 ± 32.5	377.0 ± 130.1	443.0 ± 403.1	504.0 ± 258.8	471.5 ± 187.4	426.5 ± 174.7	362.5 ± 85.6	391.5 ± 125.2	295.0 ± 125.9

[a] Average of two replications

Appendix Table 3. Concentration of MeBr in treatment B at different measurement points during a 48-hour fumigation period at Tambun Research Center Warehouse

Gas sampling position	Average MeBr concentration (ppm) ± SD at indicated hours from the start of fumigation[a]					
	1	18	24	42	48	66
Stack corner						
Top	2875.0 ± 1060.7	4594.0 ± 574.2	4312.5 ± 972.3	2156.5 ± 485.8	2406.5 ± 839.3	1750.0 ± 353.6
Middle	4594.0 ± 574.2	4594.0 ± 574.2	4312.5 ± 972.3	2000.0 ± 707.1	2187.5 ± 972.3	1469.0 ± 309.7
Bottom	5000.0 ± 0	5000.0 ± 0	4312.5 ± 972.3	2500.0 ± 0	2500.0 ± 0	1375.0 ± 176.8
Stack side						
Top	1375.0 ± 176.8	5000.0 ± 0	5000.0 ± 0	3062.5 ± 795.5	3219.0 ± 486.5	1969.0 ± 220.6
Middle	4312.5 ± 972.3	5000.0 ± 0	5000.0 ± 0	3625.0 ± 0	3281.5 ± 398.1	2344.0 ± 220.6
Bottom	5000.0 ± 0	5000.0 ± 0	5000.0 ± 0	3312.5 ± 441.9	3281.5 ± 398.1	2250.0 ± 353.6

[a] Average of two replications

Appendix Table 4. Concentration of phosphine in treatment D at different measurement points during a 5-day fumigation period at Tambun Research Center Warehouse

Gas sampling position	Average PH_3 concentration (ppm) ± SD at indicated hours from the start of fumigation[a]									
	1	18	24	42	48	66	72	90	96	114
Stack corner										
Top	344.0 ± 176.8	249.0 ± 11.3	392.5 ± 0	423.5 ± 126.6	1678.0 ± 455.4	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	1891.0 ± 154.1
Middle	325.5 ± 79.9	1737.5 ± 371.2	2000.0 ± 0	1719.5 ± 396.7	1665.5 ± 473.1	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	1845.0 ± 219.2
Bottom	1286.0 ± 790.5	1751.5 ± 351.4	2000.0 ± 0	1793.0 ± 292.7	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	1869.0 ± 185.3
Stack side										
Top	488.5 ± 299.1	1397.5 ± 644.2	1384.5 ± 461.7	1884.5 ± 163.3	1584.0 ± 588.3	2000.0 ± 0	1695.0 ± 431.3	2000.0 ± 0	2000.0 ± 0	1893.0 ± 151.3
Middle	458.0 ± 486.5	1440.0 ± 35.4	1908.0 ± 130.1	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	1862.5 ± 194.5
Bottom	938.0 ± 164.0	2000.0 ± 0	1931.5 ± 96.9	1922.0 ± 21.2	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	2000.0 ± 0	1903.5 ± 136.5

[a] Average of two replications

Appendix Table 5. Concentration of phosphine in treatment A (Eco_2Fume) at different measurement points during a 5-day fumigation period at Dolog's Buduran Warehouse (first fumigation)

Gas sampling position	Average PH_3 concentration (ppm) ± SD at indicated hours from the start of fumigation[a]										
	1	**18**	**24**	**42**	**48**	**66**	**72**	**90**	**96**	**114**	**120**
Stack corner											
Top	189.5 ± 195.9	212.0 ± 243.2	465.0 ± 26.9	440.5 ± 6.4	396.0 ± 14.1	320.5 ± 9.2	307.0 ± 25.5	272.0 ± 25.5	308.0 ± 8.5	261.0 ± 19.8	240.5 ± 51.6
Middle	776.0 ± 943.3	338.0 ± 21.2	474.0 ± 19.8	447.5 ± 13.4	296.0 ± 141.4	329.5 ± 14.8	308.0 ± 22.6	284.0 ± 24.0	306.5 ± 7.8	287.0 ± 25.5	273.5 ± 0.7
Bottom	1757.5 ± 342.9	574.5 ± 139.3	436.5 ± 72.8	448.5 ± 16.3	363.5 ± 58.7	319.5 ± 17.7	298.0 ± 42.4	308.5 ± 30.4	304.5 ± 13.4	289.5 ± 3.5	277.5 ± 14.8
Stack side											
Top	126.0 ± 142.8	244.5 ± 265.2	452.5 ± 40.3	450.5 ± 19.1	426.0 ± 41.0	330.5 ± 13.4	318.0 ± 18.4	297.5 ± 19.1	298.5 ± 2.1	288.5 ± 14.8	298.5 ± 24.7
Middle	1036.5 ± 796.9	463.0 ± 19.8	472.0 ± 31.1	453.0 ± 21.2	423.0 ± 42.4	322.0 ± 4.2	299.5 ± 36.1	319.5 ± 24.7	302.5 ± 6.4	287.5 ± 17.7	298.5 ± 31.8
Bottom	1997.0 ± 4.2	491.0 ± 24.0	463.0 ± 55.2	455.5 ± 27.6	434.0 ± 29.7	332.0 ± 19.8	329.0 ± 24.0	323.0 ± 33.9	305.0 ± 14.1	294.5 ± 13.4	298.5 ± 36.0

[a] Average of two replications

Appendix Table 6. Concentration of phosphine in treatment C (Eco_2Fume + cotton sheet) at different measurement points during a 5-day fumigation period at Dolog's Buduran Warehouse (first fumigation)

Gas sampling position	Average PH_3 concentration (ppm) ± SD at indicated hours from the start of fumigation[a]										
	1	18	24	42	48	66	72	90	96	114	120
Stack corner											
Top	164.0 ± 206.5	410.5 ± 171.8	453.0 ± 1.4	454.5 ± 43.1	390.5 ± 34.6	329.0 ± 32.5	312.0 ± 65.1	305.0 ± 31.1	311.5 ± 33.2	300.0 ± 22.6	284.5 ± 23.3
Middle	550.5 ± 31.8	323.0 ± 274.4	389.0 ± 70.7	439.5 ± 50.2	369.0 ± 21.2	332.0 ± 32.5	319.0 ± 58.0	314.0 ± 43.8	316.0 ± 21.2	295.0 ± 26.9	287.0 ± 25.5
Bottom	1975.0 ± 35.4	606.5 ± 270.8	431.0 ± 50.9	449.5 ± 37.5	395.5 ± 20.5	325.0 ± 29.7	315.5 ± 61.5	316.0 ± 42.4	316.0 ± 21.2	308.0 ± 38.2	300.5 ± 26.2
Stack side											
Top	441.0 ± 543.1	349.0 ± 96.2	451.0 ± 35.4	458.5 ± 47.4	381.0 ± 15.6	309.5 ± 54.4	314.0 ± 48.1	310.0 ± 36.8	316.5 ± 24.7	295.0 ± 45.3	292.0 ± 55.2
Middle	1039.5 ±1315.9	444.5 ± 102.5	458.0 ± 59.4	454.0 ± 42.4	402.5 ± 20.5	326.5 ± 16.3	313.5 ± 38.9	254.5 ± 113.8	307.5 ± 38.9	301.0 ± 39.6	297.0 ± 18.4
Bottom	1697.5 ± 406.6	881.0 ± 558.6	519.0 ± 107.5	447.5 ± 53.0	390.0 ± 26.9	261.5 ± 116.7	299.5 ± 30.4	298.5 ± 10.6	322.5 ± 34.6	270.0 ± 46.7	288.5 ± 24.7

[a] Average of two replications

Appendix Table 7. Concentration of MeBr in treatment B at different measurement points during a 48-hour fumigation period at Dolog's Buduran Warehouse (first fumigation)

Gas sampling position	Average MeBr concentration (ppm) ± SD at indicated hours from the start of fumigation[a]				
	1	18	24	42	48
Stack corner					
Top	1125.0 ± 0	5000.0 ± 0	3562.5 ± 0	2562.5 ± 618.7	2312.5 ± 265.2
Middle	875.0 ± 0	5000.0 ± 0	3562.5 ± 0	2312.5 ± 265.2	1875.0 ± 883.9
Bottom	687.5 ± 0	4593.8 ± 574.5	3031.3 ± 751.3	2156.3 ± 486.1	1968.8 ± 221.0
Stack side					
Top	687.5 ± 0	5000.0 ± 0	4187.5 ± 0	3000.0 ± 0	2500.0 ± 0
Middle	500.0 ± 0	5000.0 ± 0	4187.5 ± 0	3000.0 ± 0	1875.0 ± 883.9
Bottom	312.5 ± 0	4593.8 ± 574.5	3281.3 ± 397.7	3250.0 ± 353.6	2500.0 ± 0

[a] Average of two replications

Appendix Table 8. Concentration of phosphine in treatment D at different measurement points during a 5-day fumigation period at Dolog's Buduran Warehouse (first fumigation)

Gas sampling position	**Average PH_3 concentration (ppm) ± SD at indicated hours from the start of fumigation**[a]										
	1	**18**	**24**	**42**	**48**	**66**	**72**	**90**	**96**	**114**	**120**
Stack corner											
Top	0 ± 0	1283.0 ± 17.0	1042.5 ± 324.6	1846.5 ± 207.2	1545.0 ± 217.8	1371.5 ± 105.4	894.5 ± 24.7	1564.0 ± 356.4	1573.0 ± 408.7	1509.0 ± 352.1	1419.0 ± 360.6
Middle	0 ± 0	1257.5 ± 27.6	1057.5 ± 398.9	1776.5 ± 186.0	1169.0 ± 256.0	1521.0 ± 233.3	1166.5 ± 828.0	1592.5 ± 310.4	1540.0 ± 411.5	1484.5 ± 347.2	1409.0 ± 394.6
Bottom	98.0 ± 17.0	1297.0 ± 24.0	1174.0 ± 388.9	1836.0 ± 212.1	1525.5 ± 221.3	1532.5 ± 293.4	1205.0 ± 301.2	1560.5 ± 393.9	1525.5 ± 422.1	1506.0 ± 407.3	1418.0 ± 405.9
Stack side											
Top	0 ± 0	1262.5 ± 94.0	1001.5 ± 222.7	1844.0 ± 199.4	1519.0 ± 294.2	1557.0 ± 328.1	1365.5 ± 529.6	1564.0 ± 439.8	1541.0 ± 404.5	1436.0 ± 363.5	1443.5 ± 345.8
Middle	0 ± 0	1225.0 ± 67.9	1261.0 ± 195.2	1827.0 ± 168.3	1513.0 ± 265.9	1527.0 ± 338.0	1466.5 ± 548.0	1563.0 ± 373.4	1529.0 ± 388.9	1526.5 ± 385.4	1455.5 ± 347.2
Bottom	32.0 ± 21.2	1250.0 ± 93.3	1237.0 ± 203.6	1848.5 ± 191.6	1486.5 ± 202.9	1535.0 ± 298.4	1461.0 ± 538.8	1541.0 ± 339.4	1518.0 ± 394.6	1484.5 ± 385.4	1453.5 ± 440.5

[a] Average of two replications

Appendix Table 9. Concentration of phosphine in treatment A (Eco$_2$Fume) at different measurement points during a 5-day fumigation period at Dolog's Buduran Warehouse (second fumigation)

Gas sampling position	Average PH_3 concentration (ppm) ± SD at indicated hours from the start of fumigation[a]										
	1	18	24	42	48	66	72	90	96	114	120
Stack corner											
Top	344.0 ± 176.8	249.0 ± 11.3	392.5 ± 16.3	423.5 ± 111.0	379.5 ± 27.6	276.0 ± 28.3	270.5 ± 6.4	282.5 ± 0.7	267.5 ± 20.5	278.5 ± 58.7	241.0 ± 28.3
Middle	325.5 ± 79.9	336.0 ± 100.4	355.5 ± 54.4	382.0 ± 84.9	355.0 ± 73.5	316.0 ± 4.2	338.5 ± 12.0	332.5 ± 7.8	246.5 ± 61.5	300.0 ± 43.8	284.0 ± 26.9
Bottom	1286.0 ± 790.5	1006.5 ± 929.8	365.5 ± 23.3	284.0 ± 49.5	359.5 ± 24.7	232.5 ± 68.6	277.5 ± 21.9	251.5 ± 50.2	249.0 ± 67.9	277.0 ± 45.3	266.5 ± 19.1
Stack side											
Top	488.5 ± 299.1	466.5 ± 348.6	369.5 ± 31.8	347.0 ± 42.4	341.0 ± 29.7	242.0 ± 12.7	278.5 ± 50.2	251.0 ± 12.7	298.0 ± 28.3	277.5 ± 41.7	236.0 ± 75.0
Middle	458.0 ± 486.5	252.5 ± 183.1	398.0 ± 2.8	417.5 ± 77.1	436.0 ± 58.0	234.0 ± 29.7	225.0 ± 36.8	241.0 ± 31.1	306.5 ± 7.8	280.5 ± 29.0	291.0 ± 31.1
Bottom	938.0 ± 164.0	635.5 ± 265.2	510.5 ± 190.2	520.0 ± 155.6	504.0 ± 190.9	333.5 ± 43.1	282.5 ± 67.2	340.0 ± 36.8	308.0 ± 5.7	277.5 ± 13.4	264.5 ± 20.5

[a] Average of two replications

Appendix Table 10. Concentration of MeBr in treatment B at different measurement points during a 48-hour fumigation period at Dolog's Buduran Warehouse (second fumigation)

Gas sampling position	Average MeBr concentration (ppm) ± SD at indicated hours from the start of fumigation[a]					
	1	18	24	42	48	66
Stack corner						
Top	5000.0 ± 0	5000.0 ± 0	5000.0 ± 0	3000.0 ± 707.1	3281.3 ± 221.0	2312.5 ± 1149.0
Middle	5000.0 ± 0	4000.0 ± 1414.2	4062.5 ± 1325.8	3781.3 ± 486.1	2000.0 ± 707.1	1500.0 ± 0
Bottom	5000.0 ± 0	4000.0 ± 1414.2	4000.0 ± 1414.2	3375.0 ± 530.3	1625.0 ± 176.8	1500.0 ± 0
Stack side						
Top	5000.0 ± 0	4000.0 ± 1414.2	4000.0 ± 1414.2	3812.5 ± 441.9	3468.8 ± 44.2	2312.5 ± 1679.4
Middle	5000.0 ± 0	5000.0 ± 0	5000.0 ± 0	4062.5 ± 1325.8	3375.0 ± 530.3	2750.0 ± 1414.2
Bottom	5000.0 ± 0	3843.8 ± 1635.2	3843.8 ± 1635.2	2500.0 ± 1414.2	2312.5 ± 1679.4	2093.75 ± 1988.7

[a] Average of two replications

Appendix Table 11. Concentration of phosphine in treatment D at different measurement points during a 5-day fumigation period at Dolog's Buduran Warehouse (second fumigation)

Gas sampling position	Average PH_3 concentration (ppm) ± SD at indicated hours from the start of fumigation[a]										
	1	18	24	42	48	66	72	90	96	114	120
Stack corner											
Top	106.0 ± 123.0	1029.5 ± 406.6	1005.5 ± 1054.3	1587.0 ± 562.9	1395.5 ± 639.9	1717.0 ± 400.2	1265.0 ± 66.5	1553.5 ± 456.1	1371.0 ± 605.3	927.5 ± 763.0	1314.0 ± 540.2
Middle	143.0 ± 83.4	1237.0 ± 444.1	1223.5 ± 120.9	1533.5 ± 340.1	1802.5 ± 137.9	1730.0 ± 99.0	1536.0 ± 151.3	1572.5 ± 236.9	1903.0 ± 117.4	1428.5 ± 82.7	1755.5 ± 197.3
Bottom	112.0 ± 33.9	1053.0 ± 87.7	1080.5 ± 317.5	1494.5 ± 318.9	1366.5 ± 458.9	1315.0 ± 142.8	1199.5 ± 12.0	1269.5 ± 92.6	1551.5 ± 433.5	942.0 ± 490.7	1540.0 ± 435.6
Stack side											
Top	58.5 ± 2.1	980.5 ± 113.8	1381.0 ± 304.1	1479.5 ± 311.8	1777.5 ± 314.7	1348.0 ± 202.2	1440.5 ± 460.3	1427.0 ± 442.6	1885.5 ± 142.1	958.0 ± 168.3	1817.0 ± 49.5
Middle	71.5 ± 17.7	1139.5 ± 351.4	1178.0 ± 198.0	1851.5 ± 193.0	1233.5 ± 389.6	1600.0 ± 547.3	1552.5 ± 614.5	1459.5 ± 498.5	1889.5 ± 135.1	1390.5 ± 540.9	1837.0 ± 35.4
Bottom	113.5 ± 40.3	1273.5 ± 259.5	1396.0 ± 478.0	1847.0 ± 196.6	1590.5 ± 27.6	1616.0 ± 448.3	1550.5 ± 502.8	1492.5 ± 423.6	1897.5 ± 123.7	1166.5 ± 7.8	1889.0 ± 128.7

[a] Average of two replications

Appendix Table 12. Concentration of phosphine (from Eco_2Fume) at different measurement points in coffee and wood containers in Lampung (first fumigation)

Commodity/gas sampling position	Average fumigant concentration (ppm) ± SD at indicated hours from the start of fumigation[a]									
	1	18	24	42	48	66	72	90	96	114
Coffee										
Top	2000 ± 0	599 ± 21.2	529 ± 26.9	461.5 ± 2.1	434.5 ± 21.9	460.5 ± 34.6	442 ± 52.3	402.5 ± 29	359.5 ± 51.6	331.5 ± 16.3
Middle	1285.5 ± 996.3	628 ± 2.8	568 ± 83.4	483 ± 52.3	457.5 ± 31.8	470 ± 7.1	436 ± 36.8	411.5 ± 13.4	370 ± 56.6	351 ± 1.4
Bottom	2000 ± 0	635.5 ± 62.9	479.5 ± 71.4	477 ± 1.4	463 ± 14.1	489.5 ± 16.26	410 ± 8.48	415.5 ± 7.8	360.5 ± 50.2	331 ± 8.5
Wood										
Top	871 ± 0	540 ± 42.2	525 ± 21.2	346 ± 0	324 ± 22.6	245 ± 58	221 ± 0	186.5 ± 0.7	166.5 ± 9.2	135.5 ± 16.3
Middle	1274 ± 0	570 ± 14.1	515 ± 21.2	383.5 ± 29	282 ± 38.2	236 ± 22.6	210 ± 0	190.5 ± 14.8	156 ± 4.6	133.5 ± 4.9
Bottom	2000 ± 0	540 ± 14.1	477 ± 1.4	342.5 ± 46	308 ± 2.8	233.5 ± 12	242.5 ± 46	183.5 ± 4.95	165.5 ± 2.1	138 ± 18.4

[a] Average of two replications

Appendix Table 13. Concentration of phosphine (from Eco_2Fume) at different measurement points in coffee and wood containers in Lampung (second fumigation)

Commodity/gas sampling position	Average fumigant concentration (ppm) ± SD at indicated hours from the start of fumigation[a]								
	1	18	24	42	48	66	72	90	96
Coffee									
Top	2000 ± 0	626.5 ± 19.1	789.5 ± 123.74	704 ± 29.7	624.5 ± 150.61	544 ± 50.91	548 ± 62.23	460 ± 14.14	413.5 ± 40.31
Middle	2000 ± 0	668 ± 14.85	891 ± 100.41	710 ± 28.28	653 ± 106.07	509 ± 4.24	570 ± 1.41	465 ± 21.21	427.5 ± 10.61
Bottom	2000 ± 0	994.5 ± 99	880.5 ± 99.7	736 ± 8.49	661 ± 175.36	544 ± 72.12	536 ± 19.09	482.5 ± 10.61	443 ± 18.38
Wood									
Top	2000 ± 0	634 ± 115.26	558 ± 186.68	448.5 ± 118.08	419.5 ± 95.46	338.5 ± 108.19	389 ± 132.94	305.5 ± 62.93	319.5 ± 4.95
Middle	2000 ± 0	631.5 ± 72.83	581 ± 97.58	465 ± 106.07	422 ± 89.1	391 ± 93.34	353 ± 106.07	303.5 ± 68.59	263 ± 59.4
Bottom	2000 ± 0	626.5 ± 6.36	543 ± 79.9	450 ± 106.07	415 ± 106.07	367.5 ± 95.46	367 ± 107.48	289.5 ± 51.62	274.5 ± 55.86

[a] Average of two replications

Appendix Table 14. Concentration of phosphine (from Eco_2Fume) at different measurement points in coffee and wood containers in Lampung (third fumigation)

Commodity/gas sampling position	Average fumigant concentration (ppm) ± SD at indicated hours from the start of fumigation[a]								
	1	**18**	**24**	**42**	**48**	**66**	**72**	**90**	**96**
Coffee									
Top	2000 ± 0	688 ± 166.88	466.5 ± 120.92	488 ± 87.68	480 ± 70.71	457.5 ± 60.10	364 ± 76.37	342.5 ± 74.25	287.5 ± 38.89
Middle	2000 ± 0	650 ± 141.42	432.5 ± 116.67	480 ± 113.14	472.5 ± 67.18	447.5 ± 74.25	387 ± 57.98	357.5 ± 53.03	292.5 ± 17.68
Bottom	2000 ± 0	650 ± 141.42	467.5 ± 86.97	475 ± 106.07	508.5 ± 125.16	470 ± 98.99	386.5 ± 72.83	355 ± 63.64	290 ± 14.14
Wood									
Top	2000 ± 0	665.5 ± 50.20	521 ± 7.07	422 ± 9.90	386 ± 1.41	317.5 ± 17.68	342.5 ± 10.61	276 ± 12.73	240.5 ± 7.78
Middle	2000 ± 0	363.5 ± 28.99	577 ± 33.94	446 ± 15.56	403.3 ± 2.12	319 ± 22.63	335 ± 48.1	263 ± 18.38	238 ± 4.28
Bottom	2000 ± 0	626.5 ± 10.61	534 ± 12.02	425 ± 7.07	392.5 ± 3.54	302.5 ± 2.12	318 ± 22.63	263 ± 12.73	241 ± 2..83

[a] Average of two replications

Appendix Table 15. Results of rice quality analysis before and after fumigation in Bulog's Tambun Research Center Warehouse

Components	Treatments[a]	Before fumigation[b]	Months after fumigation[b]		
			1	2	3
Insect contamination (larvae)	A	0 ± 0	0 ± 0	0 ± 0	1.0 ± 0.0
	B	0 ± 0	0 ± 0	0 ± 0	0.5 ± 0.7
	C	0 ± 0	0 ± 0	0 ± 0	0.0 ± 0.0
	D	0 ± 0	0 ± 0	0 ± 0	1.5 ± 0.7
Moisture content (%)	A	14.20 ± 0.14	13.45 ± 1.06	14.10 ± 0.14	14.15 ± 0.07
	B	13.20 ± 0.92	14.15 ± 0.14	14.05 ± 0.07	13.95 ± 0.21
	C	14.13 ± 0.11	14.40 ± 0.00	14.25 ± 0.07	13.70 ± 0.00
	D	14.03 ± 0.11	13.95 ± 0.78	14.00 ± 0.57	14.00 ± 0.28
Small broken grain (%)	A	0.49 ± 0.07	1.36 ± 0.81	2.03 ± 1.70	0.85 ± 0.37
	B	0.31 ± 0.04	1.00 ± 0.06	0.68 ± 0.31	0.68 ± 0.01
	C	1.10 ± 0.42	1.02 ± 0.21	1.41 ± 0.30	1.33 ± 0.36
	D	0.64 ± 0.03	0.92 ± 0.08	0.97 ± 0.18	0.83 ± 0.36
Broken grain (%)	A	18.95 ± 1.20	19.60 ± 0.32	15.95 ± 1.32	18.41 ± 2.62
	B	21.20 ± 0.34	18.12 ± 1.36	14.98 ± 2.27	16.76 ± 1.28
	C	19.20 ± 1.13	16.90 ± 2.75	17.37 ± 1.94	20.04 ± 2.35
	D	16.52 ± 3.22	18.13 ± 2.76	16.93 ± 2.02	18.98 ± 0.88

[a] A: Eco_2 Fume, B: MeBr, C: Eco_2Fume + cotton sheet, D: Celphos (AlP). [b] Mean ± SD (average of two replications).

Appendix Table 15. *Continued*

Components	Treatments[a]	Before fumigation[b]	Months after fumigation[b]		
			1	2	3
Head rice (%)	A	80.56 ± 1.13	79.05 ± 0.49	82.03 ± 3.02	80.75 ± 3.00
	B	78.49 ± 0.38	80.63 ± 1.65	84.35 ± 2.58	82.57 ± 1.27
	C	79.70 ± 0.71	82.09 ± 2.96	81.23 ± 2.24	78.64 ± 1.99
	D	82.84 ± 3.25	80.96 ± 2.69	82.11 ± 1.84	80.20 ± 0.52
Yellow/damaged kernels (%)	A	1.76 ± 0.08	3.00 ± 0.52	2.90 ± 0.34	3.71 ± 1.48
	B	1.92 ± 0.23	2.69 ± 0.18	2.79 ± 0.78	3.91 ± 0.31
	C	2.22 ± 0.31	2.13 ± 0.24	2.25 ± 0.42	2.78 ± 0.37
	D	2.18 ± 1.10	2.61 ± 1.03	2.66 ± 1.42	4.47 ± 0.16
Chalky/green kernels (%)	A	0.31 ± 0.11	0.45 ± 0.13	0.53 ± 0.04	0.62 ± 0.35
	B	0.40 ± 0.00	0.41 ± 0.19	0.48 ± 0.07	0.42 ± 0.08
	C	0.44 ± 0.23	0.46 ± 0.21	0.44 ± 0.16	0.59 ± 0.10
	D	0.76 ± 0.06	0.71 ± 0.49	0.66 ± 0.54	0.36 ± 0.16
Foreign matter (%)	A	0.005 ± 0.007	0 ± 0	0 ± 0	0 ± 0
	B	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	C	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	D	0 ± 0	0 ± 0	0 ± 0	0 ± 0

[a] A: Eco_2 Fume, B: MeBr, C: Eco_2Fume + cotton sheet, D: Celphos (AlP). [b] Mean ± SD (average of two replications).

Appendix Table 15. *Continued*

Components	Treatments[a]	Before fumigation[b]	Months after fumigation[b]		
			1	2	3
Paddy (pieces)	A	0.50 ± 0.71	0.50 ± 0.71	1.00 ± 1.41	0.50 ± 0.71
	B	0.50 ± 0.71	1.00 ± 1.41	0 ± 0	1.00 ± 1.41
	C	0 ± 0	0 ± 0	0.50 ± 0.71	0.50 ± 0.71
	D	0 ± 0	0.50 ± 0.71	1.00 ± 0.00	0 ± 0
Red kernels (%)	A	0.28 ± 0.17	0.38 ± 0.18	0.19 ± 0.01	0.37 ± 0.02
	B	0.16 ± 0.00	0.06 ± 0.04	0.22 ± 0.19	0.37 ± 0.14
	C	0.12 ± 0.06	0.14 ± 0.05	0.30 ± 0.03	0.59 ± 0.03
	D	0.12 ± 0.06	0.40 ± 0.30	0.56 ± 0.57	0.61 ± 0.22

[a] A: Eco_2 Fume, B: MeBr, C: Eco_2Fume + cotton sheet, D: Celphos (AlP). [b] Mean ± SD (average of two replications).

Appendix Table 16. Results of rice quality analysis before and after fumigation in Dolog's Buduran Warehouse, East Java

Components	Treatments[a]	Before fumigation[b]	Months after fumigation[b]		
			1	2	3
Insect contamination (larvae)	A	0 ± 0	0 ± 0	0 ± 0	25.0 ± 18.4
	B	0 ± 0	0 ± 0	0 ± 0	0.0 ± 0.0
	C	0 ± 0	0 ± 0	0 ± 0	5.5 ± 7.8
	D	0 ± 0	0 ± 0	0 ± 0	7.0 ± 4.2
Moisture content (%)	A	14.95 ± 0.07	14.60 ± 0.00	14.50 ± 0.00	14.30 ± 0.00
	B	14.75 ± 0.21	14.85 ± 0.07	14.75 ± 0.07	14.45 ± 0.07
	C	15.05 ± 0.07	14.75 ± 0.07	14.55 ± 0.07	14.25 ± 0.07
	D	15.00 ± 0.00	15.10 ± 0.00	15.00 ± 0.00	14.95 ± 0.07
Small broken grain (%)	A	0.32 ± 0.06	0.50 ± 0.06	0.36 ± 0.01	0.51 ± 0.11
	B	0.60 ± 0.42	0.37 ± 0.14	0.46 ± 0.16	0.63 ± 0.06
	C	0.28 ± 0.00	0.48 ± 0.06	0.54 ± 0.23	0.68 ± 0.11
	D	0.61 ± 0.28	0.37 ± 0.11	0.50 ± 0.13	0.70 ± 0.03
Broken grain (%)	A	27.52 ± 0.09	26.65 ± 5.52	28.00 ± 4.32	29.48 ± 2.38
	B	26.21 ± 0.28	21.72 ± 3.71	22.36 ± 3.74	22.78 ± 4.30
	C	23.93 ± 1.08	31.40 ± 1.21	31.45 ± 0.66	31.59 ± 0.45
	D	24.27 ± 0.15	22.45 ± 1.57	23.27 ± 0.38	24.26 ± 0.35

[a] A: Eco_2 Fume, B: MeBr, C: Eco_2Fume + cotton sheet, D: Celphos (AlP). [b] Mean ± SD (average of two replications).

Appendix Table 16. *Continued*

Components	Treatments[a]	Before fumigation[b]	Months after fumigation[b]		
			1	2	3
Head rice (%)	A	72.17 ± 0.04	72.86 ± 5.45	71.65 ± 4.33	70.02 ± 2.49
	B	73.20 ± 0.14	77.91 ± 3.56	77.19 ± 3.58	76.59 ± 4.24
	C	75.80 ± 1.08	68.13 ± 1.27	68.01 ± 0.89	57.74 ± 0.55
	D	75.13 ± 0.42	77.19 ± 1.68	76.19 ± 0.45	75.04 ± 0.38
Yellow/damaged kernels (%)	A	2.32 ± 0.48	2.67 ± 0.30	2.72 ± 0.36	2.89 ± 0.18
	B	1.79 ± 0.67	2.79 ± 0.16	2.84 ± 0.11	2.95 ± 0.09
	C	2.25 ± 0.21	2.55 ± 0.12	2.61 ± 0.10	2.87 ± 0.11
	D	1.92 ± 0.26	2.90 ± 0.37	2.94 ± 0.20	3.10 ± 0.28
Chalky/green kernels (%)	A	1.07 ± 0.15	0.59 ± 0.07	0.74 ± 0.06	0.96 ± 0.71
	B	1.68 ± 0.58	1.11 ± 0.06	1.02 ± 0.03	1.12 ± 0.06
	C	1.08 ± 0.15	0.42 ± 0.08	0.42 ± 0.09	0.47 ± 0.13
	D	1.13 ± 0.15	1.17 ± 0.25	0.65 ± 0.49	0.80 ± 0.34
Foreign matter (%)	A	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	B	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	C	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	D	0 ± 0	0 ± 0	0 ± 0	0 ± 0

[a] A: Eco_2 Fume, B: MeBr, C: Eco_2Fume + cotton sheet, D: Celphos (AlP). [b] Mean ± SD (average of two replications).

Appendix Table 16. *Continued*

Components	Treatments[a]	Before fumigation[b]	Months after fumigation[b]		
			1	2	3
Paddy (pieces)	A	0.50 ± 0.71	0 ± 0	0.5 ± 0.7	1.0 ± 0.0
	B	0 ± 0	0 ± 0	0.5 ± 0.7	0 ± 0
	C	0 ± 0	1.0 ± 0.0	2.0 ± 1.4	0.5 ± 0.7
	D	0 ± 0	0 ± 0	0.5 ± 0.7	0.5 ± 0.7
Red kernels (%)	A	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	B	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	C	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	D	0 ± 0	0 ± 0	0 ± 0	0 ± 0

[a] A: Eco_2 Fume, B: MeBr, C: Eco_2Fume + cotton sheet, D: Celphos (AlP). [b] Mean ± SD (average of two replications).

Appendix Table 17. Growth of total insect population in Bulog's Tambun Research Center Warehouse as affected by fumigation treatments

Treatments[a]	Number of insects per trap at indicated months after fumigation[b]								
	1	2	3	4	5	6	7	8	9
Eco_2 Fume	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	7.5 ± 5.0	9.3 ± 9.0	8.9 ± 7.6	8.9 ± 9.6	10.0 ± 4.5	14.8 ± 7.0
Methyl bromide	0.0 ± 0.0	0.0 ± 0.2	0.5 ± 1.1	6.3 ± 4.9	11.5 ± 7.7	14.3 ± 14.6	14.3 ± 7.2	21.6 ± 24.8	39.0 ± 30.9
Eco_2 Fume + cotton sheet	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 1.5
Celphos Tablet	0.0 ± 0.0	0.0 ± 0.2	0.0 ± 0.2	6.3 ± 4.2	8.5 ± 8.3	9.5 ± 10.0	7.9 ± 8.1	15.9 ± 15.1	19.3 ± 18.6

[a] Fumigation was conducted only once. [b] Mean ± SD (average of data from two rice stacks with 12 bait traps per stack).

Appendix Table 18. Growth of total insect population in Dolog's Buduran Warehouse (East Java) as affected by fumigation treatments

Treatments[a]	Number of insects per trap at indicated months after the first fumigation[b]							
	1	2	3	4	5	6	7	8
Eco_2Fume	0.0 ± 0.0	0.0 ± 0.0	19.0 ± 9.6	43.9 ± 17.0	0.3 ± 0.6	3.6 ± 3.2	9.1 ± 4.9	26.5 ± 6.1
Methyl bromide	0.0 ± 0.0	2.2 ± 2.7	19.7 ± 7.7	56.4 ± 17.6	0.1 ± 0.3	1.7 ± 1.5	15.3 ± 6.4	33.2 ± 11.0
Eco_2Fume + cotton sheet	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	4.7 ± 4.3	0.2 ± 0.5	0.5 ± 0.8	6.2 ± 3.1	11.4 ± 4.4
Celphos Tablet	0.0 ± 0.0	2.8 ± 3.2	20.8 ± 9.6	44.0 ± 9.5	0.3 ± 0.8	1.9 ± 1.4	22.8 ± 3.5	44.9 ± 6.8

[a] Re-fumigation was conducted in the fourth month. [b] Mean ± SD (average of data from two rice stacks with 12 bait traps per stack).

Appendix 1. Abstracts of Workshop (I)

Agribusiness Management in Relation to Methyl Bromide Use vis-à-vis Trade Liberalization and Environmental Issues

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Abstract

Various international and national conventions have been ratified and implemented to anticipate the problem of methyl bromide as an ozone depleting substance (ODS). In Indonesia, methyl bromide is mainly used in post-production subsystems such as for fumigation in warehouses, pre-shipment treatment, and as quarantine measures. In relation to methyl bromide phasing out, trade liberalization and agribusiness management, development of alternatives to methyl bromide is a must. The development of such alternatives should consider environment management, environment audit, and environment labeling system in accordance to international standard system. Thus, the development of alternative technology to methyl bromide should be the concern of all sectors involved in agribusiness system so that Indonesia can exist well in the trade liberalization era.

Principles of Integrated Storage Management

Mulyo Sidik

Expert Staff of Head of Badan Urusan Logistik (BULOG), Jakarta

Abstract

Cereal commodities in the storage will always suffer quality deterioration. The decrease in quality can be inhibited by implementing various measures either prevention or curative ones. Quality management of commodity in the storage will give optimum results by integrating all preventive and control measures by considering cost environment conservation and optimum storage

duration. This concept is known as integrated storage management. IPM principles to be adopted must consider technical requirements, environmental issues, economically feasible and socially acceptable.

Postharvest Insect Pests and Their Problems

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Abstract

Various insects can become pests of post-harvest commodities in the storage. Infestation of pests in the storage may start from the field. The occurrence of physiological deterioration coupled with the poor storage conditions and long duration of storage can promote the growth of storage pest population. This can be very deleterious to the stored commodity. Two orders of insects most commonly become storage pests are Coleoptera and Lepidoptera. In addition to losses and damage caused by insect pests, commodities infested by pests can be rejected by export target countries. Therefore, implementation of integrated storage pest management needs to be done not only in the storage, but also must be done comprehensively since the commodity is still in the field, in the storage, and during transportation. Development of pest management methods must consider human safety, economic as well as technical aspects.

Post-harvest Pathogens in Storage and Their Problems

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Abstract

Post-harvest productions such as cereal grains in the storage are always threatened by infestation of microflora, insects, rats, mites, and birds. Among microflora that can cause damage or losses in the

storage, *Aspergillus* spp. And *Penicillium* spp. Are the dominant pathogens. In additions to causing damage and losses to the stored commodity, some species *Aspergillus* and *Penicillium* can produce toxic metabolites which are carcinogenic and harmful to human health.

The dominance of *Aspergillus* and *Penicillium* species depends very much on seed moisture content which is affected by air moisture and room temperature as well as physical condition of products. Integrated storage management should be implemented so as to maintain the quality of the stored commodity and prevent product losses.

Alternative Technology to Methyl Bromide

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Abstract

Methyl bromide, a widely used fumigant with well known superior properties, has to be phased out gradually because it can destroy the ozone layer. Research on alternative technology to methyl bromide has been conducted worldwide, either to search for new fumigants or to improve application methods of existing fumigants or by intensifying preventive measures. Some alternative technologies without fumigants that could be applied include modification of environmental temperature, use of physical barrier, irradiation, and integrated storage management.

Computer Module as Decision Support Tool of the Activity of Storage Pest Management

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Abstract

Various expert systems have been development and can be used to analyzed various pest problems and to provide the control solution. Grain Pest Adviser, Stored Grain Adviser and Pest Man are some computer modules developed to solve various problems in cereal grain storage and pest control system, which can function as "black boxes" in decision making.

Computer assisted learning (CAL) is a part of information technology which was developed based on grain storage system and storage pest management that been implemented by BULOG.

Principles of Fumigation Techniques and Safety

Tata Ismail and Arief Zakaria
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Abstract

Fumigation is an effective and efficient method for controlling storage pests. In the implementation of fumigation, there are three important steps: pre-fumigation, actual fumigation, and post fumigation. In addition, before being used, the properties of each fumigant need to be thoroughly understood so that its suitability with target commodities can be known, the negative impact to the environment and the health hazard to technician can be minimized.

Economic Analysis of Alternative Technology to Methyl Bromide

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Abstract

Criteria of financial analysis that can be used to analyze feasibility of a project include net present value (NPV), internal rate of return (IRR), and benefit-cost ratio (B/C). Feasibility criteria can be appropriately analyzed if the following data are available: fixed investment cost, working capital investment cost, project investment

cost, depreciation of project investment cost, cash flow analysis year 0-10, and profit-loss analysis. Without complete and accurate data, the validity of analysis may not be accepted.

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