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ACIAR Grain Storage Research Program

Research Report 1985–86

Australian Centre for International Agricultural Research
Canberra 1987

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Overview of the Program

Objectives and Organisation

The prime objective of the ACIAR Grain Storage Research Program is to develop cost-effective methods for the safe storage of grains under the difficult physical conditions of the humid tropics, particularly the Southeast Asian region.

Safe storage of grain has been signalled as a top priority problem in most developing countries of the world. The program seeks to achieve safe storage by facilitating research on the most important issues, such as grain drying and losses from pests, that have been identified as the major constraints to preserving grain quality after harvest.

The research program that has been developed since 1983 is a collaborative one, in line with ACIAR's commission to facilitate research cooperation between Australia and developing countries aimed at identifying and finding solutions to agricultural problems in those countries. The ACIAR research partnership approach seeks to exploit Australia's comparative advantage in the discipline involved, to enhance the long-term research capacity of the developing country partner, and to bring benefits to both partners.

Australia is recognised as a world leader in research and development of grain storage technology appropriate to large- and medium-scale storage systems. It is in this sector in the Southeast Asian region that research needs are greatest, where the likelihood of successful solutions to problems is highest, at least in the shorter term, and where the benefits should be maximised for the resources expended. Moreover, by working in collaboration with other regional research and development groups, the research results obtained will be transposable to smaller scale storage technology where sociological considerations have greater importance.

The primary thrusts of the ACIAR Grain Storage Research Program are to achieve first an understanding of, and then the ability to manage, grain moisture and pest activities under the humid conditions characteristic of many tropical countries.

To achieve this, four core projects have been established in Australian research institutions and linked with research institutions in Malaysia, the Philippines, and Thailand. They concern grain drying (Project No. 8308), storage of grain under plastic covers (8307), and integrated use of pesticides (8309, 8311). In addition, three other projects, designated support research, have been established to enhance understanding of moisture movement in grain (8310) and its measurement (8307D), and the effect of various protective treatments on grain quality (8314). Finally, the economics of the overall handling, drying, and storage systems are being examined, initially in a project concerning the transition from bag to bulk handling in Malaysia (8344).

The formulation and implementation of the ACIAR Grain Storage Research Program has been achieved by contracting with the CSIRO Division of Entomology for a project covering program coordination, a research information network, and conduct of workshops (Project 8312).

Project 8312 provides an operational framework for the development and coordination of ACIAR's activities in the grain storage area. This is seen as an essential component of the program in maximising its effectiveness both in terms of use of resources and research output. It had an initial duration of three years. Following an independent review of the Grain Storage Research Program conducted during March 1986, the coordination project was extended for a further two years, as Project 8612.

The project's Research Information Network and associated activities are materially increasing the availability of information on existing technology to relevant organisations in Southeast Asia, expediting conduct of the ACIAR program, increasing the impact of the program in overcoming storage problems in the area, and facilitating cooperative activities both within the ACIAR program and with other groups working in the same general field.

Core Projects

The grain drying project (Project 8308) is a joint research project of the University of New South Wales and Ricegrowers' Co-operative Ltd. The University is responsible for studies on the principles of drying (Project 8308A) and the Co-operative for the application technology (Project 8308B).

The project on long term storage of grain under plastic covers (Project 8307) is contracted in Australia with the CSIRO Division of Entomology. Work on integrated use of pesticides is another joint research effort in Australia. The Queensland Department of Primary Industries is responsible for biological and toxicological aspects (Project 8309), and the CSIRO Division of Entomology for studies of the kinetics of decay of the candidate pesticides (Project 8311).

All projects extensively involve research institutions in Malaysia, the Philippines, and Thailand.

Support Projects

In addition to the collaborative research in Australia and Southeast Asia in each core project, further support research is required in a number of specialised areas. These support projects include studies on the responses of pests to the altered atmospheres contained in grain stored under plastic covers (Project 8307B, CSIRO Division of Entomology), the movement of moisture by the natural convection processes that occur during such storage (Project 8310, CSIRO Division of Chemical and Wood Technology), and any changes in grain quality that may result (Project 8314, CSIRO Wheat Research Unit). Techniques for remote monitoring of grain moisture and moisture relationships within sealed storaged are also receiving attention (Project 8307D, CSIRO Division of Entomology).

Economic Studies

There are significant moves to bulk handling in the grain industries of most of the Southeast Asian countries involved in the program and indeed it is stated national policy to incorporate bulk handling into their storage systems. It is essential that the technology be introduced on a sound basis that takes into account local conditions. Bulk handling is not well researched for application in the humid tropics. The Grain Storage Research Program is providing information on which to base the necessary changes and, in association with the ACIAR Socioeconomics Program, is conducting a detailed feasibility study on the transition from bag to bulk handling of paddy and rice in Malaysia (Project 8344, South Australian Department of Agriculture). It is hoped to extend this, as opportunity permits, to other countries in the region and to other commodities.

Closely related to this is the objective assessment, by cost-benefit studies, of the relevance of the ACIAR Grain Storage Research Program and its component technologies to the needs of developing countries and to the order of priority for attending to these. These studies involve some measure of (a) the losses that are occasioned by the problems addressed by the program, (b) the appropriateness, acceptability, and efficacy of the technologies developed to overcome the problems, and (c) the social and economic impact of proposed changes. The development of suitable methodology and generation of meaningful data will require specific case studies. Some of these will be available from feasibility studies of bulk handling in Malaysia.

Review of Research and Related Activities

Solid progress was made in research in all the participating countries during 1985–86. Some projects are now nearing completion and there has been much discussion among staff of all projects

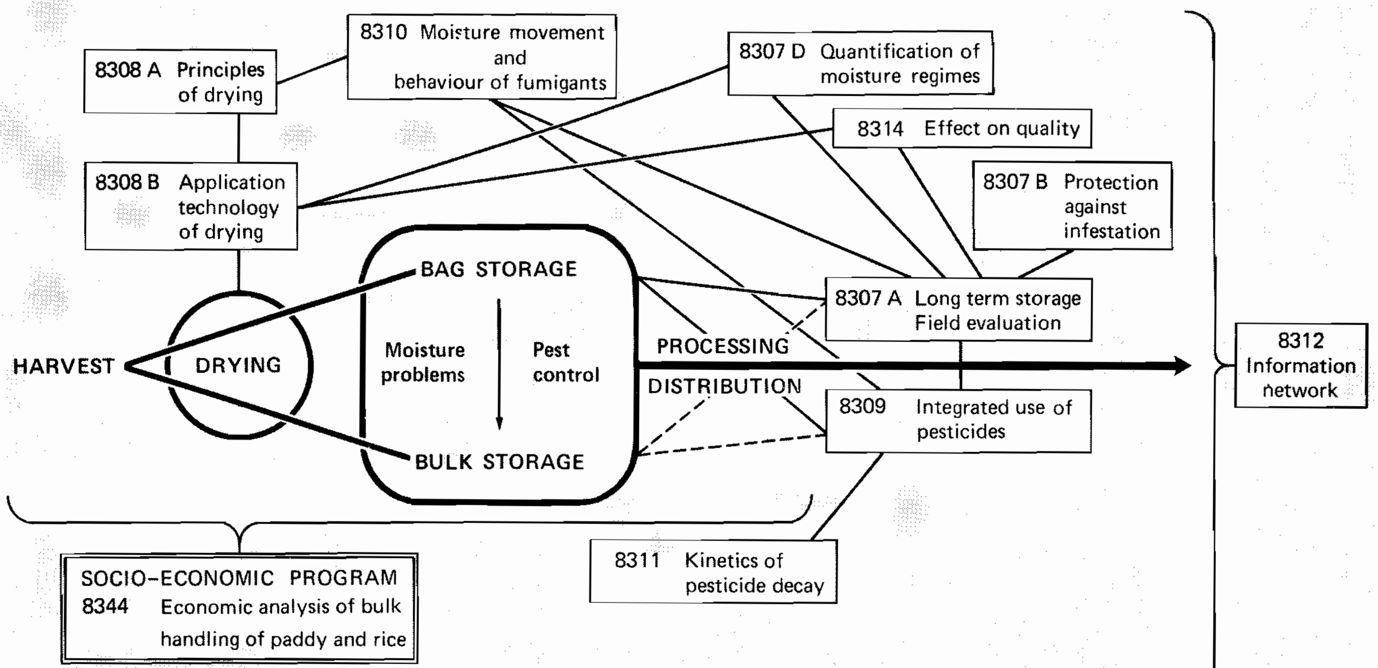
ACIAR Grain Storage Research Program

Objectives

1. To develop initially a program of core projects relevant to expressed needs of developing countries for safe storage of grain in tropical climates, specifically:-
   - (i) The drying in bulk storage of high moisture grains in tropical climates.
   - (ii) Long term storage of grain under plastic covers.
   - (iii) Integrated use of pesticides in grain storage in the humid tropics.
2. To support the core program with basic studies on:-
   - (iv) Moisture movement in grain.
   - (v) Ad hoc aspects of pesticide relationships in integrated pest control systems, viz:
     - kinetics of decay of candidate pesticides for integrated control programs,
     - prediction of potential for development of pesticide resistance to candidate materials,
     - behaviour of fumigants in grain.
3. To develop the technology for application in the first instance in the Philippines and Malaysia but to include other countries, specifically Indonesia and Thailand, when appropriate.
4. To carry out cost-benefit studies of the relevance of the program to the needs of the developing countries.
5. To carry out feasibility studies on the transition from bag to bulk handling.
6. To develop a grain storage research information network relevant to the needs of the program and to promote interchange among groups participating in the program or with common interests.

ACIAR GRAIN STORAGE RESEARCH PROGRAM

Safe Storage of Grain in the Tropics — Projects 8307 – 8312, 8314, 8344



Research strategy — Safe Storage of Grain in the Tropics as to appropriate mechanisms for extending research findings into application in the region. Considerable attention has also been given to assigning priorities to any future program activities, guided by the recommendations of the March 1986 independent review of the program and the response of the ACIAR Policy Advisory Council and Board of Management to them.

Experimental work on storage under sealed plastic covers after an initial disinfestation with carbon dioxide has shown that the method is reliable and technically feasible and has refined CO_2 dosage requirements.

In the drying project, pilot plants are operational in all participating countries. The data collected have led to development of an accurate computer model of the rice drying process which in turn has enabled development of drying strategies appropriate for Southeast Asia.

The pesticides project has identified major resistances to important grain protectants in the Southeast Asian region, highlighting the need to develop and implement pest management strategies. Laboratory work has quantified the effects of moisture on the biological activity of the grain protectants, permitting determination of appropriate application rates for their use in the humid tropics.

Fundamental studies of moisture movement have led to the development of mathematical models to quantify the effects of free convection on moisture redistribution in sealed storages. These models explain many of the phenomena encountered in practice and suggest ways of improving the design of storages to minimise moisture migration and its effects on grain quality.

The socioeconomics project is making good progress towards the development of a comprehensive economic model of the Malaysian rice industry. This model will be used to assess the implications of a change from bagged to bulk grain handling in that country. It has already shown that paddy price is the most powerful influence on the operations of the rice economy in Malaysia, suggesting that attention to pricing policy should be a high priority in paving the way for technological changes.

The Research Information Network continues to receive strong support from users and to be much in demand. The program's second seminar, on the topic 'Preserving Grain Quality by Aeration and In-store Drying', attracted some 150 participants. The 24 papers presented by invited speakers from Australia, England, Indonesia, Korea, Malaysia, the Philippines, Thailand, the United States, and West Germany were of a very high standard. Many favourable comments have been received on the utility of the published proceedings of the seminar as a text and reference book.

Discussions at the seminar itself yet again highlighted the pressing need for technologists and economists to get together to tackle the main postharvest problems of the Southeast Asian region.

The seminar confirmed that it is imperative to reduce losses occurring immediately after harvest, by introducing appropriate drying technologies into the region. Given that most agencies have been readily acknowledging this, why has the rate of adoption of artificial or mechanical drying strategies been so low? The answer appears to rest on social and economic, rather than technical issues. In Malaysia, for example, it seems that there is no incentive built into the paddy procurement and pricing system to encourage farmers to dry their paddy. It costs farmers more to dry their grain than the extra return they get from doing so.

The seminar registered that a first step towards enhancing the rate of introduction of appropriate drying technology would be to introduce grain procurement and pricing policies that reward farmers delivering dry paddy for storage.

A summary of project activities during the year follows.

Storage Under Plastic Covers

Project 8307 aims to establish the reliability and limits of applicability of long term storage of commodities within sealed plastic enclosures after an initial disinfestation using carbon dioxide. The results of the experimental work in Malaysia, the Philippines, and Thailand have now shown that the method is very reliable and technically feasible. All the treated stacks have been successfully disinfested and protected. Grain removed from the stacks at the completion of the storage period had no gross quality deterioration or moisture damage.

Laboratory work in Australia has more closely identified the dosage of carbon dioxide needed to ensure a complete initial disinfestation. Results to date suggest that, to ensure a greater than 99% kill of insects, it is necessary to increase to 15 days the period during which they are exposed to concentrations of carbon dioxide greater than 35%.

Storage trials are continuing in the three participating countries, and laboratory work on carbon dioxide regimes has been extended to the Philippines.

Grain Storage Research Program

Projects, collaborators, and commencement dates

8307*	Long term storage of grain under plastic covers A. Field assessment B. Effects of low carbon dioxide atmospheres on insects D. Moisture regimes of bulk commodities	
	CSIRO[1] Division of Entomology, Australia	4/11/83
	MARDI[2], Malaysia	25/11/84
	NAPHIRE[3], Philippines	6/6/84
	Department of Agriculture, Thailand	1/5/84
8308*	Drying in bulk storage of high moisture grains	
	A. Principles — University of New South Wales, Australia	24/5/83
	B. Application technology — Ricegrowers' Co-operative Ltd, Australia	25/3/83
	LPN[4], Malaysia	26/11/84
	NAPHIRE, Philippines	22/11/83
	King Mongkut's Institute of Technology, Thonburi, Thailand	6/7/84
8309*, 8311	Integrated use of pesticides in stored grain in the humid tropics	
	Biological and toxicological aspects (8309)	
	Queensland Department of Primary Industries, Australia	5/4/83
	MARDI, Malaysia	25/11/84
	NAPHIRE, Philippines	23/8/83
	Kinetics of decay of candidate pesticides	
	CSIRO Division of Entomology, Australia	30/7/84
	University of New South Wales, Australia	25/8/85
	MARDI, Malaysia	25/11/84
	NAPHIRE, Philippines	30/7/84
8310	Moisture movement in grain	
	CSIRO Division of Chemical and Wood Technology, Australia	3/5/83
8314	Effect of controlled atmospheres on quality of stored grain	
	CSIRO Wheat Research Unit, Australia	11/7/84
	NAPHIRE, Philippines	11/7/84
8312	Program coordination and research information network	
	CSIRO Division of Entomology, Australia	13/3/83
8344	Bulk handling of paddy and rice in Malaysia. An economic analysis.	
	South Australian Department of Agriculture	1/7/85
	UPM[5]/LPN/MARDI, Malaysia	23/7/85

* Core Project

1. Commonwealth Scientific and Industrial Research Organisation
2. Malaysian Agricultural Research and Development Institute
3. National Post-Harvest Institute for Research and Extension
4. Lembaga Padi dan Beras Negara
5. Universiti Pertanian Malaysia

Grain Drying Investigations

Project 8308A is concerned with the theoretical principles of drying bulk-stored grain. Pilot plants to study the movement of moisture fronts through grain have been commissioned in Australia, Malaysia, the Philippines, and Thailand. Thermo-physical data, especially from the Philippines, have helped in building an accurate computer model of the rice-drying process. The pilot plant studies involve small (0.5–2 t) amounts of grain. Their results are compared with the predictions of the computer model. In studies conducted in Malaysia during the first part of 1986, the drying times were predicted accurately, though some problems remain in predicting the precise shape of the drying front.

Field trials are being organised in Malaysia and the Philippines. The aim of these trials is to demonstrate the validity of the drying predictions on a commercial scale.

Project 8308B is concerned with aspects of the practical application of the grain drying strategies arising from the project.

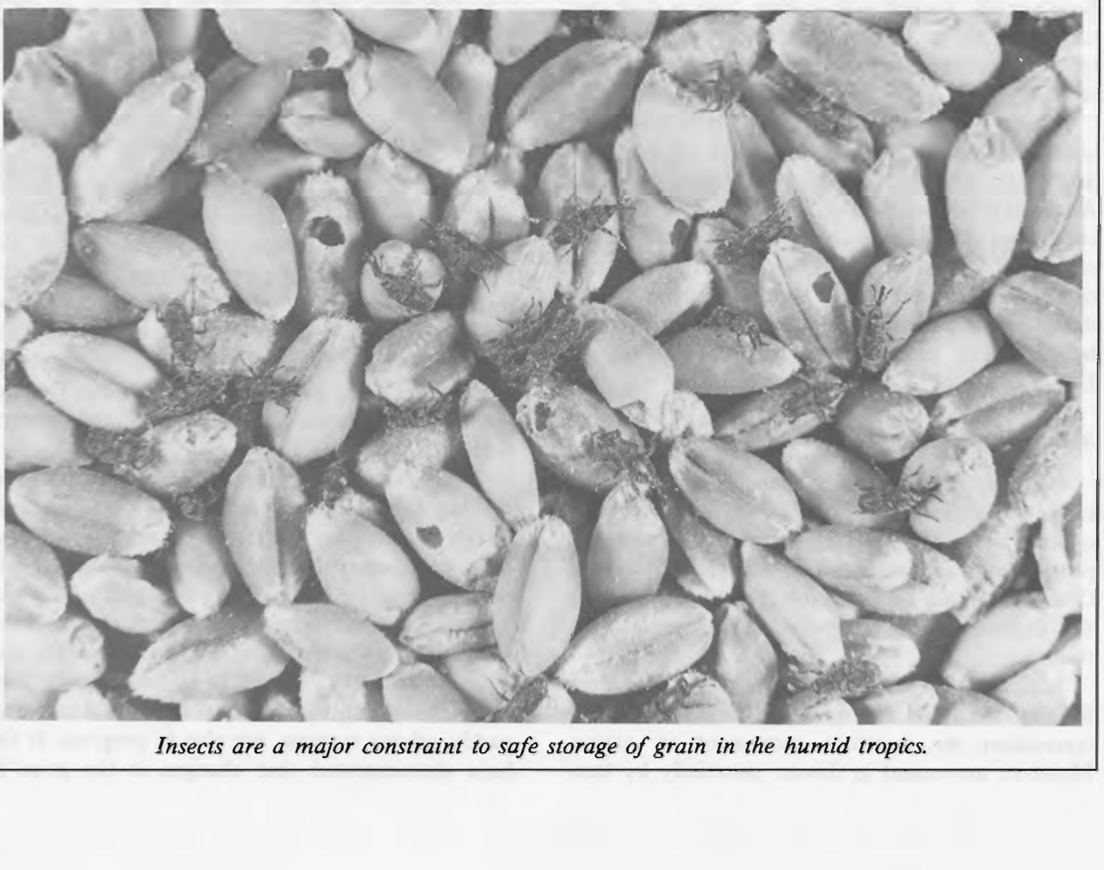
A major portion of the work completed during the last year has focussed on the collection and analysis of data in the areas of rice kernel yellowing and kernel breakage. To examine the effects of aeration on grain quality, as measured by rice kernel yellowing and kernel breakage, a 500 kg pilot drying system was commissioned. The system can generate the full range of ASEAN and Australian weather conditions with flow rates capable of fluidising a bed of paddy rice. Computer control and data logging are directly on-line. The system has enabled drying strategies with and without heated air to be examined and flow rate and burner control trials to be performed.

Project 8308B is nearing completion. All experimental work is finalised and all objectives have been achieved, on schedule and within the specified budget. Some results, including those from overseas trials, have yet to be received and analysed.

Integrated Use of Pesticides

The overall objective of Project 8309 is to develop effective insecticide treatments for tropical stored grains. The research is being carried out in Australia, Malaysia, and the Philippines.

Differences have been found between grain protectants as regards the effect of grain moisture



Insects are a major constraint to safe storage of grain in the humid tropics.

content on biological activity: the pyrethroids were less adversely affected by increasing moisture than the organo-phosphates or carbaryl. Studies in Australia to determine minimum effective application rates on maize and paddy have been completed, while studies in the Philippines are continuing. A survey of resistance to malathion, lindane, and phosphine in Malaysia is in progress, and acute toxicity tests have begun. Field trials of protectants were commenced on maize and paddy in Australia and the Philippines.

The field trials on maize in the Philippines are being carried out at General Santos City in Mindanao and on paddy at Santiago in Luzon. Grain was treated with insecticide in bulk, and then bagged. Bagged maize was shipped from General Santos to Cebu for storage. Five protectant treatments were applied to each grain, with a sixth treatment comprising 'standard pest control', that is, fumigation plus surface spraying, as currently practised in the Philippines. Samples were taken regularly for bioassay and residue analysis, during 8 months storage of maize and a planned 12 months storage of paddy. Analysis of samples is still in progress. Visual inspection of the maize stacks in July 1986 indicated that control stacks were heavily infested with insects. Insects were also seen on some protectant treatments, but all treatments were appreciably better than the controls.

Project 8311 supports Project 8309 by providing chemical data on the kinetics of decay of candidate pesticides. About 50% of the analyses for the Australian sector of the work have now been completed. The University of New South Wales is collaborating in the project. Studies on development of analytical methods and on the kinetics of the decay of the pesticide residues will be carried out by a project group recently established in the University.

Moisture Movement in Grain

Economically optimal systems of grain storage cannot be achieved without a good understanding of the basic physical, chemical, and biological phenomena that occur within the stored product. One of the main aims of Project 8310 is to provide this understanding. The project is nearing completion.

Mathematical models have been developed that, for the first time, can quantify the effects of free convection on moisture movement in grains. Moisture movement is driven essentially by temperature gradients, which are accentuated by biological activity such as the respiration of insects and microflora. Respiration also adds to the mass of free water within the systems. The models developed can now account for the respiration of microflora. They also incorporate expressions for the rates of decay of chemical pesticides.

Laboratory experiments have been carried out to show that 19% moisture content paddy can be dried to 14% moisture content by heating it in a fluidised bed for about 7 minutes. In this energy efficient process, the loss in milling yield is negligible. Theoretical studies on residence time distributions in continuous-flow fluidised beds complement the laboratory experiments. It has been shown that decreasing dispersion in fluidised beds improves their thermodynamic efficiency and, other things being equal, is likely to result in higher milling yields of dried paddy.

Effects of Storage Conditions on Grain Quality

Work in Project 8314 during the year sought to determine the possible utility of grain colour as an index of quality. The project has determined relationships between product colour and storage time and temperature, moisture content, the composition of the storage atmosphere, and other variables. Quality studies will continue for another 18 months.

Economic Analysis of Bulk Handling of Paddy and Rice in Malaysia

The basic aim of Project 8344 is to characterise in an integrated fashion all components of the Malaysian paddy and rice handling industry. To meet this objective a model has been developed and specified, and has been validated using test data. Empirical evaluation of the model is currently under way, using data collected from the Tanjung Kerang rice-growing region in north-western Selangor.

The preliminary physical and economic database relating to the current situation is being updated by the participating Malaysian organisations. These data, together with other model refinements, will be used in an initial analysis of optimal paddy and rice flows and location of handling facilities. Extensions to the basic model to include capital and labour substitution effects as technologies in handling change, as well as an analysis of alternative paddy pricing systems, are also in progress. It has been demonstrated that changes in the price of paddy have a much greater impact on the rice economy than changes in drying, transport, or other costs. Attention to the paddy pricing system is therefore seen as paramount in considering the implications of the introduction of new handling and storage technology.

Program Review

An independent review of the Grain Storage Research Program was carried out during March 1986, at a time when some projects were nearing completion. The review concluded that all projects of the program were highly relevant to existing and emerging postharvest problems in the ASEAN region and were meeting their objectives within approved time scales, that the program was well managed, and that there was scope for new projects relevant to current work.

The review of the program was carried out by a team of four specialists whose individual experiences span both postharvest technology and development assistance activities. The review team comprised Mr Hugh Baird (Australia), Dr Dante de Padua (Singapore), Mr Martin Greeley (UK), and Dr E. Magallona (Philippines).

The terms of reference were wide ranging, but key issues were relevance of the program and its projects to regional problems, and the effectiveness of the research strategy and management of the program.

The review team visited all program research groups in ASEAN and Australia. It noted in its report to ACIAR that it found '... a confidence of achievement among the ASEAN participants in the program and a most responsible leadership evidenced in the Australian-based participants'.

The report also expressed the review team's view that results of widespread benefit had been achieved by the program, noting that the quantified understanding of the grain drying process which is emerging from project work is of enormous importance to the grain-handling industries throughout the world. The development by the program of safe storage systems (freedom from infestation and minimisation of other common quality defects) for high moisture grains will, in the opinion of the reviewers, make a significant contribution to reduction of world food losses.

The principal commodities covered by the program are at present rice and maize, the highest priority grains in the region. The review team recommended that studies be extended to include legumes.

Program Review Team

Mr J.H. Baird, Team Leader, Rice Storage Consultant

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Mr M. Greeley, Economist, Institute of Development Studies, University of Sussex, England

Dr E. Magallona, Acting Vice Chancellor for Academic Affairs and Chairman, Department of Entomology, University of the Philippines at Los Banos.

The technology developed by the program is, by intent, most applicable to central storage systems. It is in this sector that research needs are greatest, the likelihood of successful solution to problems is highest, and where the benefits should be maximised for the resources expended. Nevertheless, the program review pointed up the need throughout Southeast Asia for improved practices immediately after harvest, identifying threshing and transportation in particular. These must be given equal priority with technological developments in drying and storage. Losses immediately after harvest can be extremely high, especially during wet season harvesting.

It was also recommended that attention be given to sanitation as a component of pest control programs in grain storage. The low levels of storage sanitation often practiced in many parts of the region result in a continuous reservoir of insects and other pests capable of infesting new stocks. A proposed project addressing this issue was included as part of the review report.

Particular attention was given by the review team to the need for detailed socioeconomic inputs into the three core projects of the program. There is a need to provide first, a 'choice of techniques' analysis to evaluate the technologies being developed in relation to existing technologies, and second, when cost-effectiveness studies suggest that the technologies developed by the program are suitable for diffusion on both technical and economic grounds, it is necessary to critically examine the operational feasibility of technology diffusion.

The importance of well designed communications and information systems was also stressed in the review team's report. In this context, it considered the coordination project and its asso-

Grain Storage Research Program

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ciated research information network as being vital components of the program. The team noted that more resources may need to be devoted to this area as projects move towards completion and a commitment is made to extension and technology transfer. In the view of the review team, the final transfer of applicable technology is the single common factor of greatest relevance and importance to any perceived, final success of the whole of the program.

The review committee's report was considered in detail at the Seventh Meeting of ACIAR's Policy Advisory Council in April 1986.

In general terms, the Council endorsed the continuation of the Grain Storage Research Program along the lines suggested by the reviewing team. The need to undertake comprehensive assessment studies before embarking on new project initiatives was stressed. In particular, the importance of economic analyses in identifying constraints to harvesting, drying, and storage efficiency was emphasised. Such studies could also identify the role of incentives in overcoming problems experienced in harvesting and transporting grain.

The Program's emphasis on central storage systems was given particular attention by Council, which concluded that, while this focus was appropriate in terms of Australia's comparative advantage and resource allocation for the first three years of the program, the relevance of incorporating farm and village storage arrangements in new and replacement projects should be considered.

Following Council consideration of the review, the ACIAR Board of Management, during its June 1986 meeting, endorsed the development of further activities in the Grain Storage Research Program at a total level of expenditure not exceeding that incurred during its first phase. The Board reinforced that priorities need to be established and that there must be an economics input to project formulation and activities.

Project 8312 — Program Coordination, Research Information Network, and Workshps — was extended as Project 8612 for a two-year term. The new project will have similar objectives and methods of operation to the one it replaces, but will give increased attention to socioeconomic inputs to facilitate effective transfer of the technology that is emerging as the first of the component projects of the Grain Storage Research Program move towards completion.

Economic Evaluation

Following the independent review of the Grain Storage Research Program, ACIAR commissioned agricultural economics consultant Dr G.J. Ryland to undertake an economic evaluation of its various projects and the program as a whole. The aim was to provide advice to the Centre on research priorities for extending the program after the review, to determine any modifications in research strategy that might be needed, and to develop proposals for a grains postharvest economics research project to complement the program's technical activities.

During the term of the evaluation in the early part of 1986 it became increasingly clear that basic statistical information relating to the distribution of product through the marketing channels to consumers in the various countries with which the program is concerned was not part of official data collections. Details of the types and extent of storage and pest management practices were, at best, available only through public agencies, whereas the private sector typically handles over 90% of product. Nevertheless, the evaluation attempted to place some notional relative estimates on the types of storages employed at different points in the marketing chain.

The evaluation also attempted to assess the anticipated annual gross benefits of postharvest research on grain drying and integrated pest management (IPM) on paddy and maize in the Philippines. This country was chosen because data on crop values were readily available, as also were estimates of potential reduction in postharvest losses if the new technologies emerging from the ACIAR program were adopted. Both the grain drying and pest management projects were empirically analysed to illustrate the principles involved and to gain some feeling for the

Recommendations of Program Review

Program Activities

- The coordination project (Project 8312) and its component research information network being vital to the success of the program be continued and provided with increased resources to adjust the thrust of information transfer as projects move to completion.
- The scope of current studies be extended to include grain legumes.
- Studies on threshing and transportation be developed, parallel with studies on drying and storage.
- Socioeconomic components be incorporated in all new core projects.
- Projects relevant to current studies be prepared for consideration by ACIAR.

Project Activities

- The agreed completion dates for Project 8307 in Australia, Malaysia, Philippines, and Thailand be adjusted to December 1987 to allow the planned three years of trials as originally scheduled.
- The current Project 8307 in Thailand be expanded, within the time frame proposed above, to include studies on storability of maize, mung beans, and soybeans.
- Project 8314 to be extended, within its current agreed time frame, to include Malaysia.
- Project 8308 be replaced with a new project of 18 months duration covering studies on mill-level drying, short-term quality maintenance, first-stage drying, and drying of maize and peanuts, operating selectively in Australia, Malaysia, Philippines, and Thailand.
- In view of the demonstrated potential of the technology and the need for trained personnel to facilitate its introduction, that attention be given to those communication matters that would accelerate its adoption in the region.
- Project 8310 be replaced with a further project of two years duration to validate the theoretical models on moisture movement and fumigant behaviour under practical conditions in Southeast Asia.
- Project 8309 be replaced with a new project of three years duration covering studies on grain legumes and insect growth regulators, operating selectively in Australia, Philippines, and Thailand.
- Attention be given to sanitation as a component of pest control programs. A suggested project addressing this aspect was included in the report of the review team.

distribution of the benefits of this type of research among consumers, producers, and those providing the marketing services.

This assessment of likely benefits suggested that improved grain drying technology has the potential for greater reductions in costs, and hence larger potential yield increases, as compared with improvements in integrated pest management. In contrast, however, improved IPM methods have greater probabilities of success and rates of adoption relative to grain drying, for which relatively larger amounts of capital are also required. It was therefore recommended that Project 8309 be accorded highest priority in the extension of the Grain Storage Research Program and that the extended project include a substantial economic component.

The economic evaluation made specific recommendations about each project in the program.

As regards the grain drying project, it suggested, among other things, that field evaluations should be made of grain drying facilities operated by the National Food Authority in the Philippines and the National Paddy and Rice Authority (LPN) in Malaysia, and that the participation of commercial operators in this activity should also be sought. There should, in addition, be an examination of the incentive structures for paddy procurement needed to ensure long-term commercial development of reliable drying and storage facilities.

Studies of moisture movement in grain should analyse the effects that size and type of storage have on this phenomenon, with particular reference to farm and mill level bulk storage of paddy in Thailand. Assessment of storage under sealed plastic covers after an initial disinfestation with carbon dioxide should be extended to include the use of phosphine for the fumigation phase.

At a more general level, the economic evaluation stressed the need for researchers to show greater interest in grain storage in the private sector, suggesting that ACIAR might take the lead in this regard in terms of its future postharvest activities in Malaysia and the Philippines. Looking at the application of research funds to the main commodities involved, the evaluation suggested that a useful rule of thumb is that at least 70% of research funds in the grain storage program be devoted to paddy/rice, 20% to maize, and 10% to other crops.

ACIAR Liaison Officers

ACIAR's Liaison Officers in ASEAN countries are equipped to assist ACIAR project personnel — Australian and local — in matters relating to the implementation and management of collaborative projects.

Their broad areas of activity encompass:

- administrative support for visits by project scientists and ACIAR staff;
- technical policy support services in identifying appropriate areas of activity;
- administrative, management, and support services for approved projects;
- arrangements for formal government contacts.

Names and contact addresses are as follows:

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Bangkhen, Bangkok
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Project 8307

Long Term Storage of Grain under Plastic Covers

A. The field assessment of grain storage in sealed plastic enclosures
B. The effects of relatively low (<40%) carbon dioxide atmospheres on insects

Commissioned organisation — CSIRO Division of Entomology

Abstract

THE principal objective of Project 8307 is to determine the reliability of a system of storage of grains that is based on an initial disinfestation by fumigation (using carbon dioxide in this project) in a well-sealed enclosure, followed by prolonged insect-proof storage in that enclosure. Field and laboratory experiments have identified some of the factors that may affect the reliability of the system. For example, there are stringent specifications that must be met in manufacture and sealing of the plastic enclosures. Also, laboratory studies on the effects of carbon dioxide on *Sitophilus oryzae* indicate that it is not possible to reduce the level of sealing and that it is necessary to increase previously recommended exposure periods for concentrations of carbon dioxide above 35% to achieve complete mortality of the most resistant stages of this storage pest. Full treatments have been completed on 19 bag stacks to date, with very satisfactory results. In general, insects have been found in only those trial stacks subjected to high infestation pressure from surrounding untreated stacks.

Background

Summary

In Southeast Asia, most stocks of grain are stored in warehouses as uncovered bag stacks. Reliable insect control in such stacks is a difficult and often expensive procedure. It usually consists of several fumigations as well as regular spraying or fogging with insecticides. Project 8307 is concerned with investigating the reliability and limits of applicability of long term storage of commodities within sealed plastic enclosures after an initial disinfestation using carbon dioxide. This technique has previously been shown to be technically feasible during limited field trials conducted jointly by the CSIRO Division of Entomology and various collaborating bodies in Australia, Indonesia, and Papua New Guinea.

The specific aims of the project are to determine the reliability of the overall method and to investigate some of the practical limitations to its use (8307A). These aims are being achieved through extensive replication of field treatments. In addition, laboratory studies are being conducted in order to determine the dosage of carbon dioxide needed to ensure complete initial disinfestation of insects (8307B).

Currently, methyl bromide and phosphine are the only widely available fumigants for grain storage use. Both materials are effective and acceptable in most parts of the world but there are specific locations where, for various reasons, one or the other is either not used or used only infrequently. These reasons may include one or more of the following: legislation, industrial safety, residues, poor treatment techniques, and resistance of insects to the fumigant. It is hoped that the project will lead to the development of an additional pest control method for the long term storage of grain and provide an alternative should the existing pest control methods become unavailable.

The project is being carried out in cooperation with research and grain handling authorities in Malaysia, the Philippines, and Thailand. Close liaison is maintained with groups conducting related work in Indonesia, Papua New Guinea, and Singapore.

Collaborating institutions directly involved in the project and the research leaders are as follows:

- *Australia*
  CSIRO Division of Entomology
  Mr P.C. Annis
- *Malaysia*
  Malaysian Agricultural Research and Development Institute (MARDI), in collaboration with Lembaga Padi dan Beras Negara (LPN, National Paddy and Rice Authority)
  Mr A. Robin Wahab (to December 1985)
  Mr Mohd. Shaidi Arifin (from January 1986)
- *Philippines*
  National Post-Harvest Institute for Research and Extension (NAPHIRE)
  Mrs G. Sabio
- *Thailand*
  Department of Agriculture, Entomology and Zoology Division
  Mr Montri Rumakom

Full project activities in Southeast Asia commenced in January 1985, following a preliminary experiment carried out in Thailand over the period June–August 1984. Since the beginning of 1985, 19 full treatments of bag stacks have been completed in the three participating countries. The results of this field work have shown that the method is reliable and have confirmed its technical feasibility. Levels of protection afforded have been high.

Laboratory studies in Australia have more closely defined the dosage of carbon dioxide needed to ensure complete initial disinfestation. The results of these studies indicate that it is necessary to increase to 15 days from 10 the recommended exposure period to concentrations of carbon dioxide of greater than 35%.

Expected Benefits

The results obtained from Project 8307 are expected to bring the following major benefits to the region:

1. The development of a reliable method of storing bagged commodities, free from insect infestation, that does not require the repeated use of chemicals.
2. A reduction in quality degradation of commodities during long term storage in tropical areas.
3. The parallel laboratory studies to develop a quantitative model of the toxic effects of carbon dioxide will assist in optimising treatment regimes and the degree of sealing of the storage that is required.
4. The long term storage technology that is developed will be applicable throughout the region and elsewhere, providing a system of safe storage of grain that should be universally acceptable.

Project Objectives and Operational Schedule

Field trials of storage under plastic covers previously carried out by the CSIRO Division of Entomology in Australia, Indonesia, and Papua New Guinea, supported by further trials by the United Kingdom Tropical Development and Research Institute with Badan Urusan Logistik (BULOG) at Tambun in Indonesia, and commercial experience in China, indicated the potential of the method for storing bag stacks of infestable commodities.

Project 8307 provides for an evaluation of the reliability of the method over the wide range of conditions that would be encountered in commercial use in the humid tropics, taking into account such factors as moisture, optimal sealing, dosing levels for pest suppression, and quality maintenance.

The objectives of the project are as follows:

1. To determine the applicability of plastic covers for storage of grain in warehouses and in the open.
2. To liaise closely with Project 8310 (Moisture Movement in Grain) to optimise consideration of moisture as a storage constraint.
3. To determine design and size of enclosure, maximum permissible moisture contents, and storage periods.
4. To carry out field evaluation in Australia, Malaysia, the Philippines, and Thailand, and to liaise closely with BULOG, Indonesia in similar activities.

The initial program concerns bagged paddy, milled rice, and maize but will involve support research relevant to both bagged and bulk grain. Four areas of study have been identified:

(a) the field assessment of grain storage in sealed plastic enclosures (Project 8307A), which will require support research on —
(b) the protection against infestation offered by relatively low (less than or equal to 40%) carbon dioxide atmospheres (Project 8307B);
(c) the effects of controlled atmospheres on the quality of stored grains (Project 8314); and
(d) quantification of moisture regimes in stored grain and related commodities (Project 8307D).

Subject to satisfactory realisation of objectives 1–3 of this project, and the objectives of Project 8310, it is proposed to expand activities to include storage of seed and bulk commodities under plastic covers.

The planned duration of Project 8307 is three years.

Field Studies

Specific objectives for the field studies (Project 8307A) are:

1. To determine the reliability of the sealed sheeting method of storage, in terms of protection from reinfestation by insects and maintenance of the quality of rice and other commodities.
2. To monitor gas holding and humidity within the stacks during the storage period, as a means of detecting adverse changes within the atmosphere contained in the enclosure.

The main aim of the field experimental work is to complete a large number of replicated storage trials with storage periods between 3 and 12 months. This is being achieved by starting with short storage periods and, as experience in the technique develops, progressing to longer periods. Grain stored in these trials is being examined for insect infestation and changes in quality occurring during the storage period. An attempt will be made to correlate these to aspects of the storage regime, such as pressure test results, moisture content, gas concentrations, and storage period.

Preliminary treatments were carried out in Thailand between June 1984 and August 1984, to test the feasibility of fabricating sealed enclosures at the storage site. It was concluded that to obtain adequate sealing it was necessary to use equipment that was not easily transportable and that enclosures were therefore best manufactured at a plant with appropriate facilities.

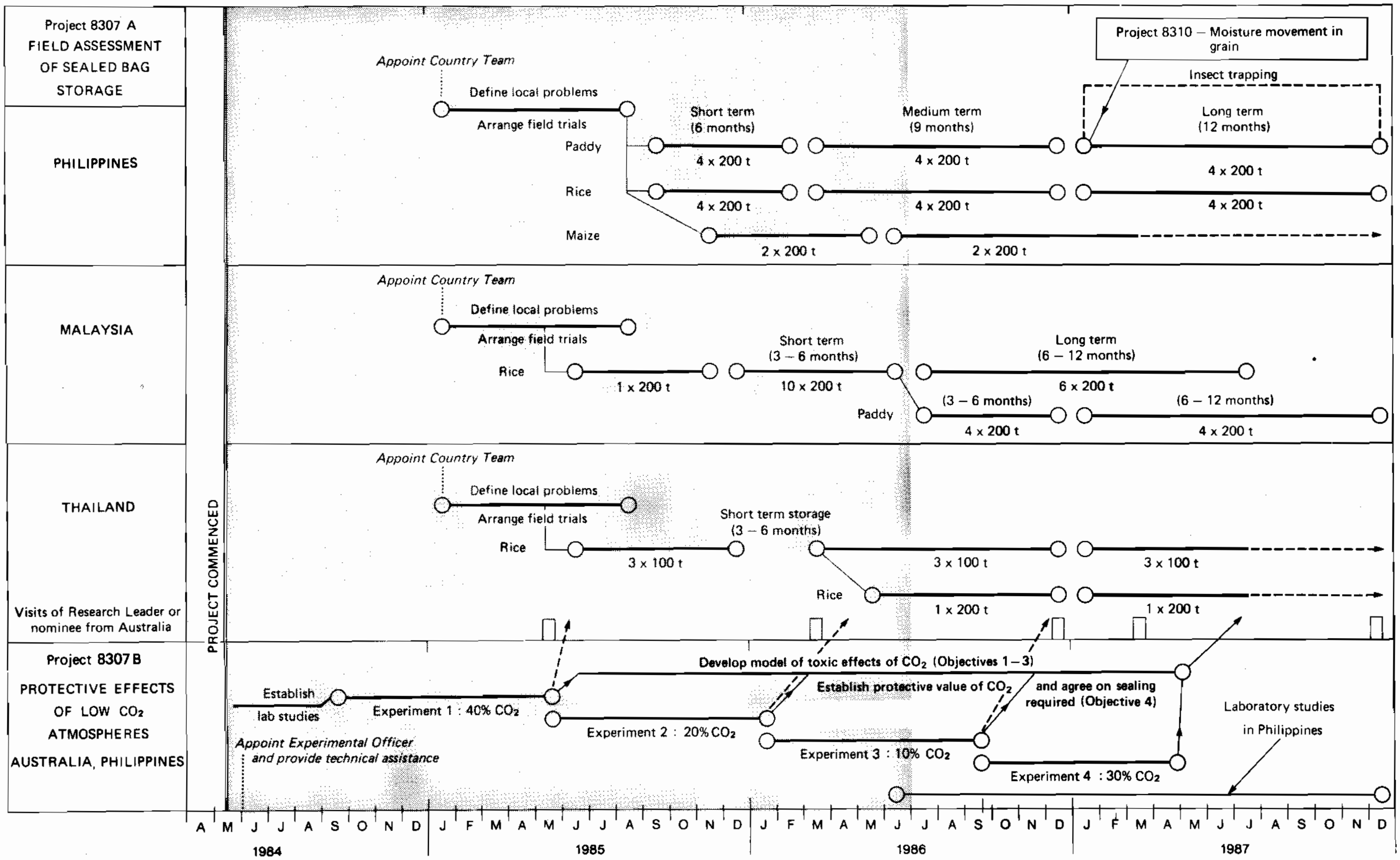
Full-scale treatments of milled rice within enclosures imported from Australia were started in Thailand (3 × 100 t) and at Pasir Gudang in southern Malaysia (1 × 200 t) in June 1985. Further treatments were initiated in October 1985, in both Malaysia, giving a total of 14 × 200 t, and Thailand, giving a total of 6 × 100 t. Trials (with rice — 1 × 200 t, paddy — 6 × 200 t, and maize — 5 × 200 t) began in the Philippines during September 1985 and have been continuing since then.

Laboratory Studies

Concurrent with the field investigations in Southeast Asia, laboratory experiments are being carried out in Australia to determine the dosage of carbon dioxide needed to ensure a complete disinfestation of insects. *Sitophilus oryzae* is being used

ACIAR GRAIN STORAGE RESEARCH PROGRAM

Project 8307 — Long term storage of grain under plastic covers



Research schedule — Project 8307 (shaded area indicates work completed)

for this study as it is known to be one of the species most tolerant to treatment with carbon dioxide. Insects of known age are exposed to a range of concentrations of CO_2 and resulting mortality is determined after various exposure periods.

Specific objectives of the laboratory studies (Project 8307B) are:

1. To quantify the response of various developmental stages of some of the insect pests of stored grains to relatively low carbon dioxide contents.
2. To confirm laboratory results in parallel field assessment of mortality with the stacks used in Project 8307A.
3. To integrate these data with those currently being obtained for high carbon dioxide contents, and thus contribute to the development of an overall quantitative model for the toxic response of insects to carbon dioxide.
4. To produce an optimal dosage regime for the use of carbon dioxide, and thus to determine the degree of sealing required to maintain this regime.

Organisation and Staff

The Record of Understanding between ACIAR and CSIRO was signed on 4 November 1983 but full-scale project activities did not commence effectively until the appointment of Mr J. van S. Graver in May 1984. Ms H. Stacey, Technical Officer and Miss A. Taylor, Technical Assistant, have been assigned by CSIRO to assist in project laboratory activities.

Agreement for operations in Malaysia was finalised with the signing of the Project Document by ACIAR and the Government of Malaysia on 26 November 1984. The initial Team Leader, Mr Ahmad Robin Wahab, of MARDI, was succeeded by Mr Mohd. Shaidi Arifin, from the beginning of 1986. Other project staff are: Mr A. Rahim Muda, Entomologist from MARDI, and Mr Ahmad Ilham, Coordinator, Mr Idris Abas, Engineer, and Mr Lee Chin Hui, Economist, from LPN.

Although the Memorandum of Agreement between ACIAR and PCARRD was finalised on 21 October 1983, arrangements with NAPHIRE for operations in the Philippines did not become effective until 6 June 1984. Team Leader, Mrs Glory Sabio, is supported by Research Assistant Mr Don David Julian and Research Aide Mr Dionisio Alvinda. Research Assistant Mr Fernando Lingan resigned during the year.

Agreement for operations in Thailand, originally as an Institute to Institute agreement between CSIRO and the Department of Agriculture, was formalised with the signing of a Memorandum of Understanding between the governments of Australia and Thailand on 18 October 1984. Mr Montri Rumakon, Director of the Entomology and Zoology Division, is Team Leader with Mr Chuwit Sukprakarn as Entomologist and Project Coordin-

Grain Storage Research Program

Project 8307A/B Staff

Australia (CSIRO Division of Entomology)
Mr P.C. Annis, Research Leader
Dr P.M. Barrer (Insect trapping studies)
Mr J. van S. Graver, Entomologist
Ms H. Stacey, Technical Officer
Miss A. Taylor, Technical Assistant

Malaysia (MARDI)
Mr Mohd. Shaidi Arifin bin Tahir, Team Leader (from January 1986)
Mr Ahmad Robin Wahab, Team Leader (to December 1985)
Mr Abdul Rahim Muda, Entomologist

Malaysia (LPN)
Mr Ahmad Ilham, LPN Coordinator
Mr Idris Abas, Engineer
Mr Lee Chin Hui, Economist

Philippines (NAPHIRE)
Mrs Glory Sabio, Team Leader, Entomologist
Mr Don David Julian, Research Assistant, Agricultural Engineer
Mr Fernando Lingan, Research Assistant, Entomologist (resigned 1985)
Mr Dionisio Alvindia, Research Aide, Microbiologist
Mr Raymundo Murillo, Research Aide, Engineer
Mr Clencio Menguta, Driver (resigned)

Thailand (Department of Agriculture)
Mr Montri Rumakom, Team Leader and Director of the Entomology and Zoology Division
Mr Chuwit Sukprakarn, Project Coordinator and Entomologist
Mrs Boodsara Promsatit, Entomologist
Mrs Kanjana Bhudhasamai, Seed Pathologist
Ms Kruawan Attaviriyasook, Agricultural Researcher
Ms Lamaimaat Khowchaimaha, Agricultural Researcher

ator. Other staff assigned to the project are Ms Kruawan Attaviriyasook, Agricultural Researcher, Mrs Kanjana Bhudhasamai, Seed Pathologist, Ms Lamaimaat Khowchaimaha, Agricultural Researcher, and Mrs Boodsara Promsatit, Entomologist.

Research Activities in Australia

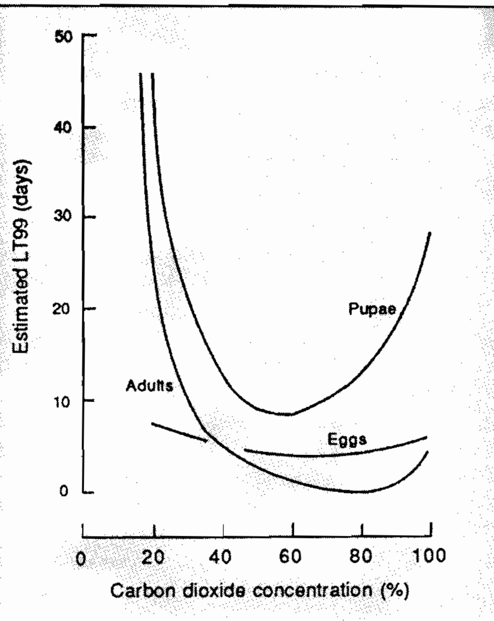
All research activities in Project 8307A are located in Southeast Asia and are reported later, under the country concerned. Activities in Project 8307B concern laboratory studies of the toxicity of carbon dioxide to grain pests. These commenced in May 1984 and are currently on schedule.

The main work being conducted in Australia is a laboratory investigation of the effect of carbon dioxide concentrations of 40% and less on various developmental stages of the rice weevil *Sitophilus oryzae*. This species is known to be one of the common stored product insects most tolerant to carbon dioxide.

Experiments using 40% carbon dioxide, described in last year's research report, showed that most stages of *S. oryzae* are killed easily at this concentration, but that the prepupae/pupae require a long exposure (greater than 20 days) to ensure complete mortality. Experimental exposures to 20% carbon dioxide were started during the past year, in order to refine understanding of dosage requirements. Although results from this concentration were not quite complete by July 1986, a very clear trend was obvious. Unlike 40% carbon dioxide, 20% has very little or no efficacy against most developmental stages of *S. oryzae*. It is surprisingly effective, however, against the eggs of this species.

The currently recommended dosage for carbon dioxide treatment is 10 days at a concentration greater than 35%. Laboratory experiments carried out during the year have shown that a dosage of 35% carbon dioxide for 10 days is inadequate to give 100% mortality of the pupae of *S. oryzae*, the most tolerant stage of this species. The sealed sheeted stacks used in Project 8307A have all maintained a concentration of above 35% carbon dioxide for more than 30 days. The recommended exposure period has thereby been substantially exceeded. The need to maintain a carbon dioxide level of greater than 35% for somewhat longer than 10 days indicates that no attempt should be made to lower the levels of sealing currently specified.

During the year, substantial progress was made in building up a numeric database of the effects



Diagrammatic representation of the effects of CO_2 concentration on time to 99% mortality in various developmental stages of Sitophilus oryzae. *LT_{99} obtained from eye-fitted probit lines.*

of carbon dioxide concentration, time of exposure, and temperature, on the mortality of a wide range of stored products insects. Preliminary analysis of these data started in June 1986, confirms that pupae of *S. oryzae* are one of the most difficult life stages to kill using carbon dioxide, but also suggests that *Trogoderma granarium* (a species neither present nor available for testing in Australia) may well be even more tolerant.

Research Activities in Southeast Asia

Field trials in Southeast Asia involve paddy, rice, and maize and have been planned as a series of short-, medium-, and long-term experiments to be carried out over the three-year term of the project.

Mr P.C. Annis, the Australian Research Leader, visited Malaysia, Singapore, and Thailand during June 1986. He was accompanied by Dr D.E. Evans, Officer-in-Charge of the CSIRO Stored Grain Research Laboratory, who was reviewing the Laboratory's involvement in Project 8307 and other Southeast Asian activities. The main objective of Mr Annis' visit was to discuss progress and formulate plans for future experiments within Project 8307.

Mr J. van S. Graver made at least four visits to each collaborating country during the year, to supervise the establishment and subsequently to observe the later stages of the treatment cycle.

The three project leaders in Southeast Asia visited Australia from 7–23 April 1986 to familiarise themselves with the Australian portion of Project 8307 and related research. During their stay they visited the CSIRO Stored Grain Research Laboratory in Canberra, N.S.W. Grain Handling Authority storages at Harden and Temora, Ricegrowers' Cooperative Ltd at Leeton, the Queensland Department of Primary Industries, the Wheat Research Institute and Grain Handling Authority in Sydney, and the Agricultural Engineering Group of the CSIRO Division of Chemical and Wood Technology in Melbourne.

During this visit, Mrs G. Sabio (Project Leader for the Philippines) and Dr P.M. Barrer made final arrangements for a series of experiments to determine the potential for reinfestation through holes in the sheeting of sealed bag-stacks. It was hoped to start these experiments in August 1986.

Malaysia

Mr J. van S. Graver visited Malaysia during August–September 1985, primarily to initiate full-scale experimental work at Pasir Gudang, where a total of 14 treatments of 200 t stacks of milled rice was subsequently undertaken during the year. He made further visits from 9–28 October 1985, 14–20 December 1985, 17 February to 2 March 1986, and 17–18 June 1986 to assist in and to observe the later stages of the experiment cycle (opening, post-treatment, sampling, sealing, and gassing). During one of these visits Mr Graver participated in the GASGA/ACIAR/LPN/MARDI/AFHB Seminar on Maintaining Grain Quality by Aeration and In-store Drying, held in Kuala Lumpur from 9–11 October 1985.

Mr A. Robin Wahab, Mr A. Rahim Muda, Mr Lee Chin Hui, and Mr Idris Abas also participated in the aeration and in-store drying seminar.

Field trials

The first of the series of trials planned for Malaysia commenced in June 1985 at the LPN complex at Pasir Gudang, Johore Bahru. This trial covered short-term storage from 3–6 months. Initially one 200 t stack of imported rice was used. This was followed by a further 6 × 200 t stacks of imported rice. Each stack was stored for 12–16 months and during this time was opened and inspected at 3–4 monthly intervals. In all cases complete disinfestation was achieved. Grain quality at

The Malaysian project team examining the sealing fabric of one of the 200 t experimental stacks of rice at Pasir Gudang, Johore Bahru.

the end of the storage period was reported to be superior to that of grain stored conventionally.

The trials were continued with 5 × 200 t stacks of local rice which were opened variously at 4, 6, 8, and 12 monthly intervals. With one exception, all treatments successfully disinfested the grain. Three of these stacks are being kept under plastic covers for long-term storage of 18–24 months. The stack in which an incomplete fumigation had occurred was found to contain one bag heavily infested by *Sitophilus* sp.. Subsequent examination of the sheet indicated that there was an undetected leak immediately above the infested bag which prevented a sufficiently high concentration of CO_2 being achieved.

All other treatments completed to date have been satisfactory, with no gross quality deterioration, moisture damage, or insect infestation being evident.

Philippines

Mr J. van S. Graver visited the Philippines on four occasions during the year (10 August–17 September 1985, 1–5 November 1985, 3–11 December 1985, and during 20 May to 12 June 1986) to initiate and monitor storage trials on milled rice and paddy at Cabanatuan City and on maize at Cebu City. The trials were carried out in National Food Authority warehouses.

During Mr Graver's first visit, he participated in the 8th ASEAN Technical Seminar on Grain Post-Harvest Technology, held in Manila from 6–9 August 1985.

As noted previously, Mrs G. Sabio visited Australia in April 1986. She also attended the GASGA/ACIAR/LPN/MARDI/AFHB Seminar on Preserving Grain Quality by Aeration and In-store Drying, held in Kuala Lumpur from 9–11 October 1985. En route back to the Philippines, Mrs Sabio visited the Thailand project for discussions on collaborative assessment of the quality of the rice from storage trials.

Field Trials

Field trials in the Philippines commenced in September 1985 and subsequently involved one 200 t stack of milled rice, six of paddy, and five of maize. Trials were still under way at the end of the reporting period.

Eight of the test stacks were reinfested by low numbers of insects after treatment, due to pressure from heavily infested grain nearby. Numbers of *Rhyzopertha dominica* and *Sitophilus* spp. had previously been seen burrowing inward through the stack covers. During the project, reinfestation has been seen only in the Philippines, and then at two storages where the reinfestation pressure was obviously high. This observation suggests that good storage hygiene and low reinfestation pressure is as appropriate to sealed stack storage as to conventional storage.

Thailand

Mr J. van S. Graver visited Thailand on four occasions (28 October–1 November 1985, 11–14 December 1985, 3–12 March 1986, and 31 May–4 June 1985) during the year to initiate and monitor storage trials on milled rice. Six 100 t stacks at the Mah Boonkrong Rice Mill in Pathumthani Province were subsequently involved. Treatments completed to date have been satisfactory as regards the quality of the product at stack opening.

As previously noted, Project Coordinator, Mr Chuwit Sukprakarn visited Australia in April 1986.

Field Trials

Following two preliminary trials reported in 1984–1985 at the Mah Boonkrong Rice Mill, using carbon dioxide and phosphine for disinfestation treatments, a further trial was carried out from 6 June to 3 December 1985 at the same site, using carbon dioxide. Three stacks of bagged milled rice, each of 72 tonnes and comprising the varieties Na Sai, wet season rice, and Hom Mali, were used. After sealing and pressure testing, the stacks were treated with 1.95, 1.97, and 2.03 kg/tonne of $C0_2$, respectively, and were opened for inspection after 60, 120, and 180 days. The temperatures and relative humidities in the enclosures were monitored throughout the trial and grain moisture content, quality, and insect infestation compared before and after storage. During storage, grain moisture content increased slightly but there was no increase in fungal infection, except in the stack stored for 180 days, where the appearance of *Penicillium* and *Fusarium* spp. contributed to a higher fungal count. Aflatoxin was not detected in any of the stacks. Grain quality decreased slightly with increase in storage time. Cooking and eating quality of all samples decreased in gel consistency and increased in volume expansion and fat acidity. The off-flavour of cooked rice could be distinguished in the stack stored for 180 days. Although a light insect infestation was present before treatment began, no live insects were found in any of the stacks after storage.

(Project 8307D)

Moisture Regimes of Bulk Commodities

Commissioned organisation — CSIRO Division of Entomology

Abstract

This support project seeks to provide a basic understanding of grain moisture phenomena. Published data on moisture sorption, desorption, and equilibria of grains and other bulk stored commodities are being catalogued and systematically evaluated. A standardised test facility has been established. It offers programmable temperature and moisture regimes for commodity samples and accurate measurement of moisture interaction between samples and their environments. The results of moisture uptake studies indicate that the rate of moisture exchange between a sample of grain and its immediate environment is directly associated with dew-point depression. Sensors have been developed for in situ monitoring of moisture in bulk stored commodities.

Background

Summary

The rate of deterioration of a foodstuff in bulk storage is determined to a considerable extent by moisture and temperature. The moisture and temperature regimes of the humid tropics are particularly conducive to stored food losses, especially through the activities of insects and moulds, which are favoured by high temperature and humidity. Despite this, moisture related characteristics of many commodities and their associated organisms are poorly understood.

Generally, moisture interchange in bulk, particulate commodities occurs via the interstitial atmosphere. In addition to its interaction with the surrounding commodity, this region largely constitutes the environment of insects and microorganisms, influencing and being influenced by their activities.

While the moisture content of commodities themselves rather than that of their interstitial micro-environments has traditionally been of primary interest, the latter is more directly relevant to quality preservation and pest management procedures. Better understanding of the interaction of commodities with their immediate environment, particularly of moisture fluxes, the associated forces, and the transport mechanisms, is therefore of considerable scientific and economic significance.

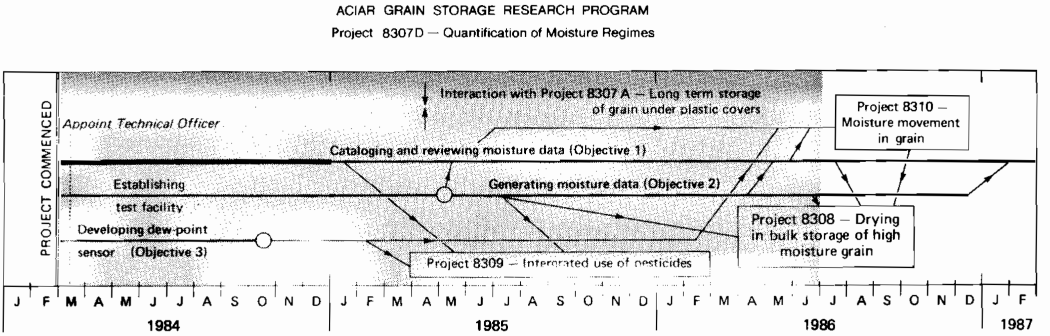
Reports of the water relationships between commodities and their interstitial atmospheres are scattered through the literature and confined largely to static equilibrium conditions. These data differ widely, reflecting not only the difficulty of measuring moisture, but also biological variability, the effects of hysteresis, and the inappropriateness of static analysis of dynamic systems. A test facility to gather standardised data has been developed.

No generally applicable methods are yet available for the precise in situ (remote) determination of the moisture content of bulk grain or similar commodities. Recent technology does, however, offer promise of good measures of the humidity of interstitial air. Coupled with improved understanding of the moisture relationships between the diverse range of commmodities stored in bulk (grains, legumes, oil seeds, etc.) and their interstitial air, these measures offer non-intrusive monitoring of product quality, and early warning of the activities of deleterious organisms. As sealed and semi-sealed storages (e.g. plastic-sheeted stacks, bunkers, or structures intended for use of controlled atmosphere or efficient fumigation) to which human access must be minimised become more common, the importance of remote moisture monitoring will increase still further.

Project 8307D is providing a better understanding of grain moisture phenomena by clarifying and evaluating existing data and rectifying deficiencies. A sensor has been developed that will enable grain moisture changes to be followed during the course of field trials and other experimentation, so that an improved understanding of grain/atmosphere moisture interactions may be applied to the management of storages.

Expected Benefits

Existing data on grain moisture relationships will become far more valuable when they are rendered more accessible, their information content is critically appraised, and that information is expressed systematically in standardised forms. A test facility allowing relatively fast collection of data in a uniform manner has therefore been



Research schedule — Project 8307D (shaded area indicates work completed) commissioned. It relies largely on the study of dynamic systems under dynamic conditions and should yield sufficient detail for concise and accurate mathematical modelling of the storage microenvironment.

An improved understanding of moisture fluxes in stored products will be of fundamental scientific significance and economic importance. Coupled with in situ measures of commodity moisture content, this understanding will contribute, particularly in tropical areas, to the enhancement of storage strategies.

Project Objectives and Operational Schedule

This project is designed to provide basic support to other ACIAR projects on matters relating to storage moisture characteristics and their measurement in cereal grains, legumes, and oil seeds.

Specific objectives of the project include the following:

1. (a) A comprehensive catalogue is being compiled in order to to provide, in readily accessible form, a listing of the diverse moisture sorption, desorption, and equilibria data at present scattered through the literature. (b) A critical assessment of existing data is being undertaken with a view to explaining differences and assessing their reliability, and pointing to the most appropriate techniques for quantifying moisture related variables of bulk stored commodities.
2. A standard test facility has been established and is being used to rectify deficiencies in the information emerging from the above and to improve its quality. Attention is concentrating on dynamic testing to provide, in addition to rapid determination of equilibrium parameters, information on non-equilibrium conditions, equilibration rates, and the forces involved.
3. A small dew-point sensor is being developed using newly available semiconductor peltier devices, to allow precise remote measurement of interstitial moisture, in order that the information derived above be directly applicable within the grain storage industries.
4. Close liaison is being maintained with Projects 8307, 8308, and 8310 in both theoretical and practical development of moisture control technology in stored grain.

The project has a term of three years.

Progress according to the agreed research schedule is illustrated in the accompanying project flow diagram.

Organisation and Staff

Arrangements for this research support project were incorporated in the Record of Understanding between ACIAR and CSIRO for Project 8307 which was signed on 4 November 1983. Staffing remains as in 1984–85: Mr J.R. Wiseman as Research Leader and Mr S.A. Rogers as Technical Officer. However, Mr Rogers resigned as from 30 June 1986.

Research Activities in Australia

Commodity Moisture Characteristics Data Bank

Assembly of data on the moisture characteristics of a diverse range of agricultural commodities is in progress, with particular attention being given to paddy and, to a lesser extent, wheat. These data have been scattered through the literature and obtained using differing apparatus and techniques. They are being rendered more accessible in a microcomputer oriented database which is being updated as additional published material on commodity moisture properties becomes available.

Generation of Data on Commodity Moisture Characteristics

These studies aim to provide data on commodity moisture in a standardised form to supplement the information currently available and to expand understanding of moisture behaviour in commodities generally.

The processes of moisture exchange are being examined using specially developed equipment which measures very precisely the rates of uptake and release of water in grain samples subjected to varying temperatures and humidities. After numerous developmental delays and difficulties, this equipment is operational. It currently offers eight chambers whose temperature/moisture status is monitored and controlled by a microcomputer. These microenvironments are maintained or modified in accordance with the test program using peltier heat pumps. Alternate chambers house

Grain Storage Research Program

Project 8307D Staff

Australia (CSIRO Division of Entomology)

Mr S.A. Rogers, Technical Officer (resigned 30 June 1986)

Mr J.R. Wiseman, Research Leader

commodity samples, the remainder being used in generating atmospheres having programmed humidities. The required atmospheres are fed through grain samples, and precise dew-point temperatures determined before and after passage through the samples. A single dew-point meter is used to monitor alternately the inlet and outlet atmospheres of a sample, providing precise differential measures from which rates of moisture uptake and release may be calculated. The microcomputer monitors and controls temperatures, humidities, and gas flow rates in a programmed manner, calculates moisture exchange, and maintains records. It may also modify test environments in the light of emerging information, offering constant, varying, or cyclic temperature and moisture conditions and, by expansion in modules of eight chambers, provides opportunity to gather data concurrently from numerous commodity samples, each subjected to a different microenvironment.

This project breaks new ground by concentrating on exchange rates, rather than commodity moisture status after equilibrium has been attained. It has become apparent from the moisture uptake studies that, over the range of interest, the rate of moisture exchange between a sample and its immediate environment is directly associated with dew-point depression (DPD), i.e. grain temperature minus dew-point temperature. Once equilibrium has been attained, samples exchange very little moisture with their gaseous environment when cycled through large temperature ranges, provided the corresponding DPD is maintained constant. This finding is at variance with the traditional view which relates equilibria with relative humidity.

Development of Remote Measuring Sensors

Two types of sensor have been examined. Firstly, simple peltier cooled devices for measuring the humidity of intergranular air were investigated. Though very promising, they were considered too costly for widespread use. An inexpensive capacitance sensitive device responding to water in its vicinity and providing temperature readings was then developed. Laboratory studies indicated that the devices, though not precision instruments, were adequately stable, and particularly sensitive to changes in commodity moisture content (m.c.). Their absolute accuracy in wheat at maximum commercial moisture content was within 1% m.c. and once installed in a static bulk, they reliably detected changes of less than 0.2% m.c. Field tests were successful, though the sensors in their present form are not sufficiently robust for widespread industrial use.

Rising heat or moisture levels may be indicative of deterioration of a stored commodity. In common with any other sensors which respond to the condition of their immediate surrounds, the speed of response of the new moisture/temperature sensors is determined by the rate at which the phenomenon of interest passes through the surrounding medium. Since heat and moisture, especially the latter, travel very slowly through a grain bulk, the detection of remote sources of heat or moisture is necessarily delayed. For this reason, many sensors would be required to adequately monitor conditions in a large bulk. Consequently, it is probable that these devices will find application mainly in small bulks, or in regions of large bulks known to be particularly susceptible to damage.

The sensors provide two output signals, temperature being represented by the magnitude of an electric current, and moisture by the rate at which current is pulsed. Although this approach offers the advantage that signals may be transmitted over long distances using only a single pair of inexpensive wires, it also calls for signal conditioning before connection to conventional logging equipment. Two prototype decoding devices have been built and it is planned to build a further unit suitable for commercial production.

Project 8308

The Drying in Bulk Storage of High Moisture Grains in Tropical Climates

A. Principles
Commissioned organisation — University of New South Wales

B. Application technology
Commissioned organisation — Ricegrowers' Co-operative Ltd.

Abstract

THE main achievements of Project 8308 have been the development and testing of a grain drying model, and associated studies on grain quality to determine optimal conditions for its use. The model is based on the assumption of thermal equilibrium between the grain in a deep bed and the drying air, and uses thermophysical data on rice properties from a variety of experimental sources relevant to grain varieties in Southeast Asia. The model was tested in each country, using pilot plants, and field trials are being used for extensive commercial scale testing to develop drying strategies. In most situations in Southeast Asia, it was found that near-ambient drying is possible, allowing the roles of drying and grain storage aeration to be combined, and that two-stage drying was the most cost and quality effective drying technique.

Background

Summary

Cereals, particularly rice, are a staple food in much of Southeast Asia. Increased planting of high-yielding varieties, greater use of mechanical harvesters, and expansion of irrigation systems have placed pressure on grain handling and drying systems which remain essentially dedicated to bag rather than bulk handling. The result of backlogs in the existing system is deterioration in quality and associated economic losses.

Undoubtedly, drying is the most effective method of preserving grain quality in storage. Experience with paddy in Australia has demonstrated that savings in drying costs are possible by using near-ambient air and bulk storage facilities. As well as being cost-efficient, these drying methods have yielded significant commercial gains in terms of improved grain quality.

This project was initiated to investigate methods of drying grain safely in the hot, humid conditions of tropical countries. Problems addressed by the project have included loss of milling yield due to the drying method currently used and loss of quality due to problems with the transport infrastructure and delays in drying. Investigations of these problems, together with information gathered during pilot plant and field studies in Southeast Asia, are allowing development of grain aeration and drying systems appropriate to the region.

The project is being implemented by a joint research arrangement between the Department of Food Science and Technology of the University of New South Wales and Ricegrowers' Co-operative Ltd, Leeton. A similar research arrangement between these two agencies has been responsible for the development of rice-drying technology in Australia. Research on the theory and principles of drying is carried out by the University, with the Co-operative's effort concentrating on quality considerations, commercial verification of the research findings, and application of the technology. Collaborative research teams have been established in Malaysia, the Philippines, and Thailand.

A list of collaborating institutions and research leaders follows.

- *Australia*
  Project 8308A — Department of Food Science and Technology, University of New South Wales
  Research Leader: Dr R.H. Driscoll
  Project 8308B — Ricegrowers' Co-operative Ltd
  Research Leader: Mr L.D. Bramall
- *Malaysia*
  Lembaga Padi dan Beras Negara (LPN, National Paddy and Rice Authority) in collaboration with the Malaysian Agricultural Research and Development Institute (MARDI)
  Team Leader: Mr Loo Kau Fa
  MARDI Collaborator: Mr Dhiauddin B. Mohd Nour/Jantan
- *Philippines*
  National Post-Harvest Institute for Research and Extension (NAPHIRE)
  Team Leader: Mr Justin Tumambing
- *Thailand*
  School of Materials and Energy, King Mongkut's Institute of Technology, Thonburi
  Team Leader: Dr Somchart Soponronnarit

The main achievement of studies at the University of New South Wales has been the development and testing of a grain drying model. The model is based on the assumption of thermal equilibrium between the grain in a deep bed and the drying air, and uses thermophysical data on rice properties from a variety of experimental sources relevant to grain varieties in Southeast Asia. It has been tested in each country, using pilot plants, and field trials for commercial scale testing have been initiated. The model has also been used to develop drying strategies. In most situations in Southeast Asia, it was found that near-ambient drying is possible, allowing the roles of drying and grain storage aeration to be combined, and that two-stage drying was the most cost and quality effective drying technique.

The studies at Ricegrowers' Co-operative Ltd. have provided valuable support to the theoretical studies, in terms of evaluating the model, developing the equipment to translate the drying strategies into practical operations, and investigating how the various factors operating during drying and storage affect the quality of the grain. Valuable data on grain yellowing and breakage have been obtained. These factors have a considerable bearing on the appropriateness of drying strategies in the humid tropics.

The project originally had a scheduled termination date of June 1986, by which time it had achieved four of the five stipulated project objectives, viz.:

- development of a heat and mass transfer model for rice drying (University of New South Wales);
- measurement of basic thermophysical data for paddy and other grains (Ricegrowers' Co-operative Ltd);

- development of aeration and drying strategies (University of New South Wales and Ricegrowers' Co-operative Ltd); and
- assessment of various energy sources for grain drying (Ricegrowers' Co-operative Ltd — rice hulls; Malaysia — commercial rice hull burners; Philippines — design of rice hull burner; Thailand — solar energy).

The completion of field trials, the project's fifth objective, has been put back because of delays to scheduled project commencement times and to the commissioning of a pilot plant for grain drying studies in Malaysia. It has been proposed that full-scale commercial introduction and testing of the strategies developed during the project be part of a new, grain drying, technology transfer project.

Expected Benefits

The results obtained from Project 8308 are expected to bring about the following major developments in the region:

1. The development of in-store drying methods for paddy (unhulled rice), maize, and other grains, that reduce losses and maximise both quality on outturn and yield in any subsequent processing.
2. A basic knowledge of the characteristics of grain bulks and the movement of moisture and temperature profiles through grain during drying. This will allow application of the technology to drying and storage in all tropical countries. Drying controllers appropriate for local conditions will be designed and commissioned in each of the countries concerned.
3. Applicability of the system for multiple use of a facility for a range of grains at different times of the year, e.g. paddy, maize, and legumes.
4. Development of technology for use of rice hulls and solar energy as energy sources where pre-heating of ambient air is required.
5. Potential for development of central monitoring systems for storage conditions and stock assessment.

Project Objectives and Operational Schedule

The overall objective of the project is preservation of quality in grain by management of moisture from harvesting through to processing.

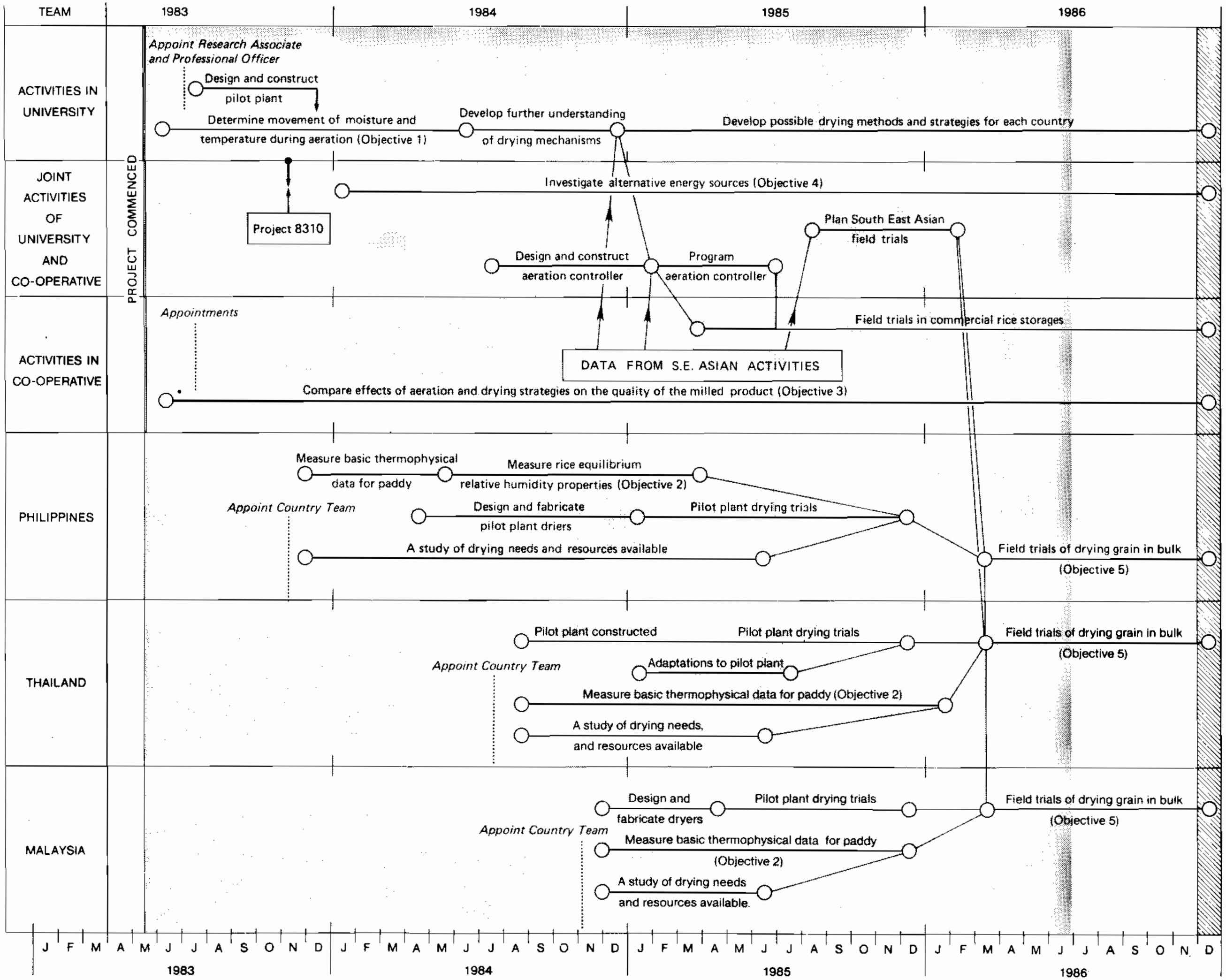
The objectives of the project thus include:

1. a study of the movement of moisture and temperature profiles through bulk stored grain when aerated and dried under various conditions;

Project 8308 Team Leader in Malaysia, Mr Loo Kau Fa (L), discusses with Mr Ahmad Robin Wahab (Project 8307) some test drying bins installed at MARDI headquarters in Serdang, Selangor.

ACIAR GRAIN STORAGE RESEARCH PROGRAM

Project 8308 — Drying in Bulk Storage of High Moisture Grain



Research schedule — Project 8308 (shaded area indicates work completed)

2. measurement of basic thermophysical data for paddy and other grains, relevant to the design of bulk storage/drying facilities for tropical climates;
3. a study of the effect of various aeration and drying strategies on the quality of stored paddy and other grains;
4. a study of various energy sources (rice hulls, solar energy, etc.) as a means of improving the drying of stored grain; and
5. field trials in Australia, Malaysia, and the Philippines of the procedures developed in this project.

The project has a duration of 3 years.

It was planned that Objectives 1–3 be achieved within the first year of the project by the University (Objective 1), the country teams (Objective 2), and the Co-operative (Objective 3, part). These studies would provide data to enable estimation of the movement of temperature and moisture profiles through bulk grain in tropical climates and thereby permit prediction of the effects on grain milling quality.

During the second year, pilot plant dryers would be tested by the country teams in Southeast Asia, while joint field trials on commercial rice bins would be carried out in Australia by the Co-operative and University. The data obtained would be used to improve the models describing the drying mechanisms. Additionally, the University and Co-operative, in collaboration with the country teams, would investigate alternative energy sources for providing supplemental heating during drying (Objective 4).

At the end of the second year, all of the pilot plant work on development of drying methods would be completed and detailed planning of Southeast Asian field trials would be finished. Controllers to implement the required drying program would be completed for delivery to Southeast Asia.

During the third year of the project, field trials would be carried out in all countries, to test and improve the method (Objective 5).

It was anticipated that, by the end of the third year, grain would have been dried in bulk storages in Malaysia, the Philippines, and Thailand.

The effective commencement dates for project activities were as follows:

• Australia	Project 8308A	July 1983
	Project 8308B	July 1983
• Malaysia	November 1984	
• Philippines	November 1983	
• Thailand	July 1984	

Progress according to the agreed research schedule is illustrated in the accompanying flow diagram.

The delays in completing agreements for operations in Southeast Asia necessitated some compression of the research schedules, particularly in Malaysia. Work during the past year saw the commissioning of the pilot plant in that country, thus completing the collection of data on pilot plant drying for all Southeast Asian participants. Field trials commenced in Malaysia and the Philippines.

Organisation and Staff

The Records of Understanding between ACIAR and the University of New South Wales and Ricegrowers' Cooperative Ltd were signed on 25 May 1983 and 25 March 1983, respectively. Agreements for overseas operations were finalised between the University of New South Wales and the collaborating institutions somewhat later — NAPHIRE in the Philippines on 22 November 1983, King Mongkut's Institute of Technology, Thonburi in Thailand on 6 July 1984, and the National Paddy and Rice Authority (LPN) in Malaysia on 26 November 1984.

The delays in commencing overseas operations occurred because agreements between the University and the overseas collaborators could not be finalised until the general agreements for ACIAR's activities in each country were formalised. Because of the need to retain the linkages between the Australian research personnel and their overseas counterparts throughout the full course of the 3-year schedules of planned project work in each country, the 3-year terms in the Records of Understanding between ACIAR and the University of New South Wales and Ricegrowers' Cooperative Ltd were extended to 30 June 1986 under the existing arrangements.

Dr R.H. Driscoll of the University of New South Wales and Mr L.D. Bramall of Ricegrowers' Cooperative Ltd are Research Leaders in Australia and the overseas Team Leaders are Mr Loo Kau Fa in Malaysia, Mr Justin Tumambing in the Philippines, and Dr Somchart Soponronnarit in Thailand. Other project staffing and responsibilities have remained essentially as during 1984–85 (see accompanying box).

In Thailand, additional assistance has been provided by graduate assistants Mr Somchai Chinsakoltanakorn (drying phase 3) and Mr Chob Laitong (moisture isotherms), and by two part-time research students, Mr Chinda Kaewkial and Mr Theeradit Duangmusik. Miss Warunee Watabutr, a lecturer at the Institute, has provided assistance with economic analyses.

Grain Storage Research Program
Project 8308 Staff

Australia (University of New South Wales
Mr T. Adamczak, Professional Officer
Dr R.H. Driscoll, Research Leader
Mrs P. Koussa, Administrative Assistant
Mr Mohd Mochtar, Postgraduate Student
Mr K. Thong Do, Professional Officer

Australia (Ricegrowers' Co-operative Ltd)
Mr L.D. Bramall, Research Leader
Mr R. Corner, Development Assistant
Mr J. Darby, Development Engineer
Mr G. Pym, Project Supervisor

Malaysia (LPN)
Mr Loo Kau Fa, Team Leader

Malaysia (MARDI)
Mr Dhiauddin B. Mohd Nour/Jantan, Collaborator

Philippines (NAPHIRE)
Mr Manolito Bulaong, Research Associate
Mr Justin Tumambing, Team Leader

Thailand (King Mongkut's Institute of Technology)
Mr Chatchai Karnjanaboon, Research Student
Mr Chinda Kaewkial, Research Student (part-time)
Mr Chob Laitong, Research Student
Miss Petchara Preechakool, Research Student
Dr Ratana Chirarattananon, Assistant
Mr Somchai Chinsakoltanakorn, Research Student
Dr Somchart Soponronnarit, Team Leader
Mr Theeradit Duangmusik, Research Student (part-time)
Miss Warunee Watabutr, Lecturer

Research Activities in Australia

Simulation Models of Grain Drying

The rice-drying model RICE developed at the University of New South Wales has been further refined with the incorporation of the isothermal model of Chung and Pfost, giving an increase in accuracy of its predictions of drying behaviour for Asian varieties. The theoretical work carried out at the University over the year has concentrated on advanced applications of the drying model.

The model has been modified also for inclusion in a simulation model of a mill-drying operation. This model predicts drying time and the economics of using flat bed batch dryers for both fast and slow drying. The mill model has now been used for simulations of typical Malaysian and Indonesian situations. To do this, a set procedure was followed to calculate the required dimensions for receival paddy bins, fast-drying (batch) bins, slow-drying bins, and aeration (storage) bins, based on selected values of the average receival moisture content, peak receival rate, and duration of harvest period, using data gathered at mill sites in Malaysia. From the simulation it was possible to highlight problems associated with particular plant configurations, to investigate the effects of maintaining quality at receival, and to predict the results of alterations to plant layout.

The grain drying model is being extended to other grains. Data files containing information on the thermophysical properties of a particular grain are read into the drying program. A major obstacle at present is the lack of adequate data. Data files for soybean and Australian and Asian rice (averages of the varieties reported in the literature) have so far been implemented.

A simplified drying model is currently being used in studies to optimise bin design. A computer program has been written which allows the effects of variations in fan size, burner capacity, and grain depth to be investigated in terms of both drying costs and product quality. Again, however, there is a shortage of data, though this is being rectified, so far as paddy is concerned, by work at Ricegrowers' Co-operative Ltd. Graphs to allow quick estimates of drying times are being drawn. They are applicable to low air speed drying (up to about 5 m/min).

Effects of Aeration and Drying Strategies on Product Quality

Modifications have been made to the model to allow quality estimation. The quality models used were dry matter loss (DML) and predictions of the milling yield, using a rough milling yield model mentioned previously. Since the model allows predictions of what is happening in each grain layer in terms of time and space, different models have been developed with a view to modelling the stress

Mr James Darby (Project 8308B) investigates a three-stage rice hull gasifier installed in a private mill in Malaysia.

behaviour of a grain during drying. Again the results have been promising, and this method of first building a theoretical model and then testing its predictions through the grain drying program may allow a more accurate model of milling yield to be developed.

Some laboratory experimental work on the effects of quality related to drying, tempering, and cooling was completed, but the results have not yet been analysed.

These studies by the University of New South Wales have been complemented by investigations at Ricegrowers' Co-operative Ltd on the effects of heating on levels of rice kernel yellowing and breakage.

Analysis of the results from yellowing response trials showed a logarithmic relationship between the kernel's reflectance measurement and time that the grain was held at a set temperature. The method for determining this relationship has been thoroughly tested and developed to the stage where it gives reproducible results.

The literature relating to rice kernel yellowing has been reviewed. It contains few items on relationships between kernel yellowing and storage factors.

In conjunction with the 1986 Australian rice harvest, investigations continued into the effects of drying and post-drying treatments on rice kernel breakage levels. Relationships have proven difficult to quantify, despite an increased understanding of the mechanism of kernel breakage.

The literature on rice kernel breakage and related areas has also been reviewed. As yet there has been no attempt to relate the level of kernel breakage to drying and post-drying treatments in a quantified fashion, and there are many conflicting opinions as to the cause of breakage.

Pilot Drying Bin Studies

As detailed later in this report, the University of New South Wales team has, over the past year, continued to assist overseas participants in the project in the construction and commissioning of pilot plant equipment. The data generated by the pilot plant dryers are being analysed as they are produced by each country. The Malaysian pilot plant data from a series of fast- and slow-drying runs for the dry season have been analysed, and show generally good agreement with the theoretical model at shallow-grain depths. However, since there were indications that the near-equilibrium model loses accuracy at grain depths greater than 1.5 m, a 3 m bed was constructed and experiments using it are under way.

Drying Strategy

Field trials on changes in moisture content in paddy in bulk storage during aeration were performed using Ricegrowers' Co-operative Ltd bins at Leeton. The results are currently being analysed, but have already helped identify problems to be solved in the field trials in the overseas countries.

Work continued during the year in the area of automatic control of drying and aeration in 'in-store' systems. The technical and commercial literature on drying and aeration controllers was reviewed. Feedback control incorporating on-line monitoring of LPG burners for supplemental heating of the drying air has been tested on the 500 kg grain drying system at Ricegrowers' Co-operative Ltd. Developmental work for these micro-processor based controllers has had high priority. A practical system suited to the requirements of the harsh grain environment has resulted.

A weather data monitoring and collection system for continuous data recording on computer tape was designed and developed. This was done in conjunction with development work on the 500 kg grain drying system. Several problems regarding communication between the weather station and the computer were overcome.

Energy consumption and efficiency of drying in in-store systems was investigated. Time was spent on developing and understanding the relationships between resistance to airflow and energy consumption. Operational characteristics of fans have accordingly been investigated.

Other Studies

Equipment has been designed and constructed at the University of New South Wales for drying rate experiments at high temperatures and drying experiments using high air speeds. Some preliminary runs have been completed with both sets of equipment.

Also at the University, a wet-bulb temperature measuring device is being tested. Initial data indicated that insufficient air passed through the device to give an accurate reading. Further development of the device will be undertaken using data from field trials planned for later in the year.

Four students have undertaken research tasks in connection with the project during the year. Aspects studied included drying flow rates, economic evaluation of drying equipment, collection of rice thermophysical data, and the drying rate equation for rice. Their findings are summarised below.

- Influence of drying flow rate on quality. Tests of different drying flow rates, varying from stationary bed drying to fluidised bed drying, were made using a computer-controlled dryer built especially for the task. Quality studies conducted at the conclusion of the drying indicated that flat bed dryers were the most quality effective of the options. The continuous flow dryer with tempering, however, was very similar in performance.
- Economic evaluation of drying equipment. Again the flat bed dryer was the most efficient, but the results are not conclusive, due to problems with the grain conditioning and heat losses through the side walls.
- Collection of thermophysical data for rice. An environment chamber was constructed to determine the hygroscopic properties of grain. Isothermal models have been obtained for typical tropical and temperate short grain and long grain cultivars and these have been implemented in the new versions of the rice drying models.
- Basic studies on the drying rate equation for rice. A thin layer drying apparatus which was constructed, uses strain gauges to measure the weight of a rice sample suspended in a moving air stream. The methods developed to accurately measure the weight of the grain have formed the basis for detailed recommendations for other countries to build thin layer drying apparatus. It was also shown that simple drying models are inadequate to accurately describe the grain drying curve over the whole drying time, and that the minimum requirement of the model was a two-term exponential series.

As can be seen from the above points, availability of basic data on rice is still a problem. Heat capacities, true grain densities, and rice bulk densities are now known, but drying equations and rewetting equations need further research. An equation for pressure drop through a rice bed (with a sounder theoretical basis than Shedd's equation) has been fitted using data from the University and from the Ricegrowers' Cooperative Ltd, and the model of water activity/moisture content behaviour is believed to be adequate.

At Ricegrowers' Co-operative Ltd, the design of a highly accurate bench-scale commodity conditioning system was completed to the stage of costing and determining construction materials. The system would enable the collection of all thermophysical data required for engineering design of commodity dryers, including airflow characteristics and fluidisation properties. The data collected would be logged by an on-line computer.

Research Activities in Southeast Asia

Malaysia

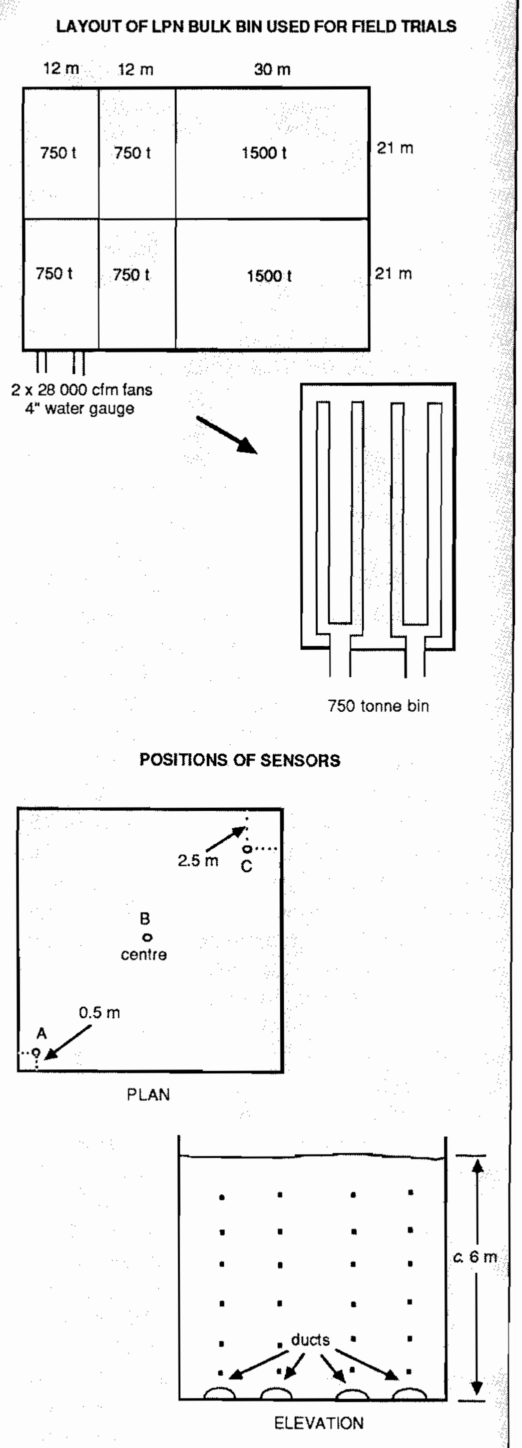
The Australian Project Leaders, Dr R.H. Driscoll and Mr L.D. Bramall, together with Mr T. Adamczak (8308A) and Mr J. Darby (8308B), attended the GASGA/ACIAR/LPN/MARDI/AFHB seminar on 'Preserving Grain Quality by Aeration and In-store Drying', held in Kuala Lumpur from 9–11 October 1985. During the same visit, Mr Bramall, Mr Darby, and Dr Driscoll also had project-related discussions with members of the Malaysian team, and inspected the pilot drying facility, private mills, and LPN complexes.

Malaysian Team leader, Mr Loo Kau Fa, also attended the aeration and drying seminar, as did MARDI collaborator Mr Dhiauddin Mohd Nour/Jantan.

Project personnel presented a number of papers at the seminar, as follows: R.H. Driscoll — The application of psychrometrics to grain aeration; R.G. Bowrey and R.H. Driscoll — A procedure to estimate the supplemental heating needs for in-store drying of paddy; G.R. Pym and T. Adamczak — Control systems for the aeration and drying of grain; K.F. Loo — Silo storage in Malaysia; L.D. Bramall — Paddy drying in Australia; J.A. Tumambing — Drying technlogies for maintaining grain quality in the Philippines; Somchart Soponronnarit — Paddy drying in Thailand.

Mr Adamczak again visited Malaysia during December, in connection with the commissioning of the pilot drying facility.

Malaysian Team Leader, Mr Loo Kau Fa, visited Australia in April–May 1986 for discussions with other project staff on the organisation of field trials in Malaysia. These trials are currently in progress at the Kang-Kong Rice Mill, Kedah. They involve a semi-cylindrical, flat bottomed bin with over-floor ducting. Grain depth is 5.5–6 m. The bin is instrumented with moisture and temperature sensors and a moisture computer. Data are collected at half-hourly intervals. The results from the field trials will be compared with the predictions of the rice-drying model, to verify its validity under Malaysian climatic conditions.



Diagrammatic details of LPN bulk bin being used for field trials in Malaysia.

Philippines

Mr Mohd Mochtar attended the 8th ASEAN Technical Seminar on Grain Post-Harvest Technology held in Manila from 6–9 August 1985 and presented a paper 'The role of tropical weather analysis in grain drying simulations'. Local project personnel Mr Justin Tumambing and Mr Manolito Bulaong also participated in the seminar.

Project 8308A Leader, Dr Robert Driscoll, accompanied by Mr Geoff Pym (8308B), visited the Philippines in September–October 1985 for project discussions with Mr Justin Tumambing, the Philippines Team Leader, and to inspect pilot facilities and NFA complexes. As noted previously Mr Tumambing travelled to Malaysia in October 1985 to attend and present a paper at the GASGA/ACIAR/LPN/MARDI/AFHB aeration and in-store drying seminar.

Pilot drying bin studies

In the wet season pilot plant drying experiment conducted from September to December 1985, 10 runs of high speed drying tests and 8 runs of in-store drying tests were conducted. The high speed drying test involved drying air temperatures of 32, 77, 88, and 97°C, air velocities of 20 and 30 m/min at grain depths of 0.30 m and 0.36 m, and grain moisture contents of 19.8–33.7% w.b. In the in-store drying tests, air velocities of 4, 5, 6, and 8 m/min were used with continuous drying with constant temperature rise of 4–5°C, continuous drying with 2°C supplemental heat from the fan, continuous drying with 3–4°C temperature rise at periods of relative humidity above 75%, and intermittent drying with temperature rise of 4°C at periods of relative humidity above 75%. Grain depths were 1.95–2.27 m and grain moisture contents 15.25–21.42% w.b.

Results showed that, for the high speed drying, the use of high drying air temperature of 77–97°C gave higher drying rates and shorter drying times but moisture content variation within the bed was also higher at 7–15.6%. The most uniform drying (1.7% moisture content gradient) was attained using air velocity of 30 m/min, a 4°C rise in drying air temperature, and a grain depth of 0.36 m. Due to uneveness in drying in flat beds and susceptibility to grain fissuring, it is not recommended that very high drying air temperatures be used, especially at very high initial grain moisture content of 28–34% w.b. The lowest specific energy cost of Pesos 0.43/cavan was obtained using an air velocity of 20 m/min, a 3°C temperature rise, and 0.36 m grain depth. Quality of high speed dried grain showed no significant difference from naturally dried control samples, provided the bottom grain in the bed was not overdried (below 17% w.b.).

In the case of in-store drying, the optimum condition was obtained at a grain depth of 2.05 m using an airflow rate of 2.0 $m^3/min/m^3$ paddy (4 m/min air velocity) for continuous drying with 3.4°C supplemental heating at periods of relative humidity above 75%. The grain was dried safely from 18% to 14% in about 134.7 hours. Energy cost for the optimum condition was Pesos 20.39/tonne (Pesos 1.02/cavan), including the energy cost from the kerosene burner. If a rice hull furnace is used to supply the supplemental heat, the energy cost will be reduced to Pesos 13.94/tonne (Pesos 0.70/cavan). Quality analysis of in-store dried paddy samples indicated no significant difference from naturally dried control samples. Head rice yield was in the range of 54.8–69.4%, equivalent to head rice recovery of 80–95%. Crack ratio varied from 0.001 to 0.081. No yellow rice grain was found in any of the in-store dried samples. No visible mould growth was found in the dried samples and germination rate ranged from 93% to 99%.

Two-stage drying

A pilot plant drying experiment on two-stage or combination drying, was conducted during dry and wet season harvests in Isabela, Philippines, to demonstrate safe drying techniques and to test and develop improved strategies for high moisture paddy under humid tropical conditions.

Results of the experiment showed that two-stage drying is a highly feasible drying strategy in terms of technical efficiency, cost effectiveness, and product quality. The most suitable drying strategy for the dry season was intermittent drying in storage for moisture content of 18–20%. For the wet season harvest, high moisture grains (above 26%) have to be dried quickly in a high speed dryer to about 18%, followed by slow drying in storage to 14% using supplementally heated air. Energy costs were substantially lower than those from conventional heated air dryers. The quality of dried samples did not differ significantly from naturally dried control samples. Head rice yields were as high as 69.4%, with no yellow rice or visible mould growth, and a 99% germination rate.

Drying strategies

A major part of project work in the Philippines was completed during 1984–85 and the results given in the research report for that year.

From the results of the experiments on physical properties of local rice varieties, pilot plant drying and field trials including those reported above, and the preliminary research work on drying needs and resources available, the following conclusions have been reached.

1. The high moisture content of grains at harvest and the unfavourable weather conditions during the wet season require that grains should be dried in several stages, preferably in two stages. The two-stage or 'combination' drying strategy developed in this project is highly recommended as a potential solution to the wet grain handling problem.
2. Local rice varieties in the Philippines vary significantly in their physical properties, particularly in terms of equilibrium moisture content. Some rice varieties, such as IR–50 and IR–58, may be exposed to relative humidities above 75% in attaining a recommended moisture content of 14% after drying.
3. No significant differences were obtained between the static and dynamic methods of equilibrium moisture content determination. Thus, either of the two methods can be used, whichever is available and practical.
4. Under the climatic conditions in Isabela, where there are generally distinct dry and wet seasons, in-store drying can be a suitable drying strategy for the dry season if premium quality grain is desired. For the wet season, two-stage drying (combination high speed drying followed by in-store drying) is an appropriate strategy for high moisture grains. With high speed drying for the first stage, drying capacity can be greatly increased to meet the high demand during the peak harvest period. In-store drying for the second stage gently dries the grain to about 14%, maintaining its quality in storage.
5. For other locations such as the Bicol Region where there is continuous and uniform rainfall throughout the year, two-stage drying is most appropriate.
6. The minimum airflow rate for dry season in-store drying of paddy with an initial moisture content of 18–20%, was found to be 4 m/min (2.0 $m^3/min/m^3$ paddy). Intermittent drying is preferable to continuous drying for a more energy efficient drying operation.
7. For the wet season, the minimum airflow rate was 4 m/min (2.0 $m^3/min/m^3$ paddy) using supplemental heating. Among the management procedures for in-store drying, continuous drying with a 3.4–4.8°C temperature rise, at periods of ambient air relative humidity above 75%, gave the most uniform drying (1.7% moisture gradient) and the least specific energy cost. Intermittent drying can also be applied, provided careful consideration is given to the allowable storage time for the grain. There are times when it rains continuously for more than a week.
8. Flat-bed batch drying for the rapid drying stage appeared to have limited application, due to the low capacity and large moisture gradient between the top and bottom layers, when the initial moisture content is high (28–34%). Other forms of high speed drying, such as continuous flow, fluidised bed, and spouted bed, where there is provision for mixing the grain to ensure uniformity of drying, should be examined.
9. High temperatures (as high as 100°C) at high airflow rates (20–30 m/min, air velocity) can be used for the high speed drying stage without affecting the grain quality, particularly head rice yield. Nevertheless, at this stage, grains should not be dried below 17% as the kernels are susceptible to fissuring.
10. Quality tests showed that combinations of high-speed and in-store drying have no detrimental effects upon milled rice recovery, head rice yield, crack ratio, yellowing, dry matter loss, and germination rate. Head rice yields as high as 69.4% (95% equivalent head rice recovery) can be achieved, provided that the paddy is of premium quality. There are no significant differences in the quality of the samples from the different layers of the bed after drying.
11. The wet season field trial confirmed the validity of the two-stage drying strategy developed in the pilot plant drying experiment on a commercial scale.
12. The two-stage drying strategy can be applied to other commodities, such as maize and peanuts. Further investigations, however, are required.
13. In-store drying has been found to be applicable to humid tropical conditions, such as in the Philippines, at commercial scales of operation.

In this context, 123 tonnes of pre-dried paddy at 18% and 4.2 m grain depth, was dried gently to about 12% in 222.8 fan operating hours, or 31 days drying period without serious grain quality deterioration. The quality tests indicated significant improvement in quality, in terms of head rice recovery and germinability, in the dried paddy samples at the bottom layer, due to ageing, gentle drying, and fluctuation in dry ambient air temperature. However, lower quality stocks used for drying and the longer period (more than 3 weeks) for drying have contributed to an increase in percentage of yellowing and damaged grain in the top layer.

14. The use of rice hull furnaces to supply the required supplemental heat has been found to be a suitable method for the drying in bulk storage of high moisture grains. Further refinements in the design of the rice hull furnace, however, are needed if used in automatic operation with the computerised aeration controller. Estimates from the pilot plant drying experiment showed that the energy costs using rice hull furnaces for supplemental heat are lower than those from kerosene burners and electric heaters by at least 1.5 and 3 times, respectively.
15. The drying capacity of the 3 tonne per hour Cimbria continuous flow dryer was increased two times by using the combination drying strategy. Further increases in drying capacity can be obtained if higher drying air temperatures (a maximum of 100°C) and shorter exposure times of grain (15–20 minutes) are used.
16. Two-stage or 'combination' drying has three advantages — flexibility in meeting the drying requirements, particularly during the peak harvest period; substantially lower energy costs than conventional heated air drying; and high quality of the dried grain. Investment costs will also be greatly reduced if integrated into milling and storage operations.
17. The following factors are constraints to successful adoption of combination drying.
    - handling practices in the field and at procurement centres;
    - low volume of harvest per farmer, leading to non-uniformity in quality of paddy during receival;
    - expertise in operating the computerised controller and availability of spare parts;
    - specific drying requirements;
    - demand for high quality milled rice; and
    - capacity to invest in a capital intensive drying and storage technology.

Thailand

Project 8308B Leader, Mr Lindsay Bramall, visited Thailand in October 1985, accompanied by Mr Tom Adamczak (Project 8308A), for discussions with project staff at King Mongkut's Institute of Technology. Mr Adamczak visited Thailand again during December of the same year for further discussions concerning commissioning of the pilot plant facility. Thailand Team Leader, Dr Somchart Soponronnarit attended the GASGA/ACIAR/LPN/MARDI/AFHB seminar on grain aeration and drying, held in Kuala Lumpur, Malaysia, from 9–11 October 1985, and presented a paper on paddy drying in Thailand.

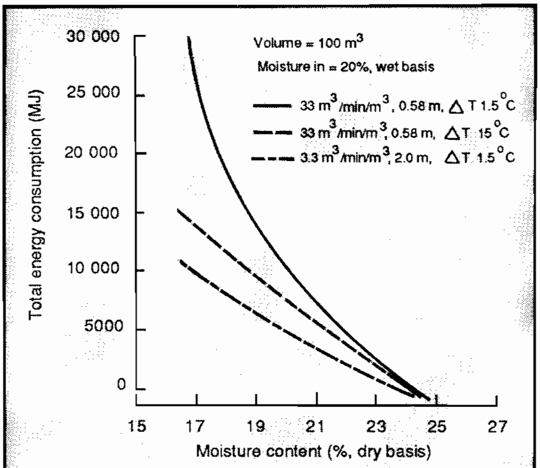
Work in Thailand during the year refined the extensive pilot drying bin studies carried out during 1984–85. The results of the initial studies were given in the research report for that year.

Energy analysis in grain drying

Energy analyses of grain drying were carried out using a mathematical model comprising various submodels, i.e., calculation of temperature rise by shaft work for driving fan, prediction of drying rate, calculation of moist air properties, prediction of dry matter loss, and prediction of grain bulk shrinkage. Predictions of drying rates and grain bulk shrinkage agreed reasonably with experimental data. The simulated results of energy analysis in grain drying show that energy utilisation in drying paddy is most efficient with low airflow rates. At high airflow rates, minimum energy consumption is obtained when the air is heated approximately 15°C. Quality assessments of paddy such as head yield and mould growth are included in the analysis.

Drying strategies

Studies in Thailand have shown that in-store drying is feasible for paddy in hot and humid climates. The recommended maximum initial moisture content is 18% w.b. Energy consumption is approximately one half that used in batch drying and quality after drying is very high. Both intermittent and continuous ventilation, together with relative humidity control, are recommended. When initial paddy moisture contents are higher than the 18% maximum value, two-stage drying is recommended. High moisture paddy should be

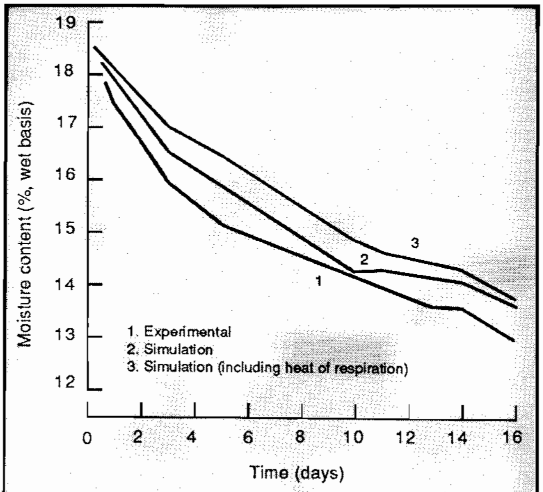


Simulation of energy consumption versus moisture content for different drying conditions.

dried rapidly with high airflow rates and temperatures, followed by in-store drying where the drying rate is relatively slow.

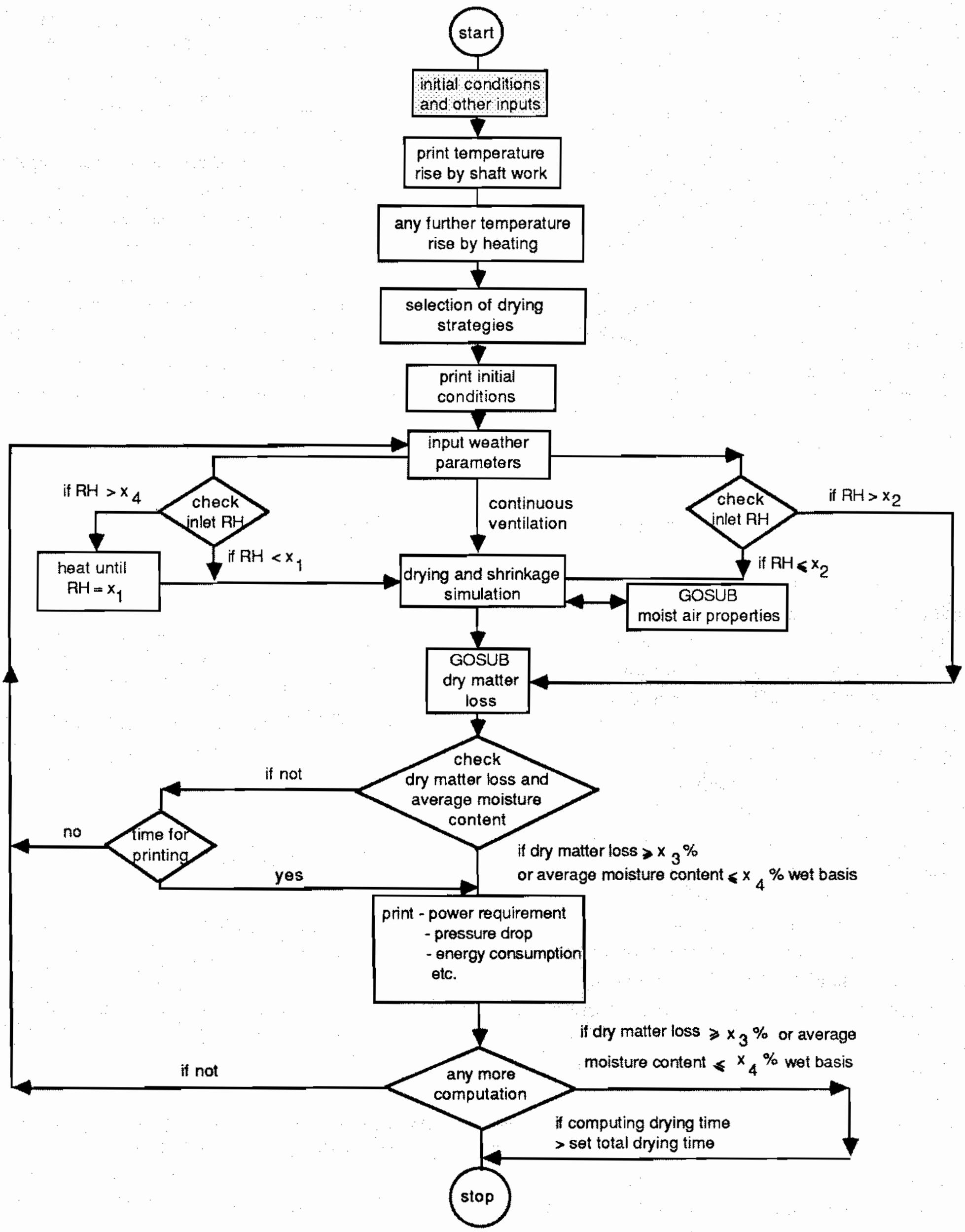
Specific conclusions are as follows:

1. Drying paddy at low airflow rates (in-store drying) consumes about one half the energy that is used in drying with high airflow rates (batch drying). Grain of high quality is obtained.
2. In hot and humid weather conditions, the maximum initial paddy moisture content should not be higher than 20% or would be better at 18% w.b. Two-stage drying (fast drying at high temperature during the first phase followed by slow drying with near-ambient air during the second phase) is recommended for commercial-scale operations, but not for small farm-scale storage (10 tonnes).
3. For paddy dried at low airflow rates (in-store drying), the drying strategy in which the fan is operated when ambient air relative humidity is less than 75% is preferable because the energy consumption is lowest. The moisture gradient is slightly higher, however, compared with the strategy of continuous ventilation with near-ambient air. The strategy of continuous ventilation, together with control of air relative humidity to not higher than 75% at the inlet of the drying bin is also of interest although the energy consumption approximates that of continuous ventilation with near-ambient air. This is due to the contribution of the supplemental heat to the total energy consumption in the former strategy.
4. For drying paddy with high airflow rates (batch drying), air should be heated to about 43–49°C. Energy consumption may be high if drying is done with near-ambient air.
5. From simulated paddy drying results, the maximum grain bed depth should be about 6 metres if the initial moisture content is limited to 18% w.b. The recommended airflow rate for the Central Plain of Thailand is 0.7 $m^3/min/m^3$ of grain. The pressure and power required for the fan are 1860 Pa and 42 W/m^3 of grain, respectively. Drying time is about 470 hours. The energy consumption is approximately 2.8 MJ/kg of water evaporated, or slightly higher if the top layer of the grain bulk has to be dried to a safe storage moisture content. The above figures are for the strategy of continuous ventilation with near-ambient air but are applicable to the strategies of continuous ventilation with control of air relative humidity, and intermittent ventilation. The operating costs of the latter two strategies are lower due to the contribution of heat lowering total energy consumption.



Comparison of simulated and measured average paddy moisture contents in a typical test run in Thailand.

6. The thermophysical properties of two varieties of long grain Thai rice have been studied. Equations describing these properties (thin layer drying rate, sorption isotherms, bulk density, specific volume, void fraction, and specific heat) have been established.
7. Heat liberated from the respiration process may be significant in the mathematical paddy drying simulation, particularly for drying with relatively low airflow rates and near-ambient air.



Flow chart of computer program written by the Thailand Project Team for simulation of paddy drying.

Projects 8309 and 8311

Integrated Use of Pesticides in Grain Storage in the Humid Tropics

Commissioned organisations — Queensland Department of Primary Industries (8309) — CSIRO Division of Entomology (8311)

Abstract

THE overall objective is to develop effective insecticide treatments for grains stored in the humid tropics. Differences were found amongst grain protectants in the effect of grain moisture content on biological activity: the pyrethroids were less adversely affected by increasing moisture than the organophosphorus compounds or carbaryl. Studies in Australia to determine minimum effective application rates on maize and paddy are complete, while similar studies in the Philippines are continuing. A survey of resistance to malathion, lindane, and phosphine in Malaysia is in progress, and acute toxicity tests have begun. Field trials of protectants have commenced on maize and paddy in Australia and the Philippines.

Background

Summary

A system of integrated use of pesticides has been developed and implemented in Australia such that losses due to insects in bulk-stored cereal grain are negligible. The research program has primarily concerned wheat stored under dry conditions. Relatively little is known of the insecticide treatments needed at higher moisture contents characteristic of the tropics, on grains such as paddy rice and maize that also have some significance in Australia. Projects 8309 and 8311 are developing effective pesticide treatments for such grains in the humid tropics. Project 8309, which is commissioned in the Queensland Department of Primary Industries, is concerned with biological and toxicological aspects of the investigations. Project 8311, which is commissioned in the CSIRO Division of Entomology, centres on chemical aspects. These activities are being carried out in cooperation with research and grain handling authorities in Malaysia and the Philippines.

A list of the collaborating institutions and research leaders follows.

- *Australia*
  Project 8309 — Queensland Department of Primary Industries, Entomology Branch
  Research Leader: Dr M. Bengston
  Project 8311 — CSIRO Division of Entomology
  Research Leader: Dr J.M. Desmarchelier
- *Malaysia*
  Malaysian Agricultural Research and Development Institute (MARDI), in collaboration with Lembaga Padi dan Beras Negara (LPN, National Paddy and Rice Authority)
  Project 8309
  Team Leader: Mr A. Rahim Muda
  LPN Collaborator: Mr Wang Yung Shyen
  Project 8311
  Team Leader: Mr Ong Seng Hock
- *Philippines*
  National Post-Harvest Institute for Research and Extension (NAPHIRE), in collaboration with the National Food Authority (NFA).
  Project 8309
  Team Leader: Mrs P. Sayaboc
  Project 8311
  Team Leader: Mr C. Mordido Jr. (to May 1986)
  Ms C. Rosario (from May 1986)

In Australia, the adverse effect of grain moisture on insecticidal activity was compared between protectant compounds and formulations. Formulation was unimportant, but there were differences between compounds: some organophosphorus insecticides were more affected by moisture than others, while the synthetic pyrethroids were less affected by moisture than the organophosphorus compounds. These data will aid the selection of appropriate protectants for grain of high moisture content. Several factors influence choice of the best protectant under high moisture conditions. Depending on the leeway allowed by maximum residue limits, it may be more economical to increase the application rate of a protectant that is sensitive to moisture, rather than switch to an alternative compound that may be more expensive. However, the results indicate that when moisture content is high, use of particular compounds such as the pyrethroids should become increasingly attractive.

Laboratory determinations of minimum effective application rates of protectants on maize and paddy rice were completed, and field trials were commenced based on the results. Trials were set up on maize at Atherton, Queensland, and on paddy rice at Home Hill. Six different protectants or protectant mixtures were applied in each trial. Samples were then taken every 6 weeks for bioassay and residue analysis during 6 months storage for maize and 9 months for paddy. Maize storage has now concluded, although analysis of samples is not complete, while paddy has been stored for 6 months. Maize treated with deltamethrin at 1 mg/kg became infested with weevils (*Sitophilus zeamais*), while moth infestations (*Ephestia cautella*) occcurred in both maize and paddy treated with methacrifos at 16 and 30 mg/kg, respectively. Future work will involve inclusion of the synergist piperonyl butoxide with deltamethrin and supplementary application of dichlorvos for moth control with methacrifos.

In Malaysia, a survey of stored product pests and insecticide resistance has continued. *Sitophilus zeamais* has proved to be the dominant weevil species, especially in milled rice. *S. oryzae* has been found in stored paddy. Resistance to both malathion and lindane has been detected.

Acute toxicity tests of protectants are continuing. Equipment has been supplied from Australia for a field trial planned to start later in 1986, subject to approval of the Malaysian regulatory authorities.

In the Philippines, acute toxicity tests of 10 protectants against four major coleopterous pests on maize and paddy were completed. Laboratory studies are continuing, in order to determine minimum effective application rates of the protectants during prolonged storage.

Field trials were commenced on maize at General Santos City in Mindanao and paddy at Santiago in Luzon. Grain in bulk was treated with insecticide and then bagged. Bagged maize was shipped from General Santos to Cebu for storage. Five protectant treatments were applied to each grain. A sixth treatment comprised 'standard pest control': that is, fumigation plus surface spraying, as currently practised in the Philippines. Samples were taken regularly for bioassay and residue analysis, during 8 months storage of maize and a planned 12 months storage of paddy. Analysis of samples is still in progress. Visual inspection of the maize stacks in July 1986 indicated that the control stacks were heavily infested with insects. Insects were also seen on some protectant treatments, but all treatments were appreciably better than the controls.

The project has already established that, because of the development of insecticide resistant strains, the insecticide malathion, commonly used in grain storage in Malaysia and the Philippines, is no longer effective. Data from trials by regional teams are now providing valuable information on a range of possible alternatives.

Expected Benefits

The results of Projects 8309 and 8311 are expected to bring the following major benefits to the region.

1. The development of systems of integrated use of pesticides that will reduce losses due to pest infestation during storage of commodities of high moisture content in humid tropical environments.
2. Acquisition of a basic understanding of the influence of grain moisture and grain species on the biological activity and residual behaviour of pesticides used to protect stored grain which, together with the local capability to design and conduct proving trials for new materials and techniques, will allow future development of storage technology based on protectants.
3. The technology developed in these projects will be applicable throughout the grain storage sectors of Malaysia and the Philippines, particularly in the central handling systems, but also in the cooperatives and village stores and, if necessary, on farms. It will also be relevant to other countries in the region, providing systems for control of pests that should be acceptable both locally and in international trade.

Project Objectives and Operational Schedules

The overall objective of the projects is to develop efficacious pest control programs for protection of grain in storage in the humid tropics. This primarily involves determining effective insecticide treatments for cereals and legumes in storage from a detailed study of the various factors that affect pesticide activity in warm, high moisture grain.

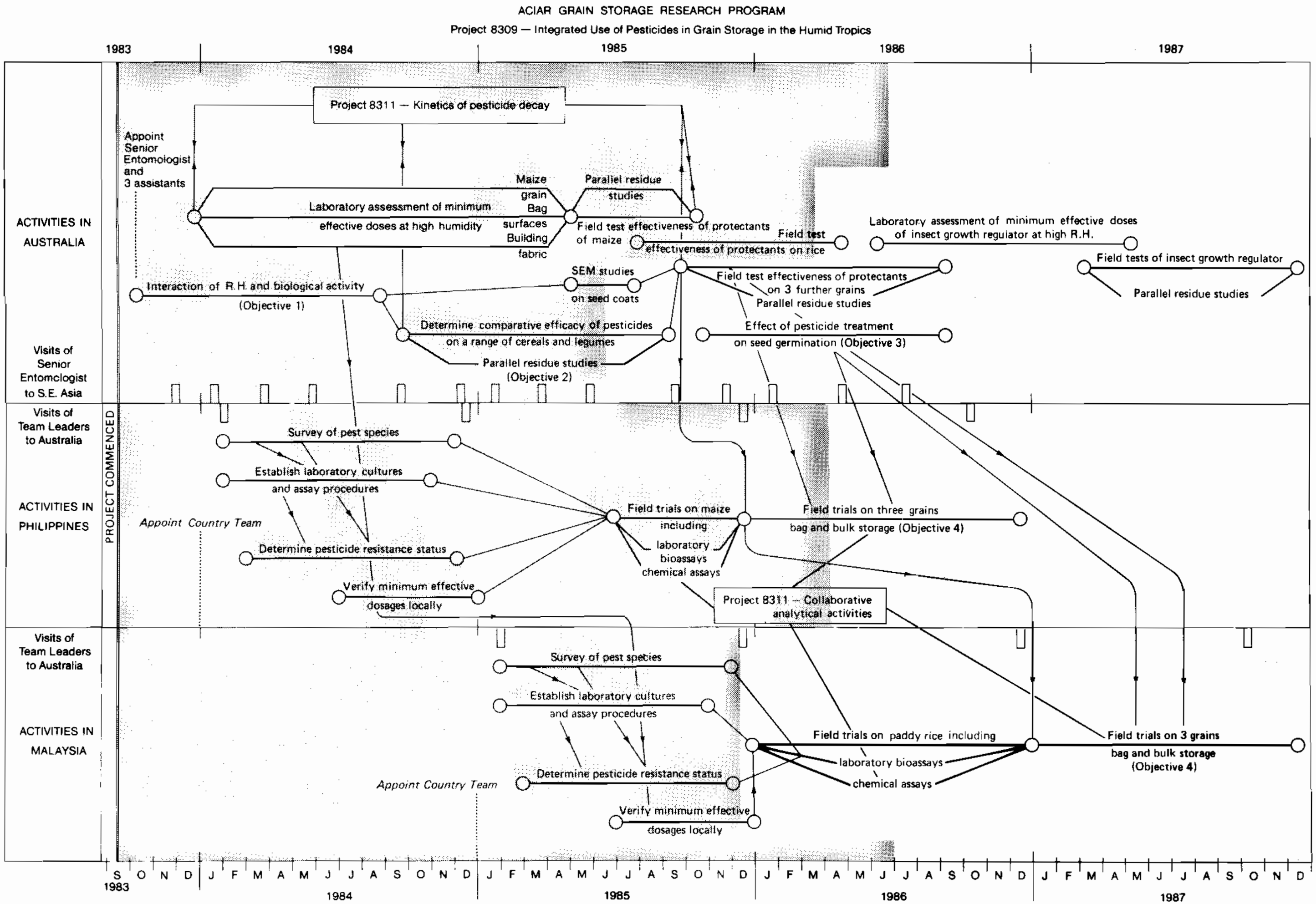
Project 8309 is concerned with biological and toxicological aspects of the study. It has the following specific objectives:

1. determination of the effect of high levels of grain moisture on the biological activity of grain protectants and fabric treatments, including treatment of bag stacks;
2. determination of the variation in the biological activity of grain protectants on a range of cereal and legume species;
3. determination of the effect of phosphine on germination of seed fumigated at high moisture levels; and
4. conduct of field trials in Australia, Malaysia, and the Philippines to evaluate fabric and grain protectant treatments developed in the project and integrated as necessary with fumigation and other control measures.

Project 8311 provides support data from a laboratory study of the kinetics of loss of insecticides during storage and processing, monitors pesticide residue behaviour, and otherwise services the chemically oriented requirements of Project 8309. All data will be unified, as far as possible, by the use of models from physical chemistry so that, in conjunction with biological data from Project 8309, correct application rates can be calculated for each commodity, having regard to storage period, temperature, relative humidity, and method of processing.

The specific objectives of Project 8311, following on from those of Project 8309, are:

5. establishment of suitable procedures for analysis;
6. determination of the effects of such parameters as temperature and moisture content on the stability of various insecticides during storage;



Research schedule — Projects 8309 and 8311 (shaded area indicates work completed)

7. determination of the effects of processing on the stability of various insecticides;
8. Conduct of laboratory studies on model compounds, relating stability in storage and processing to physical parameters such as partition coefficients; and
9. comparisons in field trials of data obtained commercially with data predicted from laboratory models.

The effective commencement dates for project activities were as follows:

- Australia — September 1983
- Malaysia — November 1984
- Philippines — January 1984

Progress according to the agreed research schedule is illustrated in the project flow diagram.

Overall, the projects are realising their original objectives according to a revised schedule that takes into account the actual commencement dates.

Organisation and Staff

The Record of Understanding between ACIAR and the Queensland Department of Primary Industries (Project 8309) was signed on 5 April 1983, and between ACIAR and CSIRO (Division of Entomology, Project 8311) on 30 July 1984. Project activities in Australia commenced in September 1983. CSIRO subcontracted to the School of Chemistry of the University of New South Wales, the laboratory studies on development of analytical techniques for grain protectants and on the kinetics of loss of these materials when applied to grain. Arrangements were finalised on 25 August 1985 and studies commenced in January 1986 with the availability of two postgraduate students, Mr J. Bryan and Mr G. Sharp. Dr P. Haddad and Dr S. Dili were nominated as their supervisors.

Arrangements in the Philippines for cooperative activities in NAPHIRE in Project 8309 were formalised on 23 August 1983, but the project did not become operational until January 1984. The agreement with CSIRO for the complementary studies in Project 8311 was signed on 30 July 1984 and became effective immediately.

In Malaysia, arrangements with MARDI for both projects were finalised on 25 November 1984.

The commencement dates for the Philippine and Malaysian components of the projects were later than anticipated because agreements between the Queensland Department of Primary Industries, CSIRO, and the overseas cooperators could not be finalised until the general agreements for ACIAR's

Grain Storage Research Program Project 8309/8311 Staff

Australia (Queensland Department of Primary Industries) Project 8309

Dr M. Bengston, Research Leader
Mr E.L. Hamacek, Laboratory Technician (from March 1986)
Ms A.L. Jones, Laboratory Technician
Ms J.A. Keating, Laboratory Technician (to January 1986)
Mr R.J. Parker, Laboratory Technician
Dr P.R. Samson, Entomologist

Australia (University of New South Wales, School of Chemistry), Project 8311

Dr P. Haddad, Supervisor
Dr S. Dili, Supervisor
Mr J. Bryan, Postgraduate Student
Mr G. Sharp, Postgraduate Student

Australia (CSIRO Division of Entomology), Project 8311

Dr J.M. Desmarchelier, Research Leader, Project 8311

Malaysia (MARDI and LPN)

Mr A. Rahim Muda, Team Leader, 8309, MARDI
Mrs Jamiah Jaafar, Technical Assistant, 8309, MARDI
Mr Jumali Juratman, Chemist, 8309, MARDI
Mr Ong Seng Hock, Team Leader, 8311, MARDI
Mr Rasali Musa, Technical Assistant, 8309, MARDI
Mrs Siti Rahmah, Research Assistant, 8311, MARDI
Mr Wang Yung Shyen, LPN Collaborator, Project 8309
Mr Zulkilfli Zainudin, Assistant Research Officer, 8311, MARDI

Philippines (NAPHIRE)

Ms Cristina P. Bautista, Team Leader, 8311 (from May 1986)
Ms Miriam A. Acda, Research Assistant (Entomologist), 8309
Mr Casimiro R. Arceo Jr., Research Aide, 8309
Mr Guillermo P. Arguilles, Laboratory Technician, 8309
Mr Felipe A. Cano Jr., Research Assistant (Engineer), 8309
Mr Alexander Joel G. Gibe, Research Assistant (Entomologist), 8309
Mr Willy M. Martin, Laboratory Technician, 8311
Mr C. Mordido Jr., Team Leader, 8311 (to May 1986)
Ms Perlina D. Sayaboc, Team Leader, 8309
Mr Rolando R. Villanueva, Research Aide, 8309

activities in each country were formalised. These delays have resulted in the operational schedules for Australia and the overseas countries being out of phase. Because of the need to retain the linkages between the Australian research personnel and their overseas counterparts throughout the full course of the 3-year schedules of the planned project work in each country, and with a prospect of further activities in integrated pest control being developed, the 3-year term in the Record of Understanding between ACIAR and the Queensland Department of Primary Industries for Project 8309 was extended to 30 June 1986 under the existing arrangements.

Ms Cristina P. Bautista replaced Mr C. Mordido Jr. as Team Leader for Project 8311 in the Philippines from May 1986.

In Australia, Miss Julie A. Keating (Project 8309) resigned as Laboratory Technician in January 1986 and was replaced by Mr Edward L. Hamacek on 3 March 1986.

Research Activities in Australia

Effect of Moisture on Biological Activity of Insecticides

The comparative effect of moisture content on the biological activity of 11 grain protectants on stored maize was measured using adults of *Tribolium castaneum* (Herbst) and *Rhyzopertha dominica* (F.). Against *T. castaneum*, the activities of emulsifiable concentrate (EC), wettable powder, and dust formulations of fenitrothion were reduced in the same proportion by increasing grain moisture in the range 10 to 18% m.c. The proportion of the residues of the three formulations that was extracted by a surface wash with solvent also declined in the same proportion as moisture increased from 10 to 28% m.c. Among five organophosphorus compounds (all EC) tested against *T. castaneum*, fenitrothion was the most adversely affected by moisture content (14 and 18% m.c.) and chlorpyrifos-methyl the least, and all were more affected than the pyrethroid deltamethrin (suspension concentrate). Against *R. dominica*, the activity of methacrifos and carbaryl (water-dispersed colloid) was much reduced at the higher moisture content, while that of five pyrethroids (all EC except deltamethrin) was slightly reduced.

Curves relating activity one day after application to moisture content in the range 10–28% were measured for chlorpyrifos-methyl, pirimiphos-methyl, and fenitrothion against *T. castaneum*, carbaryl against *R. dominica*, and deltamethrin against both species. Moisture had a considerable effect on activity of the organophosphorus compounds only above an equivalent equilibrium relative humidity of 70 to 80%. No such threshold was measured for carbaryl, an increase in moisture having a considerable effect on activity even when the grain was quite dry. The effect of moisture on the activity of deltamethrin was significant but relatively small, particularly against *T. castaneum.*

Application Rates for Protectants for Paddy Rice and Maize

Experiments to determine minimum effective application rates of 10 protectants on paddy rice and maize were completed. These rates were defined according to their ability to prevent the production of progeny of several test insect species in samples taken at different times after treatment. The estimates were used to set application rates for field testing.

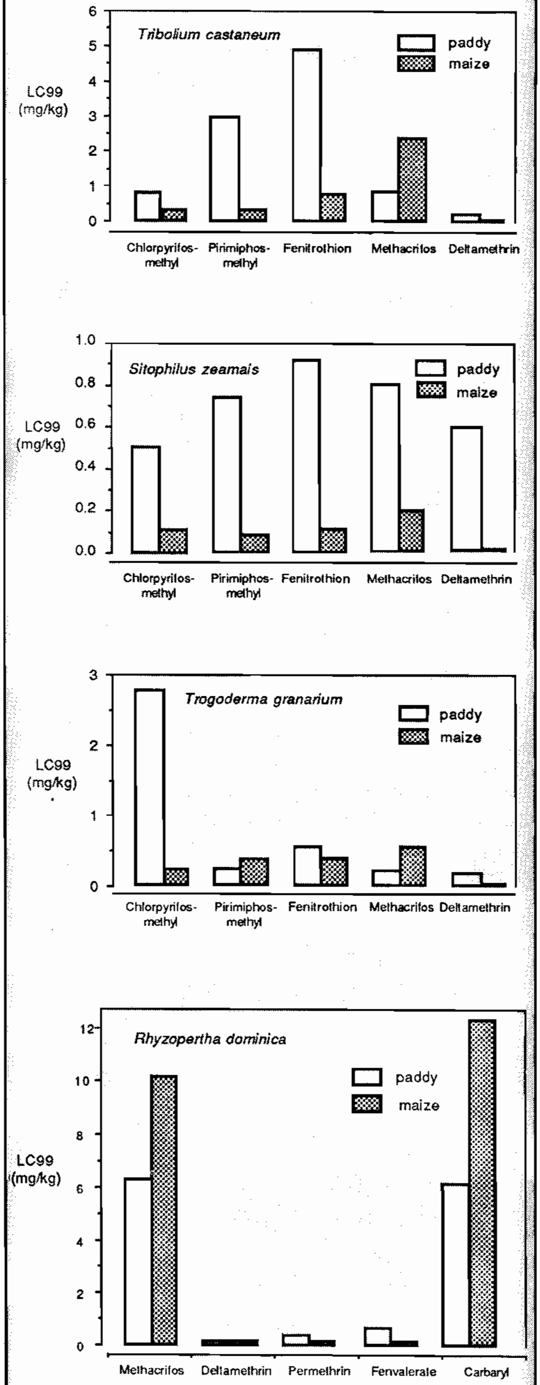
Field Trials on Paddy Rice and Maize in Tropical Queensland

Six different protectant treatments were applied to paddy rice at Home Hill, as listed in Table 1. Samples for biological assay and residue analysis (Project 8311) were taken every 6 weeks during 6 months storage, with a final sample to be taken after 9 months. Some moth pupae were observed in the methacrifos treatment after 6 months storage. Staining of rice milled from the storage bin treated with the combination fenitrothion plus permethrin plus piperonyl butoxide is to be investigated. Milled samples of all treatments have been sent to the CSIRO Wheat Research Unit (Project 8314) for quality assessment.

Six different protectants or protectant mixtures were applied to maize bins at Atherton, as listed in Table 2. Samples were taken from each bin every 6 weeks during a total of 6 months storage. An infestation of *Sitophilus zeamais* in the deltamethrin treatment necessitated fumigation of the bin. Moths (*Ephestia cautella*) on the surface of the methacrifos bin required surface sprays of first fenitrothion, and subsequently dichlorvos, for control.

Comparative Effectiveness of Protectants on Cereals and Legumes

In an extension to an earlier study of the comparative effectiveness of a range of protectants on wheat, maize, and paddy rice, an investigation has now commenced of the effectiveness of fenitro-



Comparative toxicities on paddy and maize of eight protectants to four grain pest species.

thion on a range of grains, including cereals and legumes. Effectiveness is measured shortly after application at two moisture contents and again after 3 months storage at the lower moisture content. An attempt will be made to correlate efficacy with physical characteristics of the grain kernels, supplemented by scanning election microscope studies.

Analytical Methods for Grain Protectants

A review of the analytical chemistry of grain protectants has been prepared.

Development of multi-residue methods for analysis of grain protectants on paddy has been completed. This has involved extraction studies, a minimal clean-up with Sep-pak cartridges where required, and determination of the protectants by both reversed phase high performance liquid chromatography using an ultraviolet detector and capillary gas-liquid chromatography using a flame ionisation detector. As with wheat, polar solvents such as methanol are required for complete extraction of organophosphorus insecticides.

Preliminary studies on multi-residue analytical methods for other cereals, legumes, and oil seeds indicate that the methods for paddy are suitable for maize, mung beans, soy beans, and with difficulty, for sunflowers.

Kinetics of Decay

A study on the kinetics of loss of insecticides on paddy is largely completed. The benefits of partially cooling grain, e.g. from 35° to 25°C, are apparent from this study, for insecticides such as fenitrothion, chlorpyrifos-methyl, and carbaryl.

Research Activities in Southeast Asia

Overall project activities in Southeast Asia are meeting the original objectives according to the timetable revised to account for actual commencement dates. The major field trials in the Philippines are in progress and the necessary initial laboratory work is under way in Malaysia.

The resistance survey in Malaysia confirms earlier findings in the Philippines: resistance to malathion is present in virtually all populations of *Tribolium castaneum*, and alternative insecticide treatments are required urgently.

It is too early to assess the results of the field trials, as bioassay results and residue analyses are not complete. However, application rates of some protectants may prove to have been too low. In that case further trials using adjusted application rates would be desirable.

Table 1. Bins of paddy treated with grain protectants at Home Hill, Australia. All bins were horizontal, of steel construction, and aerated.

Treatment		Date treated	Quantity of grain treated (tonnes)
Chlorpyrifos-methyl	10 mg/kg	7, 8 Jan. 1986	350
+ fenvalerate	0.5 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		
Fenitrothion	25 mg/kg	9, 10 Jan. 1986	350
+ bioresmethrin	1 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		
Pirimiphos-methyl	15 mg/kg	14–17, 20, 21 Jan. 1986	980
+ carbaryl	10 mg/kg		
Fenitrothion	25 mg/kg	22–24, 28–31 Jan. 1986	1000
+ permethrin	1 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		
Methacrifos	30 mg/kg	31 Jan., 3, 4 Feb. 1986	350
Pirimiphos-methyl	15 mg/kg	4–6 Feb. 1986	300
+ *d*-phenothrin	1 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		

Table 2. Bins of maize treated with grain protectants at Atherton, Australia. All bins were vertical, of concrete construction, and aerated.

Treatment		Date treated	Quantity of grain treated (tonnes)
Pirimiphos-methyl	6 mg/kg	1–3 Oct. 1985	570
+ carbaryl	8 mg/kg		
Chlorpyrifos-methyl	10 mg/kg	4–9 Oct. 1985	570
+ fenvalerate	0.5 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		
Fenitrothion	12 mg/kg	7–11 Oct. 1985	600
+ bioresmethrin	1 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		
Deltamethrin	1 mg/kg	10–15 Oct. 1985	570
Methacrifos	16 mg/kg	14–17 Oct. 1985	620
Chlorpyrifos-methyl	10 mg/kg	21–24 Oct. 1985	620
+ permethrin	1 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		

There is considerable concern in Southeast Asia about the safety of residues on insecticide-treated grain. This must be overcome by information and education.

Mr A. Rahim Muda (MARDI) and Mrs Miriam Acda [formerly Amoranto] (NAPHIRE) from Project 8309 each visited Australia for two weeks from 12–26 April 1986 and 10–24 May 1986, respectively. Both spent time in the Queensland Department of Primary Industries at Indooroopilly and visited field trial sites in northern Queensland.

Malaysia

The Australian Project Entomologist, Dr P.R. Samson, visited MARDI from 9–17 September 1985 to assist with laboratory studies. He made further visits from 15–17 December 1985 and 23–27 June 1986 during the course of the resistance and acute toxicity testing.

The Malaysian Team Leaders of Projects 8309 and 8311, Mr A. Rahim Muda and Mr Ong Seng Hock, attended the 8th ASEAN Technical Seminar on Grain Post-Harvest Technology held in Manila from 6–9 August 1985 and the GASGA/ACIAR/LPN/MARDI/AFHB Seminar on Preserving Grain Quality by Aeration and In-store Drying held in Kuala Lumpur from 9–11 October 1985. Mr Wang Yung Shyen also attended the latter seminar.

Survey of pesticide resistance

Studies were continued to determine the resistance of major coleopterous pests to the residual insecticides malathion and lindane and the fumigant phosphine. All strains of *Tribolium castaneum* were resistant to malathion, which has been in use for more than 20 years. Two strains showed potential for cross-resistance to other organophosphorus insecticides. Two strains of *Sitophilus zeamais* were resistant to malathion. Resistance to lindane was found in all strains tested. There were indications of slight phosphine resistance in *T. castaneum.*

The specific identity of *Sitophilus* strains was determined by dissection of genitalia. Most were *S. zeamais* but two strains were *S. oryzae*. The former were found in milled rice warehouses, and the latter in paddy.

Minimum effective application rates on paddy rice

Acute toxicity tests were commenced of commercial formulations of grain protectants applied to paddy rice to control selected strains of major pest species.

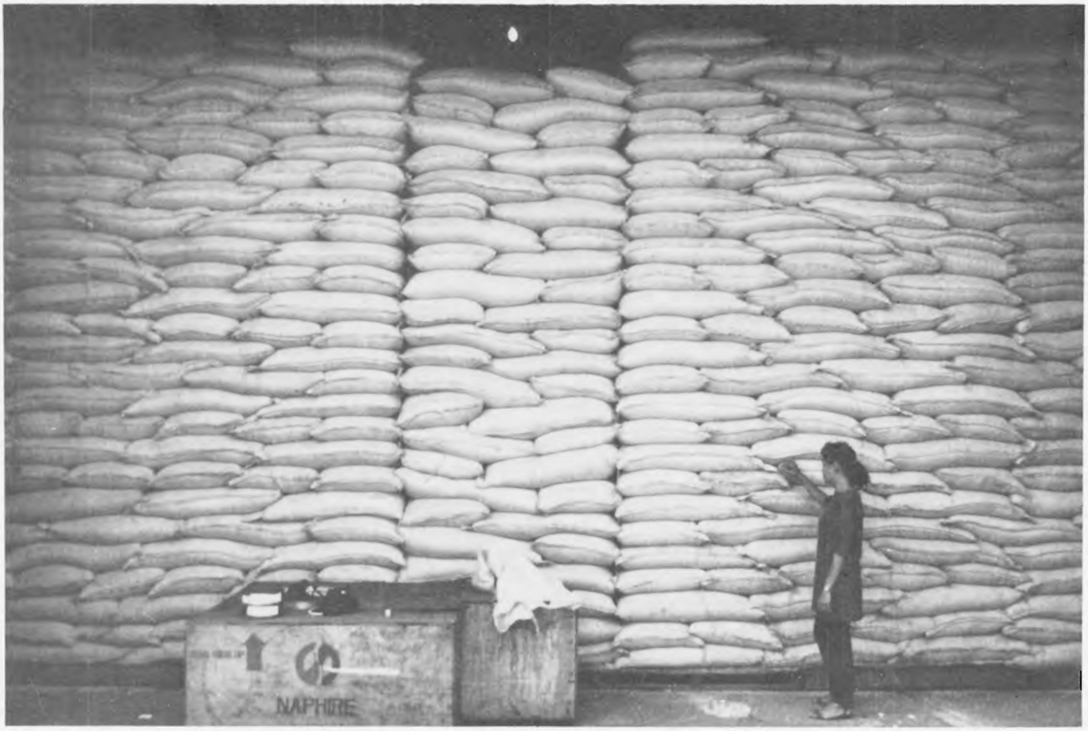
Use of an adapted vacuum cleaner to sample maize treated with protectants at Atherton in the north of Queensland.

Table 3. Toxicity to insect pests of various grain protectants applied to maize

Grain protectant	LC$_{50}$ (mg/kg)				LC$_{99}$ (mg/kg)			
	T. castaneum	*S. zeamais*	*R. dominica*	*T. granarium*	*T. castaneum*	*S. zeamais*	*R. dominica*	*T. granarium*
Chlorpyrifos-methyl	0.23	0.06	—	0.05	0.34	0.11	—	0.19
Pirimiphos-methyl	0.09	0.04	—	0.03	0.32	0.09	—	0.37
Fenitrothion	0.23	0.05	—	0.05	0.74	0.13	—	0.37
Methacrifos	0.72	0.10	1.65	0.06	2.40	0.21	10.05	0.53
Deltamethrin	0.03	0.03	0.01	0.02	0.06	0.06	0.02	0.10
Permethrin	—	—	0.06	—	—	—	0.14	—
Fenvalerate	—	—	0.04	—	—	—	0.18	—
Bioresmethrin	—	—	0.11	—	—	—	0.33	—
d-Phenothrin	—	—	1.11	—	—	—	0.28	—
Carbaryl	—	—	1:75	—	—	—	12.20	—

Table 4. Toxicity to insect pests of various grain protectants applied to paddy

Grain protectant	LC$_{50}$ (mg/kg)				LC$_{99}$ (mg/kg)			
	T. castaneum	*S. zeamais*	*R. dominica*	*T. granarium*	*T. castaneum*	*S. zeamais*	*R. dominica*	*T. granarium*
Chlorpyrifos-methyl	0.41	0.14	—	0.60	0.84	0.51	—	2.80
Pirimiphos-methyl	1.20	0.25	—	0.11	2.90	0.75	—	0.27
Fenitrothion	1.00	0.27	—	0.21	5.00	0.92	—	0.58
Methacrifos	0.19	0.19	2.10	0.15	0.81	0.81	6.30	0.21
Deltamethrin	0.06	0.11	0.01	0.01	0.24	0.62	0.08	0.17
Permethrin	—	—	0.06	—	—	—	0.35	—
Fenvalerate	—	—	0.08	—	—	—	0.58	—
Carbaryl	—	—	1.75	—	—	—	6.20	—



Mrs Perlina Sayaboc, Philippine Team Leader for Project 8309 inspects a stack of protectant-treated maize at Cebu City.

Field trials

A spray pump, a supply of carbaryl, and grain sampling equipment were shipped to Malaysia from Australia in preparation for a field trial on paddy rice, planned to start later in 1986.

Philippines

The Australian Project Entomologist, Dr P.R. Samson, visited the Philippines from 24 August to 8 September 1985 to assist the NAPHIRE team in establishing a field trial on maize at General Santos City, Mindanao, and Cebu City. He again visited the Philippine team from 2–14 December 1985 to assist in establishing a field trial on paddy at Santiago, Isabela. From 16–22 June 1986, he inspected the maize from the field trial stored at Cebu City and visited the new NAPHIRE laboratory at Munoz.

The Philippine Team Leaders of Projects 8309 and 8311, Mrs P. Sayaboc and Mr C. Mordido Jr., attended the 8th ASEAN Technical Seminar on Grain Post-Harvest Technology held in Manila from 6–9 August 1985.

Survey of pesticide resistance

The nationwide survey to identify populations of *Rhyzopertha dominica, Sitophilus zeamais,* and *Tribolium castaneum* that were resistant to malathion and pirimiphos methyl continued.

As reported earlier, all 61 populations of *T. castaneum* that were tested were resistant to malathion, whereas all 38 populations of the dominant weevil, *S. zeamais*, were susceptible to both malathion and pirimiphos methyl. Further testing of *R. dominica* revealed a total of 9 out of 11 populations resistant to malathion, including one population resistant to pirimiphos methyl.

The *T. castaneum* populations tested showed high levels of resistance to malathion ($\times 25-\times 423$ at the KD_{50}) and a degree of resistance to pirimiphos methyl ($\times 6$ at the KD_{50} and $\times 3$ at the $KD_{99.9}$). Populations of *R. dominica* were found to have a moderate level of resistance to malathion ($\times 9$ and $\times 11$ at the KD_{50} and $\times 5$ and $\times 15$ at the $KD_{99.9}$) and low levels of resistance to pirimiphos methyl ($\times 2$ at the KD_{50} and $\times 4$ at the $KD_{99.9}$).

Table 5. Maize treated with grain protectants at General Santos City, Mindanao.

Treatment		Date treated	Quantity of grain treated (tonnes)
Chlorpyrifos-methyl	10 mg/kg	31 Aug.–1 Sept. 1985	253
+ permethrin	1 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		
Fenitrothion	12 mg/kg	2, 3 Sept. 1985	266
+ fenvalerate	0.5 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		
Pirimiphos-methyl	6 mg/kg	4, 5 Sept. 1985	276
+ carbaryl	8 mg/kg		
Methacrifos	20 mg/kg	5, 6 Sept. 1985	258
Deltamethrin	1 mg/kg	6, 7 Sept. 1985	260

Table 6. Paddy treated with grain protectants at Santiago, Isabela.

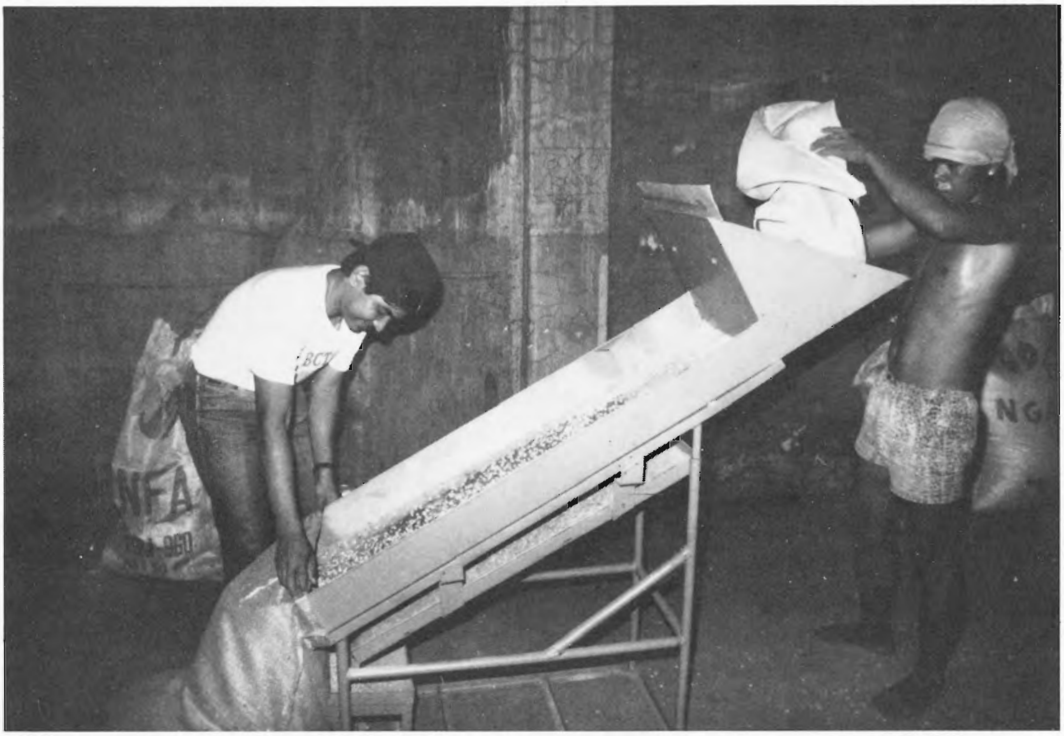
Treatment		Date treated	Quantity of grain treated (tonnes)
Chlorpyrifos-methyl	10 mg/kg	7, 8 Dec. 1985	208
+ permethrin	1 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		
Fenitrothion	25 mg/kg	9, 10 Dec. 1985	207
+ fenvalerate	0.5 mg/kg		
+ piperonyl butoxide	8 mg(A.I.)/kg		
Pirimiphos-methyl	15 mg/kg	6, 7 Dec. 1985	211
+ carbaryl	10 mg/kg		
Methacrifos	20 mg/kg	5 Dec. 1985	206
Deltamethrin	1 mg/kg	10, 11 Dec. 1985	206

Minimum effective application rates on maize and paddy rice

Toxicities of freshly applied deposits of 10 grain protectants to four major coleopterous pests on maize and paddy rice are given in Tables 3 and 4. *Sitophilus zeamais* was more responsive to organophosphorus compounds than was *Tribolium castaneum*, but less responsive to deltamethrin. Of the four insect species tested using methacrifos and deltamethrin, *Rhyzopertha dominica* was the least responsive to methacrifos and the most responsive to deltamethrin. *d*-Phenothrin seemed the least potent of the pyrethroids tested against *R. dominica*. Protectants generally had high activity against *Trogoderma granarium*. Higher application rates of most protectants were needed on paddy than on maize to give the same insect response. Laboratory studies were continued, in order to determine minimum effective application rates of the protectants during 9 months storage of maize and paddy.

Field trials

A field trial of protectants on maize was carried out at General Santos City, Mindanao, with the five treatments listed in Table 5. A sixth treatment,



Sampling bags of protectant-treated maize at Cebu City, using an inclined sieve sampler.

representing 'standard pest control' (fumigation plus surface sprays of residual insecticide), was included as a control. Treated grain was bagged and shipped to Cebu City for stacking. Thermocouples were built into each stack for temperature measurement. Samples were taken at 6 week intervals from marked bags (36/stack) for bioassay and residue analysis (Project 8311). Final sampling after 8 months storage was done in July 1986. The control stack was heavily infested by this time, and all treatments appeared to give significantly improved insect control.

A field trial of protectants on paddy was carried out at Santiago, Isabela, as listed in Table 6. Methods were similar to those used on maize at General Santos, during a planned storage of 12 months.

Project 8310

Moisture Movement in Grain

Commissioned organisation — CSIRO Division of Chemical and Wood Technology

Abstract

ONE of the principal objectives of Project 8310 is to gain an understanding of the fundamental physical and biological phenomena that cause moisture migration in stored grains. Through intensive numerical analysis, considerable progress has been made towards meeting this objective, and mathematical models of moisture movement caused by free convection have been developed. Experimental and theoretical studies of moisture migration under forced convection are well advanced. Results from the fundamental studies are, in addition, of practical significance to ACIAR work on long-term storage of grain under plastic covers (Project 8307) and on drying in bulk storage of high moisture grains in tropical climates (Project 8308).

Background

Summary

When food grains are stored in bags or bulk, moisture migration from warm to cool regions may cause serious spoilage of the commodity. In those tropical regions in which grains are harvested warm and possibly wet, conditions are almost ideal for the proliferation of insect pests and microflora. There is a pressing need to design cost-effective systems for delivering, drying, and storing damp grains.

The realisation of economically optimal systems will be considerably assisted by a good understanding of the basic physical, chemical, and biological phenomena that occur in stored grains. One of the main aims of Project 8310 is to provide this understanding. To date, mathematical models have been developed that, for the first time, can quantify the effects of free convection on moisture movement in grains. Moisture migration is driven essentially by temperature gradients, which are accentuated by biological activity, such as the respiration of insects and microflora. Respiration also adds to the mass of free water within the systems. Mathematical models developed during the course of Project 8310 can now take account of respiration of microflora. Expressions for the rates of decay of chemical pesticides have also been incorporated into the models.

The models have been used to investigate alternative physical configurations of different moisture content grains stored in a range of different temperature environments. The models indicate the amount of dry matter loss and pesticide decay that occur during the different storage regimes, and this represents a first step to the economic optimisation of the construction and operation of non-aèrated grain stores.

Theoretical and laboratory studies on the important problem of moisture movement in aerated grain stores are continuing. This work is also important in the optimal design of grain handling and storage systems. A commercial prototype solar grain cooler has been fabricated, and experiments on its performance are being conducted in Australia by an ACIAR/ADAB Graduate Research Fellow.

Laboratory experiments have been carried out that show that 19% moisture content paddy may be dried to 14% moisture content by heating it in a fluidised bed for about 7 minutes. In this energy efficient process, the loss of milling yield is negligible. Theoretical studies on residence time distributions in continuous-flow fluidised beds complement the laboratory experiments. It has been shown that decreasing dispersion in fluidised beds improves their thermodynamic efficiency and, all things being equal, is likely to result in higher milling yields of dried paddy.

Other studies have involved statistical analyses of climatic data in tropical regions, energy requirements for cooling and drying grains, and fundamental studies on sorption in grains and the fluid mechanics of grain storage systems.

Expected Benefits

Long-term storage of grain and other foodstuffs under plastic covers is potentially a very useful and cost-effective method of maintaining strategic reserves of these commodities in good condition. Because of high ambient temperatures and humidities, storage conditions must be defined precisely. The studies outlined here will enable adequate definition of the storage parameters and design of storage systems that minimise losses due to moisture problems. The information will be equally relevant to short-term storage of high moisture grain whether stored in bags or bulk.

Project Objectives and Operational Schedule

Project 8310 was designed to provide basic research support for other more applied projects in the ACIAR Grain Storage Research Program, particularly Project 8307 which is concerned with long-term storage of grain under plastic covers. The basic information available on moisture movement in grain was inadequate to enable reliable storage systems to be designed for the grain moisture contents typical of the humid tropics.

The objectives of the project are:

1. To conduct extensive experiments on heat and moisture transfer by natural convection in porous hygroscopic media.
2. To carry out numerical analyses of buoyancy forces in grain bulks, and determine their influence on the micro-environment.
3. To study the distribution of fumigants in non-aerated grain stores.
4. To study the effects of aeration on moisture movement within grain stores, with particular emphasis on moisture distribution near the walls of the grain stores. In so far as the thermodynamic state of the grain affects the rate of pesticide decay and biological behaviour, this aspect of the project relies on data generated by Projects 8309 and 8311.

5. To carry out full-scale field trials of promising improved storage methods and monitor, in conjunction with Project 8307, their performance as measured by grain quality and insect population indices.
6. To adopt a systems approach to the handling and storage of grain to minimise the harmful effects of moisture migration, and to ensure that grains can be stored with minimal loss of quality.

Progress according to the agreed research schedule is illustrated in an accompanying flow diagram. It is expected that the project will be completed by September 1986.

Organisation and Staff

The Record of Understanding between ACIAR and CSIRO on Project 8310 was signed on 3 May 1983. The project gained full momentum after the appointment of Dr T.V. Nguyen as a Research Fellow on 5 December 1983 and, with the appointment of Mr S.G. Wilson on 5 March 1984 and the part-time secondment of Mr T.F. Ghaly as Experimental Scientists to the project, work has proceeded on schedule.

In addition to the above ACIAR-funded staff, considerable inputs to Project 8310 have been provided by Dr A.J. Hunter (fluid mechanics of airflow through grain and moisture sorption phenomena) and Mr J.W. Sutherland (mathematical modelling and methods of rapidly drying grain).

From February 1986 the effort on Project 8310 was further augmented by two ACIAR/ADAB Graduate Research Students, Mr R. Cachuela from the Philippines and Mr Z. Ismail from Malaysia. Mr Cachuela is jointly supervised by Dr D.E. Angus of the University of Melbourne and Dr T.V. Nguyen of the CSIRO. His studies are concerned with the experimental validation of free convective heat and mass transfer in grains. To date, a box-shaped enclosure has been designed and partially constructed. The enclosure can be fitted with a combination of walls that can be electrically heated, thermally insulated, or cooled by a temperature controlled refrigerated water supply. The aim of the experiments is to fill the enclosure with grains and other porous media and observe a variety of transient heating modes in the granular material.

Mr Ismail is carrying out an experimental evaluation of a commercial prototype solar grain cooler. A 5.5 m^2 solar cooler has been fabricated and installed at Highett. Preliminary tests began recently.

Grain Storage Research Program

Project 8310 Staff

CSIRO Division of Chemical and Wood Technology

Mr R. Cachuela, ACIAR/ADAB Graduate Research Fellow
Mr T.F. Ghaly, Experimental Scientist
Dr A.J. Hunter, Principal Research Scientist
Mr Z. Ismail, ACIAR/ADAB Graduate Research Fellow
Dr T.V. Nguyen, Research Fellow
Mr J.W. Sutherland, Experimental Scientist
Dr G.R. Thorpe, Research Leader
Mr S.G. Wilson, Experimental Scientist

Research Activities

Studies in this research support project have been centred in the CSIRO laboratories at Highett in Victoria to take advantage of the facilities available there and the opportunities for collaboration with other researchers engaged in closely related studies at the CSIRO Division of Energy Technology. Nevertheless, there has been significant involvement in program activities in Southeast Asia.

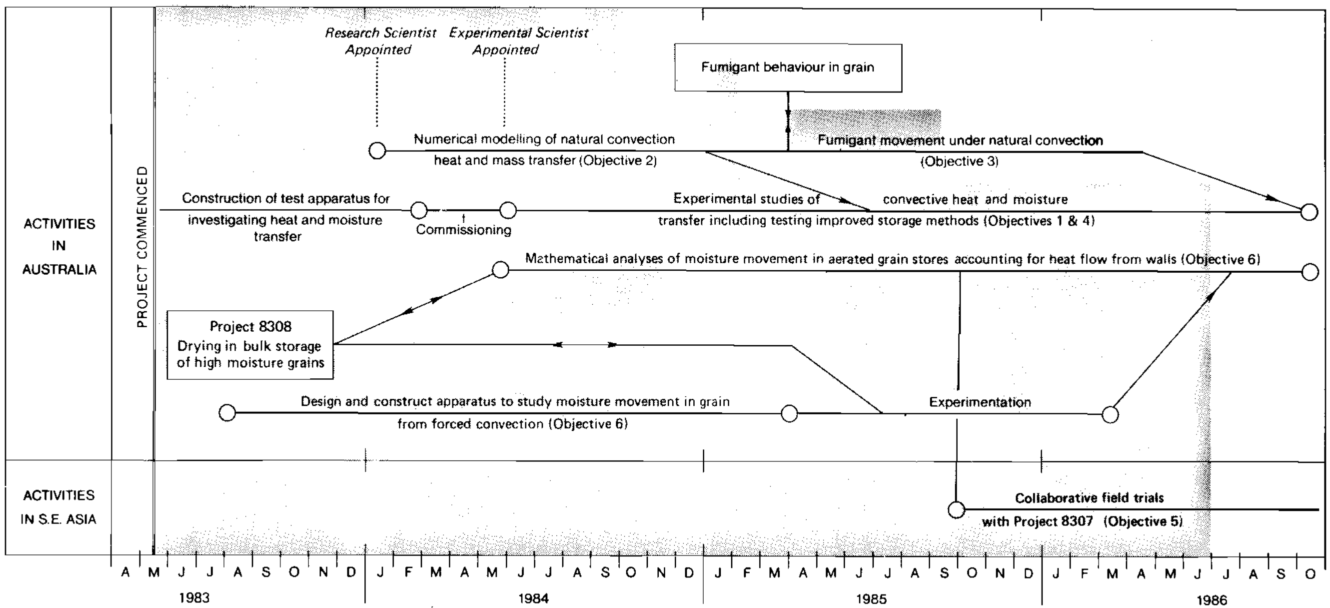
Dr A.J. Hunter, Dr T.V. Nguyen, Dr G.R. Thorpe, and Mr J.W. Sutherland participated in the GASGA/ACIAR/LPN/MARDI/AFHB Seminar on 'Preserving Grain Quality by Aeration and In-store Drying' which was held in Kuala Lumpur from 9–11 October 1985. Dr Thorpe presented a paper on 'Some fundamental principles and benefits of aeration of stored grain', Dr Nguyen a paper on 'Modelling temperature and moisture changes resulting from natural convection in grain stores', Dr Hunter a paper on 'Design of air distribution systems and fan selection for grain aeration', and Mr Sutherland a paper on 'Grain aeration in Australia'.

Mr S.G. Wilson visited Project 8307 staff in Malaysia, the Philippines, and Thailand in May 1986 for discussions on field validation of the models developed in Project 8310 and to explore possible collaborative activities on grain cooling.

In Australia, Dr T.V. Nguyen presented a paper on 'Transient heat transfer in porous media — a two temperature model' at the Computational Techniques and Applications Conference held in Melbourne in August 1985. Mr T.F. Ghaly presented a joint paper with Mr J.W. van der Touw on 'Heat sensitivities of two varieties of rough rice' at the 35th Australian Cereal Chemistry Confer-

ACIAR GRAIN STORAGE RESEARCH PROGRAM

Project 8310 — Moisture Movement in Grain



Research schedule — Project 8310 (shaded area indicates work completed)

ence of the Royal Australian Chemical Institute held in Sydney from 30 September to 3 October 1985.

Mathematical Modelling of Natural Convection

Considerable progress has been made on the understanding of the fundamental mechanisms of moisture migration and fumigant movements in stored cereal grains. Mathematical models, using a number of highly efficient numerical methods, have been developed and tested to cover a wide range of applications, as follows:

Heat and mass transfer in hygroscopic porous media

Moisture migration, airflow patterns, and temperature distributions have been obtained for various grain storages. For a rectangular bin partially filled with warm grain, the complex processes of heat and mass transfer across the porous interface have been solved. The results are shown in Figure 1. The cores of the convection cells develop and reside in the air gap, and the flow penetration into the grain results in regions of cool grain at the top surface (Fig. 1(b)). The moisture taken from these outer regions by the warm air is deposited in the central region as shown in Figure 1(c). Figure 2 shows results for a bagged stack of paddy in a cool room. The stack is not sealed and air flows freely around it, but follows a more tortuous path through the stack as a result of high temperature gradients along the vertical sides. After one week of storage, only paddy at the outer top regions (Fig. 2(b)) is cooled by the convection currents. The other areas along the boundaries are affected by conduction. The moisture distribution in Figure 2(c) shows various regions of wet and dry paddy resulting from natural convection.

Movement of fumigants in bulk grain

Fumigation of sealed storages mainly relies on free convective currents to distribute the gas. Present studies on the flow patterns and temperature distributions in grain stores of different shapes and sizes under various boundary conditions offer insights into the phenomenon that should help to improve the fumigation processes.

Respiration of grain

Heat of respiration, as a function of temperature and moisture content, has been incorporated into the time-dependent numerical models to predict the movement of moisture and the resulting spoilage.

Pesticide decay

The concentration of pesticide in grain depends on grain temperature and moisture content. The rate of pesticide decay and the pesticide concentration in a non-aerated grain store have been calculated by the predicted temperature and moisture changes. Plots of streamlines, isotherms, moisture distribution, and malathion concentration for a typical sealed storage with grain initially at 30°C and 14% moisture content are shown in Figure 3.

Design of bunker storages

Simulations of grain bunkers show the observed accumulation of moisture in the top regions. Experimentation on the shape of bunkers and boundary conditions in order to reduce the convection currents and eliminate moisture transfer is being carried out.

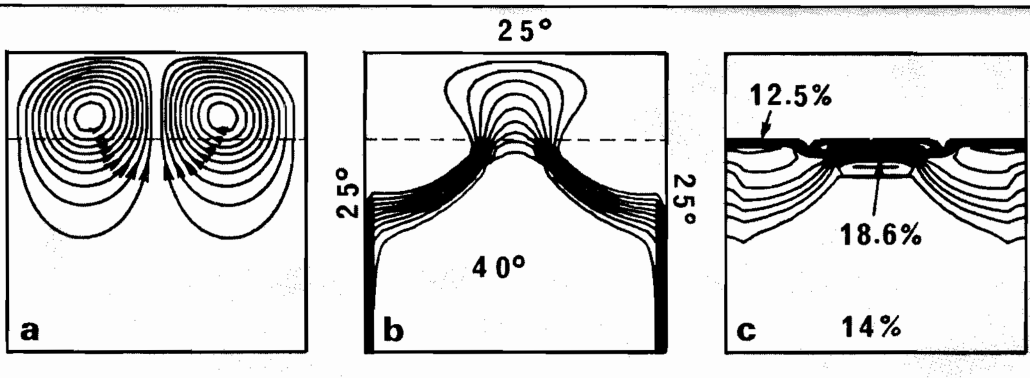


Figure 1. Conditions inside a grain store with headspace after 3 months of storage: (a) streamlines; (b) isotherms; and (c) moisture distribution.

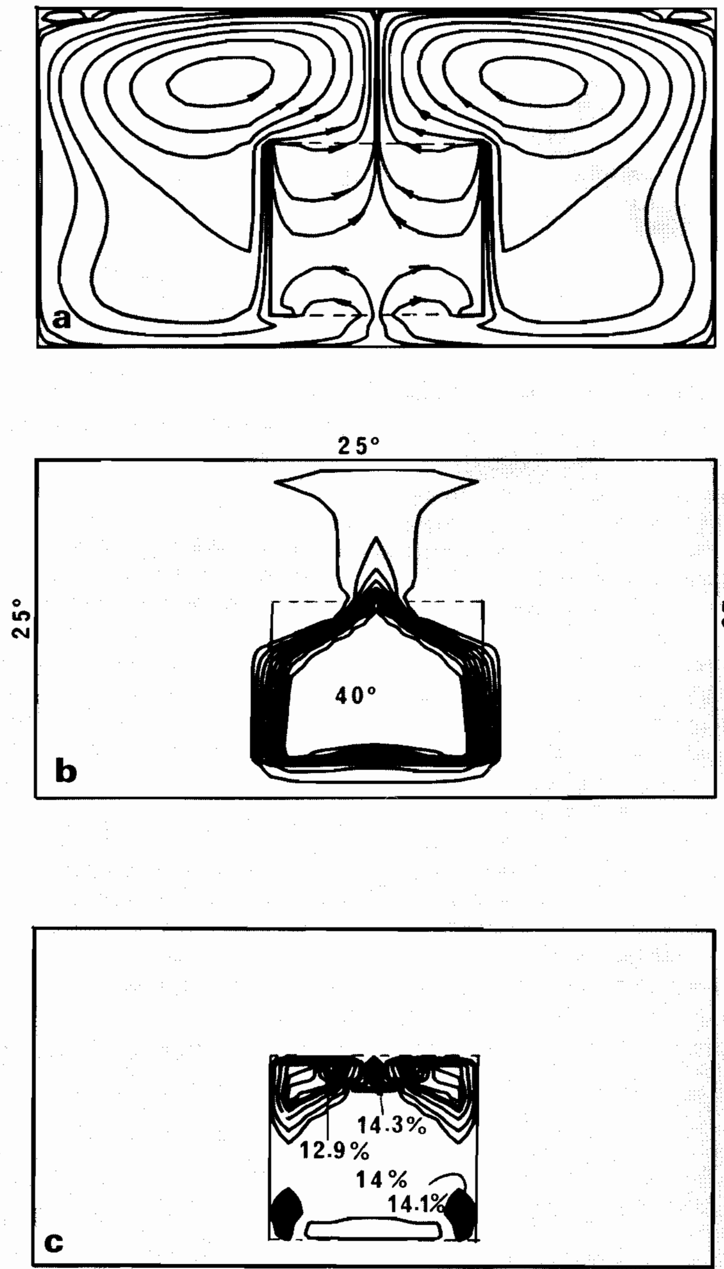


Figure 2. Conditions in and around a bagged stack of paddy in a cool room after 1 week of storage: (a) streamlines; (b) isotherms; and (c) moisture distribution.

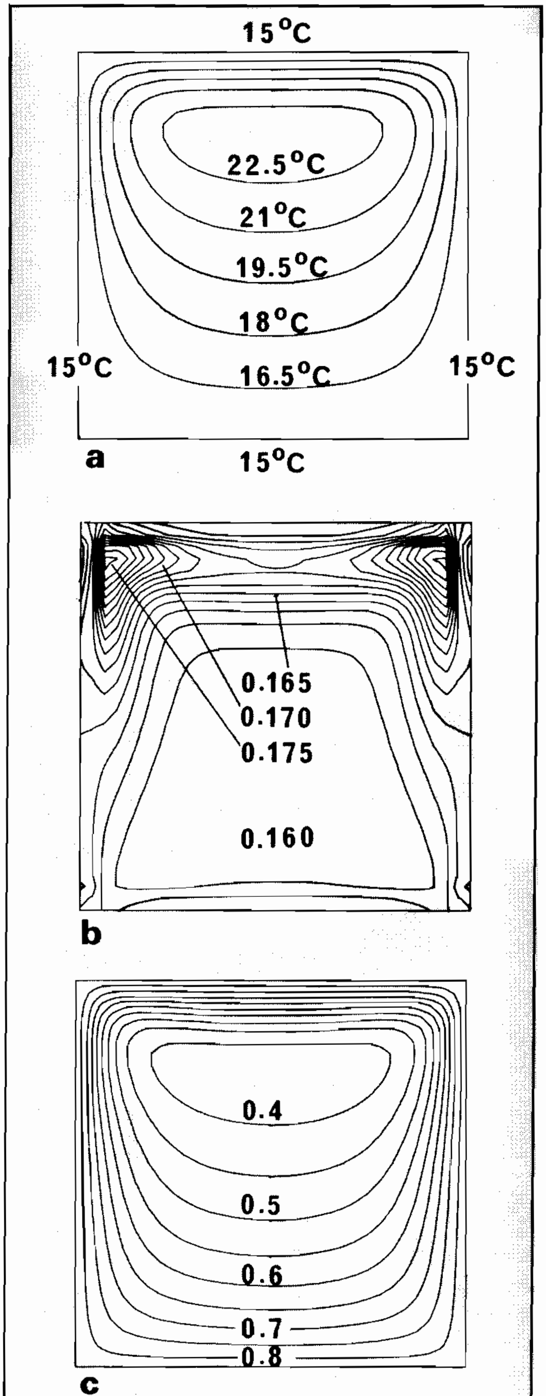


Figure 3. Conditions inside a bulk of warm grain in a cool environment after 75 days storage: (a) isotherms; (b) moisture distribution; and (c) malathion concentration.

Studies of Forced Convection

Research on forced convection over the past year has involved both modelling and experimental work.

Modelling

Equations describing the rate of forced-convection heat and moisture transfer inside a cylinder have been derived. They are:

Energy balance

$$\frac{\delta T}{\delta t} = \frac{1}{Pe*}\nabla^2_{ax}T - \frac{(\rho C_p)_f}{(\rho C_p)^*}v.\nabla T$$

$$- \frac{\rho_f \frac{dh}{dw}}{(\rho C_p)^*\Delta}v.\nabla w$$

$$- \frac{\rho_s(1-\epsilon)\frac{dH}{dw}}{(\rho C_p)^*\nabla T}\frac{dW}{dt} - \frac{\rho_f\epsilon\frac{dh}{dw}}{(\rho C_p)^*\nabla T}\frac{\delta w}{\delta t}$$

[Transient term = Diffusion of sensible heat – Convection of sensible heat – Convection of latent heat – Latent heat due to moisture transfer from grain – Latent heat due to moisture transfer from air.]

Grain moisture balance

$$\frac{dW}{dt} = \frac{Dk}{U_0}(W_e - W)$$

[Transient term = Thin-layer drying equation describing the rate of inter-grain kernel water vapour diffusion.]

where

k is the rate coefficient, usually defined by an Arrhenius equation, e.g. for Australian paddy

$$k = 12.58\ e^{-3650/T^1}$$

W_e is the equilibrium grain moisture content, usually defined by a sorption isotherm equation

Air moisture balance

$$\frac{\delta w}{\delta t} = \frac{D^*_{water}}{U_0 D}\nabla^2_{ax}w - \gamma\frac{dW}{dt} - \frac{1}{\epsilon}v.\nabla w$$

[Transient term = Diffusion of moisture in air – Moisture transfer from grain – Convection of moisture.]

A finite-difference simulation program has been written to solve these equations. Typical results for a cooling simulation where the side walls are heated and cold air is blown into the cylinder are given in Figure 4. The air inlet condition was 15°C and 0.005 kg water per kg dry air, with an inlet velocity of 20 mm per second. The walls were maintained at 30°C and initial conditions in the paddy were 35°C and 0.19 kg water per kg dry grain.

Solving these equations for grain drying conditions involves considerable difficulties which have now been overcome. These difficulties arise for two reasons.

1. As the above equations describe non-equilibrium heat and moisture transfer, both moisture condensation and air humidities above saturation are possible. (These processes also occur in the real world, but it is not possible to simulate them properly with non-equilibrium models.) In order to model condensation and to prevent supersaturation, the air-water saturation condition must therefore be imposed upon the above equations.
2. The air moisture balance equation involves a source term and the usual finite-difference extrapolation techniques for obtaining boundary values therefore cannot be used. This situation is further complicated by the steep temperature and moisture gradients next to the side-wall. The wall has the lowest temperature in the solution field, so it is a prime site for condensation. Specialised solution procedures have therefore been developed for the wall, centre-line, and outlet boundaries.

Experimental work

The thermal boundary layer experimental apparatus has been completely rebuilt and now includes an open-circuit wind tunnel allowing a uniform velocity profile to be maintained at the cylinder entrance. This will not only enable more carefully controlled forced-convection heat and moisture transfer experiments but may also permit experiments with mixed forced and free convection to be undertaken.

List of Symbols

C_p	specific heat capacity at constant pressure (kJ/kg °C)
D	diameter (m)
D*	air-water mass diffusivity (m^2/sec)
h	air enthalpy (kJ/kg)
H	grain enthalpy (kJ/kg)
k	intra-grain kernel moisture transfer rate coefficient (sec^{-1})
k*	effective conductivity of the air-grain continuum (kJ/m °C sec)
P	kernel density (kg/m^3)
Pe*	Peclet number (dimensionless) = ρC_p v D/k*
T	temperature (dimensionless)
T′	temperature (K)
t	time (dimensionless)
U	axial velocity
v	superficial axial velocity (dimensionless)
v_0	superficial axial inlet velocity (m/sec)
w	air absolute humidity (kg water/kg dry air)
W	grain moisture content (kg water/kg dry grain)
∇T	characteristic temperature difference (°C)
∇	Grad (spatial gradient) (m^{-1})
∇^2_{ax}	axisymmetric Laplacian operator (m^{-2})
ϵ	porosity (dimensionless)
γ	capacity ratio = $P(1-\epsilon)/\rho\,\epsilon$
ρ	density (kg/m^3)
Subscripts	
e	equilibrium
f	fluid
o	inlet condition solid (grain)
Superscript	
*	air-grain continuum

Rapid Drying of Paddy

Progress has been made in both experimental and theoretical studies of the drying of paddy. The experimental studies have been aimed at devising strategies for the very rapid drying of paddy in fluidised beds, and the theoretical studies have elucidated the effects of dispersion of solids in such equipment.

In the laboratory studies, freshly harvested Calrose (medium grain rice) of 18.9% moisture content (wet basis), was dried in a small batch fluidised-bed rig to approximately 14%, using intermittent drying and tempering. Air-drying temperatures of 45, 50, 55, 60, and 65°C and total heating periods of between 7.2 and 17.7 minutes, depending on the temperature, were used. The results of these studies showed that the total amount of actual heating time was substantially reduced (by 72–80%) when intermittent drying and tempering were used instead of continuous drying.

In continuous-flow fluidised beds the solids residence time exhibits dispersion about the mean. This affects the thermal efficiency of drying processes and, because some grains may have a long residence time, this could have a deleterious effect

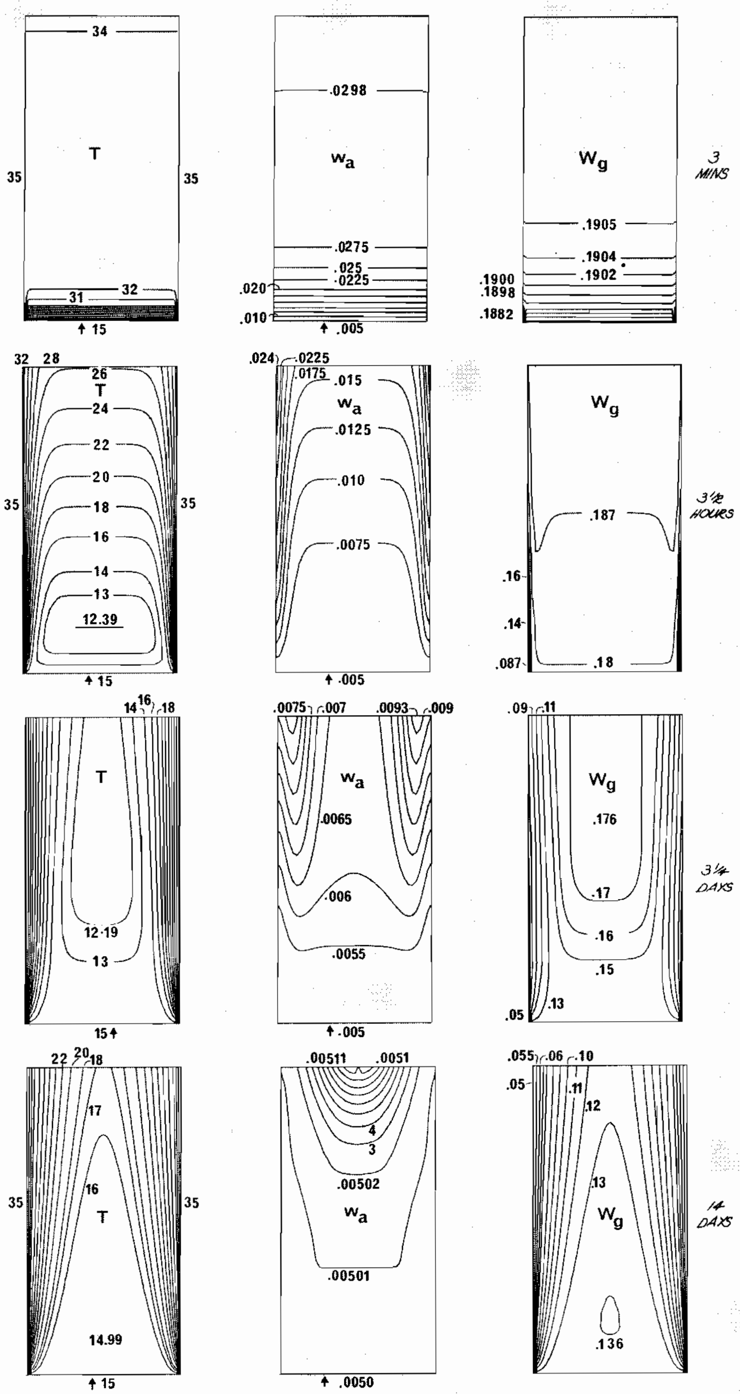


Figure 4. Formation of thermal and moisture boundary layers inside a cylinder of stored paddy. See text for initial air and paddy conditions. T = temperature; w_a = air absolute humidity; and W_g = grain moisture content.

on grain quality. Expressions for the probability density functions of solids moisture content have been derived for a multi-stage fluidised-bed dryer. In addition, a simple and elegant recurrence relationship for the moments of moisture content distribution has also been derived. The analysis has been applied to the drying of cereal grains and it has shown how the degree of drying and hence thermodynamic efficiency increases with decreasing dispersion. Furthermore, all things being equal, decreasing the degree of dispersion is expected to lead to an improvement in grain quality.

Sorption Studies

Quantification of sorption properties of food grains is of fundamental importance in mathematical modelling of heat and mass transfer processes. As part of the project studies, a generalised expression has been derived that enables the relative humidity of air (hence its absolute moisture content) in thermodynamic equilibrium with grain of arbitrary temperature and moisture content to be calculated.

The expression takes the form

$$r = r_0\left(\frac{p_s}{p_0}\right)^{\frac{h_s}{h_v} - 1}$$

where r and p_s are the relative humidity of air and saturated vapour pressure of water, respectively. The constants r_0 and p_0 are empirical constants, whilst the ratio of the heat of sorption on grain to the latent heat of free water is calculated from

$$\frac{h_s}{h_v} = 1 + \frac{(c_1 \ln (c_2 W) - c_3 W)^{c_4} (c_5 \ln (c_6 w))}{(1 + (c_3 W))^{c_4}}$$

where W is the moisture content of the grains and c_1 to c_6 are further grain-specific empirical constants.

Project 8314

Effect of Controlled Atmospheres on Quality of Stored Grains

Commissioned organisation — CSIRO Wheat Research Unit

Abstract

This project examines the effects on grain quality of storage under controlled atmospheres, particularly those with high contents of carbon dioxide. It also provides quality testing services for other projects in the ACIAR Grain Storage Research Program. Results show that storage under carbon dioxide/air mixtures causes premature yellowing of milled rice and white maize, particularly at high storage moisture contents. The results are well described by a conventional chemical rate equation. The rate of yellowing in stored paddy is comparable with the rate of yellowing in stored milled rice. Sorghum viability is severely reduced by long storage under 60% carbon dioxide in air, whereas preliminary results with mung and soybeans indicate that carbon dioxide atmospheres are better for storage than storage in air.

Background

Summary

Each year, large amounts of grain and other products stored in stacks of bagged commodity are damaged by insects. To prevent this, CSIRO has developed technology for controlling insect infestations by storing bagged products in controlled atmospheres under plastic covers (Project 8307).

Project 8314 is designed to determine how oxygen and carbon dioxide tensions in the storage atmosphere interact with temperature and moisture and the effects these interactions have on the quality of the commodities in storage. This information will determine the conditions required for safe storage of the commodities and the modifications necessary to existing systems to achieve this. The data will also be used for developing models for heat and moisture balance that will enable extension of the technology into storage of commodities in bulk.

Differences in the retention of quality under different atmospheres may take many months to become apparent at the storage temperatures normally encountered in the tropics. Some form of accelerated storage test is thus highly desirable to quantify, in a reasonable time, the effects of controlled atmospheres on the quality of grain. A systematic study of the combined effects of atmospheric composition, temperature, and relative humidity on the quality of various grains during storage is in progress. The temperatures used in the study are above the normal range encountered in storage in the humid tropics. It is assumed that the changes observed will parallel those that occur more slowly under normal storage conditions. This assumption has yet to be tested thoroughly.

The research is being carried out in Australia and the Philippines. In Australia, the research is being conducted at the CSIRO Wheat Research Unit, where extensive storage trials, under strictly controlled conditions, are in progress with a range of commodities, including two varieties of rice (paddy and milled), white maize, sorghum, soybeans (two cultivars), mung beans, coffee, cocoa, and some spices. Objective testing of all stored grains is being done in Australia, but the vitally important organoleptic and quality testing of rice and maize is being done in the Philippines at the National Post-Harvest Institute for Research and Extension (NAPHIRE). Similar quality testing is also being carried out for other projects operating in the Philippines in the ACIAR Grain Storage Research Program.

Experiments on storage of rice, maize, and sorghum under a range of oxygen and carbon dioxide concentrations are well under way. The results show that storage under carbon dioxide/air mixtures causes premature yellowing of milled rice and white maize, particularly at higher storage moisture. The results are well described by a conventional chemical rate equation. The rate of yellowing in stored paddy is comparable with the rate of yellowing in stored milled rice. Crude fibre contents of paddy, milled rice, or maize were not altered by storage at elevated temperatures considered equivalent to several years normal storage. Sorghum viability is severely reduced by long storage under 60% carbon dioxide in air. Preliminary results from the storage of mung and soybeans have shown that carbon dioxide atmospheres are better for storage than is air.

Future research will determine whether the similarities between varieties currently assessed are general or cultivar dependent, and if growth environment has a significant effect on storage potential. Developments in technology have provided the means to automate many of the labour-intensive test methods used, particularly in the rice industry. Some effort will be expended to determine if these methods would simplify current analytical procedures.

Expected Benefits

1. Development of a quantitative understanding of the interaction of atmosphere composition, temperature, and water activity on the quality of commodities in storage. This information is necessary for efficient and safe utilisation of the storage technology being developed in ACIAR Project 8307 on Long Term Storage of Grain under Plastic Covers, which is being conducted by the CSIRO Division of Entomology.
2. Acquisition of basic data for integration into models of heat and moisture environments in storages (ACIAR Project 8310 on Moisture Movement in Grain) to allow further development of the technology.
3. The activities in the Philippines will provide a model for a quality testing facility to support continuing research programs in that country.

Project Objectives and Operational Schedule

This project is designed primarily to provide basic support to ACIAR Project 8307 on Long Term Storage of Grain under Plastic Covers and to provide data and a grain quality testing facility for other projects in the ACIAR Grain Storage Research Program.

The specific objectives of the project include the following:

1. Determination of the influence of oxygen and carbon dioxide tension in the storage atmosphere, in combination with temperature and water activity, on the viability and end-use parameters of stored grains, spices, and pulses.
2. Provision of these data in a form which can be integrated in an overall model of heat and moisture balance in storage systems.
3. Examination of the relationship between water production and various storage gases (including phosphine) during storage in closed systems.
4. Provision of grain quality testing facilities for other projects in the ACIAR Grain Storage Research Program.

All storage experiments are being carried out in Australia. Quality evaluations are being made in Australia and the Philippines.

The commodities concerned are eight grains, three spices, three pulses, and two coffees. Samples of these of known moisture provenance are being subjected to controlled atmospheres at elevated temperatures which simulate longer term storage at the particular moisture level. The experimental conditions are as follows:

Temperatures:	30, 35, 47, and 60°C
Humidities:	40, 60, 80, and perhaps 90%
Atmospheres:	0.2% oxygen, balance nitrogen
	2% oxygen, balance nitrogen
	21% oxygen, balance nitrogen (i.e. air)
	100% oxygen
	7.5% carbon dioxide, 8.4% oxygen, balance nitrogen
	15% carbon dioxide, 8.4% oxygen, balance nitrogen
	30% carbon dioxide, 8.4% oxygen, balance nitrogen
	60% carbon dioxide, 8.4% oxygen, balance nitrogen

The maximum proposed range of experiments is given in an accompanying table.

After storage for the maximum practicable periods, commodities are being tested in collaboration with the research team in the Philippines for quality characteristics related to the end-use of each commodity. These characteristics, which include quality standards currently used by the Philippine National Food Authority, are germination, colour, milling yield, moisture content, cooking characteristics, and microbial activity.

Thirty of the storage experiments have been completed or are under way. These are indicated in the accompanying table. Progress according to the agreed research schedule is illustrated in the project flow diagram. The schedule was interrupted because of the need to calculate equilibrium moisture contents at the proposed moisture conditions but has now been resumed.

Organisation and Staff

The Record of Understanding between ACIAR and CSIRO was signed on 11 July 1984.

Dr P. Gras and Dr I. Batey were nominated by CSIRO as joint Research Leaders. The CSIRO Wheat Research Unit also nominated Mr M. Bason, an Experimental Scientist, to be responsible for conduct of experimental work in Australia and Miss Alison Morris, Technical Assistant, to support these activities. Further laboratory assistance was provided by Miss Rhonda Foley, who was employed part-time during 1985, and by three students, Miss Christine Brown, Miss Claire Hampton, and Miss Belinda Nissen, who were employed during the vacation period. Miss Sharee McCammon joined the project as a Technical Assistant in March 1986.

The Memorandum of Agreement between ACIAR and the Philippine Council for Agriculture and Resources Research and Development for

Grain Storage Research Program
Project 8314 Staff

CSIRO Wheat Research Unit

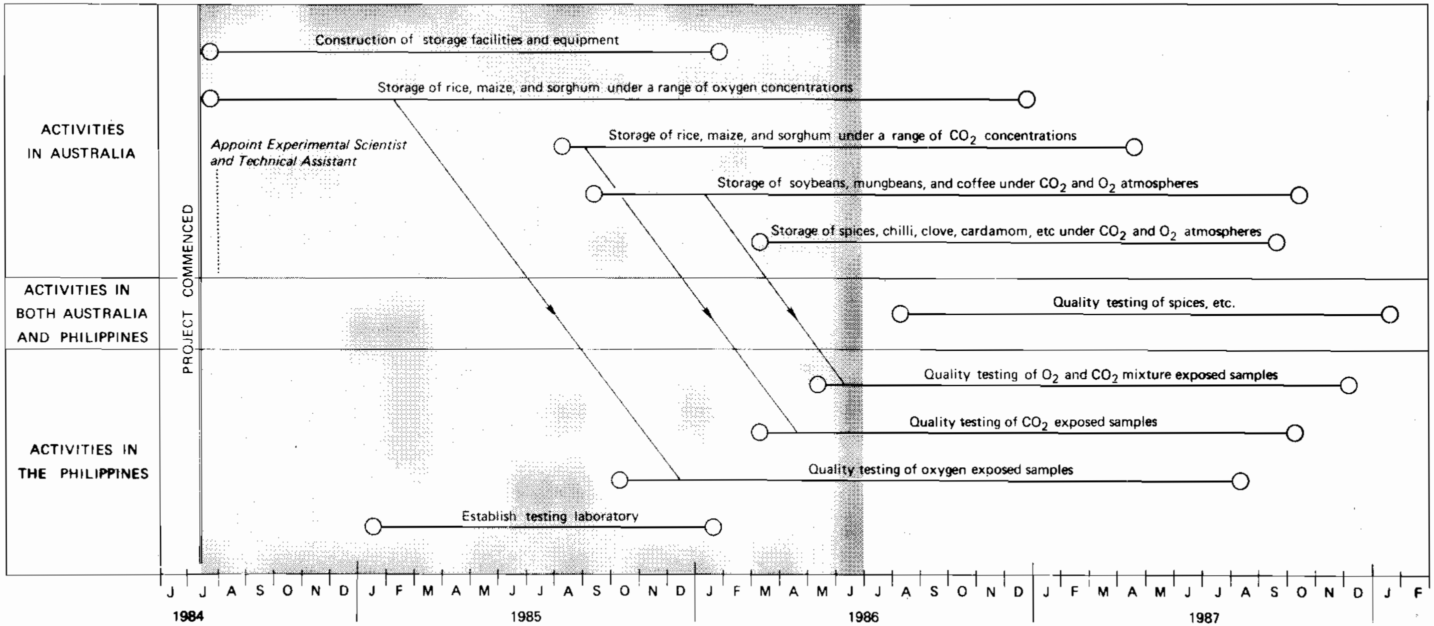
Mr M. Bason, Experimental Scientist
Dr I. Batey } Research Leaders
Dr P. Gras }
Miss A. Morris, Technical Assistant
Miss S. McCammon, Technical Assistant (from March 1986)
Miss R. Foley, Laboratory Assistant (part-time 1985)
Miss C. Brown, Vacation Student
Miss C. Hampton, Vacation Student
Miss B. Nissen, Vacation Student

NAPHIRE

Mr C. Mordido, Jr., Team Leader (to May 1986)
Miss L.P. Arriola, Team Leader (from May 1986)

ACIAR GRAIN STORAGE RESEARCH PROGRAM

Project 8314 – Effects of Controlled Atmospheres on Quality of Stored Grains



Research schedule — Project 8314 (shaded area indicates work completed)

collaborative activities with NAPHIRE was finalised on 14 July 1984. NAPHIRE nominated Mr Cris Mordido Jr. as Team Leader in the Philippines. Miss L.P. Arriola replaced Mr Mordido as Team Leader in May 1986.

Research Activities in Australia and Southeast Asia

The Australian Research Leader, Dr P. Gras, visited Malaysia from 11–24 January 1986 to discuss sampling techniques and to review project progress. He visited the Philippines from 24 May to 7 June 1986 to assist in the reorganisation of project activities associated with the move of NAPHIRE to its new laboratories at Munoz in Nueva Ecija.

Grain Moisture Content Determination

Preliminary storage experiments have revealed the need to set the grain moisture content at its equilibrium for the proposed storage conditions before storing it at those conditions. As a result, the equilibrium moisture contents of the various grains at the proposed experimental conditions are currently being determined. Before grain is exposed to the experimental storage conditions, it is conditioned to the appropriate moisture content, as determined from those determinations.

Effect of Controlled Atmospheres on Quality of Rice and Maize

Experiments on storage of rice and maize under a range of oxygen and carbon dioxide concentrations are in progress. Similar storage regimes are being examined for mung and soybeans. Sorghum has been examined also for a limited range of oxygen atmospheres.

Preliminary results suggest that storage under carbon dioxide/air mixtures causes premature yellowing of milled rice and white maize, particularly at high storage moistures.

Crude fibre contents of paddy, milled rice, and maize were not altered by storage at elevated temperatures considered equivalent to several years normal storage. Sorghum viability is severely reduced by storage under 60% carbon dioxide in air at elevated temperatures.

Proposed grains and conditions for controlled atmosphere storage experiments. Proposed experiments are indicated by a cross; experiments under way or completed are indicated by a value denoting the moisture content (wet basis) of the grain.

Temperature (°C)		30			35			47			60	
Relative humidity (%)	40	60	80	40	60	80	40	60	80	40	60	80
Rice												
Paddy Pelde		×	×		12.0	×	×	11.5	15.0	×	9.3	
Milled Pelde		×	×		12.9	15.5	9.5	12.1	×	×	10.5	
Paddy Calrose		×	×		12.3	×	9.0	12.0	×	×	9.7	
Milled Calrose		×	×		13.2	×	9.5	13.1	×	×	10.4	
Maize												
Manning White		×	×		12.6	14.7	×	11.1	×	×	10.4	
Hickory King						15.3		×				
Cornflake (hybrid XL94)						14.9		×				
Other												
Sorghum					14.0						×	
Soybean cv. Forrest		×	×		10.1	×	×	×	×	×	9.4	
Soybean cv. Davis		×	×		9.8	×	×	×	×	×	8.7	
Mung Bean cv. Berken		×	×		11.3	×	×	×	×	×	10.3	
Coffee (Arabica)					×	×			×		×	×
Coffee (Robusta)					×	×			×		×	×
Spices												
Chilli					×	×			×		×	×
Cardamom					×	×			×		×	×
Cloves					×	×			×		×	×

Yellowing

Experiments on the storage of milled and paddy rice and white maize under atmospheres containing a range of oxygen concentrations are well advanced, and experiments on the same grains under a range of carbon dioxide concentrations have been commenced. The experiments of most significance are those at 30° and 35°C, and the changes required for proper interpretation are larger than those anticipated in the field. Consequently, the most important data take the longest time to acquire, and are typically not yet available. Nevertheless, preliminary indications show an acceleration of yellowing in milled rice under carbon dioxide at 80% equilibrium relative humidity. At 60% R.H., colour changes, as measured with a Hunterlab colour difference meter, show a steady increase in colour (b-value) with time. Although apparently slightly dependent on oxygen concentration, the major process appears to be predominantly moisture and grain dependent. Much better data should be available in the next six months. Nevertheless, regression analysis of the rate of colour change as a function of the reciprocal of absolute temperature shows an excellent fit to the observed data, and this has been taken to mean that the yellowing observed at high temperatures is the same process as occurs more slowly in rice at normal storage temperatures. Analysis of the Arrhenius plots of the rate of change of colour suggests a process with an activation energy of about 190 kJ/mole. On this basis, a change of one Hunterlab 'b-value' in the colour of milled rice can be expected in the times set out in the Table 1. How this can be related to change in grade for rice grading systems in the Philippines, Malaysia, and other countries must be the subject of further research.

Table 1. Observed and calculated times for milled Calrose rice to change in colour by one Hunterlab 'b' unit, in days at 60% equilibrium R.H. Asterisks denote calculated values.

Temperature of storage (°C)	Time for colour change by 1 b unit (days)
20	289*
25	162*
30	91
35	53
60	4.4

Viability

Determinations of the effects of gas concentrations, temperature, and storage humidity on the viability of stored grain have not been completed. Preliminary examination of the results shows a consistent reduction in viability in grain stored under 60% carbon dioxide in air, especially at high values of equilibrium R.H. Detailed analysis of the results will have to await the completion of further experiments, mostly at 30°C and 35°C.

Crude fibre content

Paddy rice, milled rice (cv. Calrose and cv. Pelde), and three varieties of maize (cv. Manning White, Hickory King, and an experimental yellow hybrid maize) have been stored at 60°C and 60% R.H. for periods of 7 and 45 days, specifically to test for changes in crude fibre content during storage. Atmospheres used were 0.2% oxygen in nitrogen, air, and 60% carbon dioxide in air. (This regimen is considered to be equivalent to storage for periods of about one and five years at 30°C.) No detectable differences in crude fibre content could be found between the zero time, 7-day, and 45-day samples for any of the grains tested in any atmosphere. This was not unexpected, and confirms that changes in fibre content are not expected in grain stored under controlled atmospheres. It may be supposed that changes in grain crude fibre contents noted in some countries may be the result of preferential consumption of the less fibrous parts of the stored grain by insect pests.

Germination of Sorghum

Experiments on the storage of sorghum under a range of oxygen concentrations have been temporarily suspended. Germination of sorghum (the only quality parameter tested) was dramatically reduced by storage under 60% carbon dioxide in air, but was little affected by differing oxygen contents. Further work will be done with a range of carbon dioxide concentrations. Storage of sorghum for seed purposes under carbon dioxide enriched atmospheres is therefore not recommended until further work can be completed.

Mung and Soybeans

Mung and soybeans are currently being stored under the ranges of oxygen and carbon dioxide concentrations. Some preliminary results are expected in the next six months.

Project 8344

Bulk Handling of Paddy and Rice in Malaysia: an Economic Analysis

Commissioned organisation — South Australian Department of Agriculture

Abstract

The basic aim of this project is to develop a model of the Malaysian rice economy which integrates all components of the paddy and rice handling industry. To meet this objective, a model has been developed and specified and has been validated using test data. The model is currently being evaluated empirically using observed data from the Tanjung Kerang area of North-West Selangor. This preliminary physical and economic database relating to the current situation is being updated by the Malaysian organisations involved. The data, together with other model refinements, will be used in a preliminary analysis of optimal paddy and rice flows and location of handling facilities. Extensions of the basic model to include capital and labour substitution effects as technologies in handling change, and an analysis of alternative paddy pricing systems, are in progress.

Background

Summary

Malaysia currently produces about 75% of its rice needs, and could move closer to self-sufficiency if avoidable postharvest losses were reduced. Malaysian institutions involved in the handling and milling of paddy and the distribution of rice believe that the introduction of innovations in handling paddy, coupled with an improved grading system, will reduce losses significantly. The innovations envisaged include the use of bulk handling equipment, more efficient drying equipment, and increased milling capacity to reduce delays before milling. The Malaysian authorities, in planning investments in handling facilities, are also confronted with the complex and recurring problem of determining the most efficient locational pattern, number, and size of procurement centres, drying plants, and rice mills. Against this background, the Malaysian Government, through its Economic Planning Unit, requested assistance from and collaboration with Australian institutions in researching the optimal postharvest storage, handling, drying, and grading requirements for their rice industry.

A collaborative project was developed between the South Australian Department of Agriculture, Universiti Pertanian Malaysia (UPM), and the Malaysian National Paddy and Rice Authority (LPN) to provide appropriate methodology for analysis of the rice industry and so enable objective recommendations to be made on matters relating to procurement, transportation, and storage, particularly as related to bulk handling.

The core component of the project is the development and specification of a mathematical programming model. This work is being carried out by the South Australian Department of Agriculture in Adelaide.

A Malaysian research team is responsible for assembly of the database and for placing the data in a form suitable for subsequent processing in the model. In addition, it is envisaged that the model developed in Australia will be implemented as soon as possible on a suitable computing system in Malaysia.

The two-year project commenced on schedule, on 1 July 1985. In Malaysia, pre-commencement planning and visits to Malaysia by the Project Director in February 1985 enabled the project to be fully operational immediately. Considerable momentum has been built up and it is very pleasing to note that five papers have already been delivered at international symposia and workshops. Survey and field work are continuing in Malaysia, in order to collect primary data on transport and assembly costs of paddy as well as physical data on paddy supplies. The survey results have been influenced by the protracted nature of the 1985 wet season harvest in August/September. An additional survey was carried out during the 'dry' season harvest in February–March.

Model specification and development in Australia is at an advanced stage. Collaboration with the Malaysian counterparts has been an important and significant component of this modelling process. Work on quality analysis and cost functions of milling, drying, and storage of paddy is proceeding. There have been problems in obtaining reliable and consistent data for the estimation of drying, milling, and storage cost functions. A cross-sectional survey of rice mills was conducted to improve the information base for this analysis. Technical collaborators engaged on the project in MARDI performed a range of experiments so that the relationship between moisture content and rice recovery rates could be better understood.

Preliminary results with the model using observed data contained in a series of papers delivered at an ACIAR workshop in Adelaide during January are currently being analysed. A system for generating solutions and writing reports is currently being designed for future implementation on a suitable Malaysian computer.

Expected Benefits

The project will use current modelling technology to indicate the extent to which postharvest losses in rice can be reduced by the adoption of more efficient handling systems. The models developed will also be used to evaluate the additional cost savings in paddy transport, drying, storage, and processing from improvements in postharvest handling.

Quantification of the potential net benefits from changing to an improved bulk handling system is difficult. The main benefits will presumably be in the reduction in postharvest losses of paddy. In the Selangor project area alone, it is estimated that the gross value of annual paddy production can be increased by around 10% if postharvest losses of paddy could be reduced by 50%, from around 18% to 9%. This would mean an extra $A3–4 million of extra revenue to the region, which also represents the potential dividend from an investment in bulk handling facilities.

In addition to the potential benefits from reduced paddy losses, significant benefits are likely to be realised from rationalisation of existing grain handling facilities and transport networks. Studies elsewhere suggest that reductions of 20–30% in present marketing costs can be achieved by handling paddy and rice more efficiently. In the Selangor region, this would mean an extra $A2–3 million could be saved annually, simply by implementing a more efficient handling and transportation system.

If the benefits estimated for the Selangor region were extrapolated to include the whole Malaysian Peninsula this would mean an annual saving to the country's rice economy of between $A90–110 million, which is a significant return on investment in bulk handling facilities and research costs.

A further benefit will be an enhancement of the capacity of the Malaysian institutions to undertake applied economic research in transport, processing, distribution systems, and cost and quality analyses.

Project Objectives and Operational Schedule

Specific objectives of the project are:

1. to develop an appropriate methodology for analysing, from the viewpoint of the Malaysian rice economy, the optimal postharvest storage, handling, drying, and grading requirements and shipment patterns of paddy and rice;
2. to calibrate and empirically evaluate the model, using observed data collected in a given season for a specified region in Malaysia; and
3. to analyse, using the model, the effect of nominated changes in appropriate decision variables, such as storage and transportation costs and capacities of the distribution system, on total paddy handling costs.

The original objectives of the project have been extended to include the impact of changes in rice handling technologies on labour and capital requirements and to analyse the impact of alternative paddy pricing systems on locational pattern and flows of paddy and rice. The latter is felt to be the prime determinant of the analysis.

The basic objective of the project is thus to develop a model of the Malaysian rice economy which integrates all diverse components of the paddy and rice handling industry. The model will be evaluated empirically using observed data from the Tanjung Kerang area in North-West Selangor. The extent to which the model is generally applicable to other rice producing regions in Malaysia will be assessed. The model will be used to analyse alternative paddy transport and handling activities as well as paddy grading systems so as to determine the most socially efficient locational pattern, number, and size of paddy handling and rice distribution facilities.

Sensitivity analyses will also be conducted of the effect of nominated changes in appropriate decision variables on total system costs, such as handling and transportation costs, timeliness of the delivery system, and capacities of the handling and distribution system, for a range of rice qualities and standards. Issues relating to the efficiency and distribution effects of changes in paddy pricing structures on the optimal solutions will also be analysed.

The project gained momentum following the appointment of a senior economist to the project, based in Adelaide, and the arrival in Adelaide of the collaborating Malaysian research economist. Full momentum was achieved through the project director's visit to Malaysia during August 1985. Since these events the project has proceeded on schedule. Progress is outlined in the accompanying research schedule.

An economic model of the Malaysian paddy and rice economy has been specified and tested using synthetic data. The pilot model was subsequently extended to include actual data provided by the Malaysian project team, whose major activities include data collection and estimation of the various cost functions for use in the model.

Following the arrival of the Malaysian research economist in Adelaide, work in Australia has proceeded on the collection of the project's physical data needs, such as the definition of paddy supply points and the resultant paddy supplies entering the marketing (handling) network.

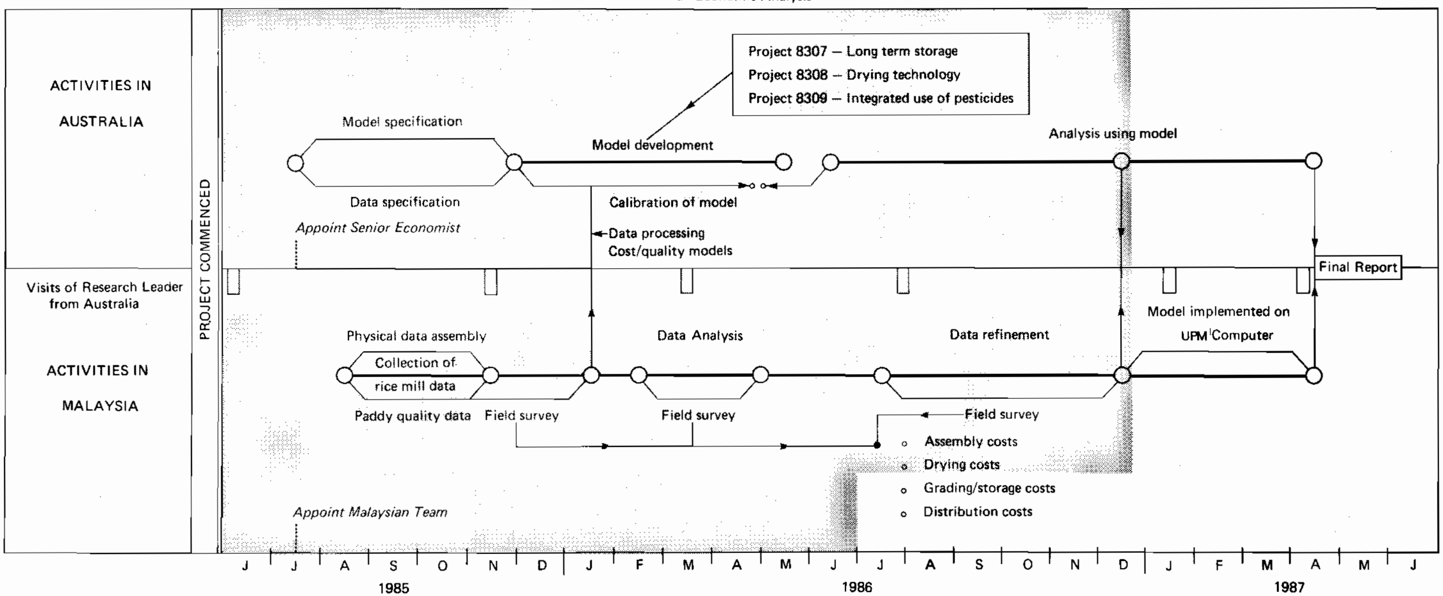
In Malaysia, progress has been satisfactory. The basic background information has been compiled. A first round survey of handling facilities has been conducted and analysed to derive transportation, queueing, and transfer cost functions of paddy. Preliminary investigations of costs associated with rice milling and drying have also been made.

A cross-sectional survey of paddy and rice complexes has also been conducted, in order to refine earlier estimates of milling and drying costs. Quality considerations in paddy and rice are also being investigated.

The protracted nature of the 1985 wet season harvest in Selangor, and the difficulties in obtaining

ACIAR GRAIN STORAGE RESEARCH PROGRAM

Project 8344 – Bulk handling of Paddy and Rice in Malaysia : an Economic Analysis



Research schedule — Project 8344

estimates of milling and drying costs using aggregate data, necessitated changes in sampling procedure and methodology.

Organisation and Staff

The Record of Understanding between ACIAR and the South Australian Department of Agriculture was signed on 26 June 1985 with a scheduled start on 1 July 1985.

Dr G.J. Ryland, Chief Agricultural Economist, was nominated by the South Australian Department of Agriculture as research leader. A senior research economist, Mr B. Hansen, was appointed on 7 July 1985 to work in Adelaide with Dr Ryland. They are supported by Mr Omar Bin Yob, a research economist from LPN who took up duty in Adelaide on 20 July 1985 and who is also undertaking postgraduate training within the project. Project administration is the responsibility of Dr G. Simpson and Mr J. Fargher of SAGRIC International. These personnel comprise the Australian research team.

The Malaysian research team operates from UPM, in close collaboration with MARDI and LPN. The agreement for these operations was finalised with the Economic Planning Unit of the Malaysian Government on 27 July 1985 for a formal start on 1 July 1985, as with activities in Australia. Dr Mohd Ghazali Mohayidin and Dr Chew Tek Ann are joint research leaders in Malaysia. They are supported at UPM by two senior research economists, Dr Fatima Mohd. Anshad (cost and quality analysis) and Dr Roslan Abd. Ghaffar (systems analysis), three research associates, Mr Muzafar Shah Habibullah, Mr Azman Hassan, and Miss Hafrizah, and two graduate assistants funded by the Canadian International Development and Research Centre (IDRC), Mr Salleh Yahya and Mr Seow Keat Foo. MARDI collaborators are Dr Othman, agronomist, and two economists, Mr Shaiban and Dr Syed. Mr Loo Kau Fa, Chief Engineer, is the prime contact in LPN. Mr Faisal, Deputy Director, North-West Selangor Integrated Development Project is also assisting with the collection of estimates of physical supplies of paddy from each block in the project area.

During the period 1 January to 30 June 1985, the management structures were developed and all other arrangements for project activities were finalised.

Grain Storage Research Program
Project 8344 Staff

South Australian Department of Agriculture
Dr G.J. Ryland, Project Director
Mr B. Hansen, Senior Research Economist
Dr G. Simpson } Project Administration
Mr J. Fargher }

Universiti Pertanian Malaysia
Dr Mohd Ghazali Mohayidin } Research Leaders
Dr Chew Tek Ann }
Dr Fatimah Mohd. Anshad, Senior Research Economist (Cost and Quality Analysis)
Dr Roslan Abd. Ghaffar, Senior Research Economist (Systems Analysis)
Mr Muzafar Shah Habibullah, Research Associate
Mr Azman Bin Hassan, Research Associate
Miss Hafrizah, Research Associate
Mr Salleh Yahya, Graduate Assistant (funded by IDRC)
Mr Siow Keat Foo, Graduate Assistant (funded by IDRC)

Malaysian Agricultural Research and Development Institute
Dr Othman, Agronomist
Mr Shaiban, Economist
Dr Syed, Economist

Lembaga Padi dan Beras Negara
Mr Omar Bin Yob, Economist (based at S.A. Department of Agriculture)
Mr Loo Kau Fa, Chief Engineer

Research Activities in Australia

The main activities in the Australian research program over the past year have been the development, specification, and preliminary analysis, using observed empirical data, of a model of the Malaysian rice economy. This has included compilation of a comprehensive bibliography of research and case studies of models which have been developed for other situations.

The model developed by Mr Hansen and Dr Ryland seeks to maximise net revenue of the processing industry, assuming that rice mills compete for supplies of paddy on the basis of locational advantage. Other spatial models are usually concerned with minimising costs for one set of facilities only — either grain dryers or rice mills.

The model is concerned with determining optimum location of all facilities, i.e. procurement, storage, drying, and milling of paddy, and storage of milled rice simultaneously. The basic, and perhaps unresolved, issue for planning purposes is whether these facilities should be concentrated in a few larger central integrated complexes or disaggregated in a large number of small facilities. The former strategy assumes that savings in cost from economies of scale in milling and drying more than offset increases in assembly costs, including transport, transfer, and congestion at fewer larger complexes. However, where there are additional incentives to increase efficiency, in terms of a paddy pricing system which reflects at least the market costs of drying wet paddy, then the additional revenue of supplying dried paddy of higher quality may be sufficient to bring about a greater degree of decentralisation of facilities. This is a critical issue which will be investigated using the model.

Using the model, the increases in net revenue to the rice processing industry from changes in rice handling technologies will be assessed. The changeover to an improved handling system such as bulk handling may bring about an improvement in internal efficiency of the rice handling industry but at the same time may create undesirable external inefficiencies in terms of employment and capital requirements. The work of Timmer (1973)[1] on rice milling in Indonesia is being examined as a methodology for extending the model to include external consequences. Other issues that are being addressed using the model are documented in Ryland and Hansen's paper to the Adelaide workshop described later. The basic network of the rice handling system, from individual blocks to procurement centres, integrated complexes, and private mills, has been analysed by Mr Omar Bin Yob, who presented preliminary results to the January workshop in Adelaide. This work has involved determining the basic source of paddy supply in the model and then carefully identifying the appropriate network through which paddy can flow before storing, drying, and processing. In addition, the work has provided estimates of the supply of paddy at each specified supply source based on yields and area of each for both the dry and wet seasons harvests. This work was done in collaboration with Mr Faisal of the North-West Selangor Integrated Development Project.

A workshop originally planned for December 1985 was held in Adelaide on 14–15 January 1986

[1] Timmer, C.P. 1973. Choice of techniques in rice milling on Java. Bulletin of Indonesian Economic Studies, Canberra.

Project 8344 Adelaide workshop participants (L–R): Dr Roslan Abdul Ghaffar, UPM; Dr Mohd Ghazali Mohayidan, UPM; Mr Omar Bin Yob, Project Economist, Australia; Dr Bruce Champ, ACIAR; Dr Mulyo Sidik, BULOG, Indonesia; (rear) Mr Brian Hansen, Project Economist; Dr George Ryland, Project Director; Mr Chrisman Silitonga, BULOG; Dr Chew Tek Ann, UPM; Dr John Quilkey, La Trobe University, Australia; Dr Saran Wattanutchariya, Katsetsart University, Thailand; Mr Concepto Irigo, National Food Authority, Philippines; Dr Joe Remenyi, ACIAR.

to review the project's overall objectives and the progress in their accomplishment.

The meeting was attended by: Dr Mohd Ghazali Mohayidan and Dr Chew Tek Ann, joint Malaysian research leaders; Dr Roslan Abdul Ghaffar, senior project economist in Malaysia; Mr Omar Bin Yob, LPN project economist in Australia; Dr Leo Fredericks, Director, ASEAN Food Handling Bureau; Dr Mulyo Sidik, Research Coordinator, and Mr Chrisman Silitonga, Head, Research and Development, BULOG, Indonesia; Dr Saran Wattanutchariya, Department of Agricultural Economics, Kasetsart University, Thailand; Mr Concepto Irigo, National Food Authority, Philippines; Dr J. Quilkey, La Trobe University, Melbourne; Dr J. Remenyi, Socioeconomics Research Program Coordinator, ACIAR; Mr B. Hansen, senior project economist in Australia; Dr G.J. Ryland, project director; and Dr B.R. Champ, Grain Storage Research Program Coordinator, ACIAR.

The workshop was opened by Dr J.C. Radcliffe, Director-General of Agriculture, South Australia. The following position papers were presented:

'Progress report for Malaysia', by Dr Mohd Ghazali Mohayidin

'Progress report for Australia', by Dr G.J. Ryland

'Physical data presentation — N.W. Selangor area', by Mr Omar Bin Yob (Description of marketing network; region supply data; transportation network including distance data; exogoneous stock levels for paddy and rice; capacity data for storage, drying, and milling; demand data for paddy and rice.)

'Transportation cost functions for paddy and rice', by Dr Mohd Ghazali Mohayidin (Description of transport methods; specification of cost functions; presentation of data.)

'Queueing cost functions for paddy and rice', by Dr Roslan Ghaffar (Description of storage methods; specification of storage functions; presentation of data.)

'Drying cost-functions for paddy', by Dr Chew Tek Ann and Dr G.J. Ryland (Description of drying methods; specification of drying function; presentation of data.)

'Quality payment schemes in Asia', by Dr Chew Tek Ann and Dr Fatima Arshad (Discussion of work to date.)

'Milling cost functions for paddy', by Dr Roslan Ghaffar (Description of milling methods; specification of milling function; presentation of data.)

'Model specification and some indicative solutions', by Dr G.J. Ryland and Mr B. Hansen (Equation description; indicative solutions.)

The participants from other countries welcomed the opportunity to discuss the methodology being used in the development of the Malaysian project and to discuss the extent to which the model would need to be modified to simulate the circumstances in their countries.

Workshop participants inspected the Port Adelaide Grain Terminal on the morning of Monday 13 January 1986 and, in the afternoon, grain harvesting and handling on the properties of Mr J. Crawford, 'Fordvale', Sandergrove, and A.B. Eckert and Sons, Belvidere. After the workshop, Drs Ghazali, Ghaffar, and Chew, and Messrs Hansen and Omar travelled to the Griffith and Leeton area to inspect rice handling and storage facilities there.

A further review of progress in the project was held in Adelaide on 25 April 1986. This workshop was attended by Dr Ghazali, Dr Chew, Dr Ghaffar, Mr Omar, Mr Shaharuddin Hj. Haron, Director-General of LPN, Mr Loo Kau Fa, Chief Engineer of LPN, Mr Hansen, and Dr Ryland. After the workshop, Dr Ryland accompanied Mr Shaharuddin on a four-day visit to the rice-growing industry of the Burdekin area in north Queensland. Dr Yusof bin Hashim, the Director-General of MARDI joined them for this visit, which was arranged by the Queensland Department of Primary Industries, the Lower Burdekin Rice Producers Association, and the Irrigation Commission. Dr Ghazali, Dr Chew, Dr Ghaffar, and Mr Loo stayed on in Adelaide and in the following week, in company with Mr Hansen and Mr Omar, briefly visited the Lower Burdekin and Mareeba rice-growing areas.

Research Activities in Malaysia

General

The project director, Dr G.J. Ryland, conducted a seminar at Universiti Pertanian Malaysia on 3 May 1985, broadly outlining the project to Malaysian participants and setting the scene for the scheduled start of project activities on 1 July 1985. Dr Chew Tek Ann, Dr Roslan Ghaffar, Mr Azman Hassan, and Mr Loo Kau Fa attended the 8th ASEAN Technical Seminar on Grain Post-Harvest Technology held in Manila from 6–9 August 1985. Dr Chew and Mr Loo presented a joint paper on

'A survey of the literature on drying and milling of paddy in Malaysia'; Dr Ghaffar and Mr Hassan presented a joint paper on 'A preliminary investigation of the costs associated with rice drying and milling in Peninsular Malaysia'; and Dr Mohd Ghazali Mohayidin, Mr Nik Faud Bin Mohd. Kamil, and Dr Ghaffar presented a joint paper on 'Estimating the cost functions of rice processing in Malaysia'. Dr Ryland, Mr Omar Bin Yob, and Mr B. Hansen also attended the seminar from Australia. Dr Ryland and Mr Hansen presented a paper on 'Bulk handling of paddy and rice in Malaysia — model development and specification'. After the seminar, they travelled to Malaysia to participate in field surveys, review project establishment, and attend a workshop to discuss project implementation and to define work area responsibilities of all team members. During their visit to Malaysia, three visits were made to the Tanjung Kerang area to arrange cooperative data collection activities with local personnel.

The GASGA/ACIAR/LPN/MARDI/AFHB Seminar on 'Preserving Grain Quality by Aeration and In-store Drying' which was held in Kuala Lumpur from 9–11 October 1985, was attended by Dr Mohd Ghazali Mohayidin, Dr Chew Tek Ann, Dr Roslan Ghaffar, Dr Fatimah Arshad, and Dr G.J. Ryland. Dr Chew and Dr Ghaffar presented a joint paper on 'Some economic aspects of drying of paddy by farmers in Selangor, Malaysia', and Dr Ryland a paper on 'The economics of grain drying in the humid tropics'.

During the week following the seminar, Dr Ryland worked at Universiti Pertanian Malaysia with the Malaysian team on various issues relating to paddy pricing and specification of alternative cost-models of paddy drying, storage, and milling.

Dr Ryland and Mr Omar Bin Yob visited Malaysia again from 11–22 February 1986 to review project progress. At the request of LPN, they also visited the Muda area in Kedah to examine aspects of the transportation network in that rice growing zone.

Dr Ryland made a further visit to Malaysia from 17–31 May 1986 to discuss research progress, budgets, and preparation of the annual report. During this period, discussions were held with LPN on alternative pricing systems for paddy and on technical specifications of alternative paddy handling systems. Visits were also made to Tanjung Kerang for further discussions involving Mr Faisal, Deputy Director of the North West Selangor Integrated Development Project.

Collection of Data

At the commencement of the project it was decided that there were three areas in which data would have to be collected from primary sources for the empirical evaluation of the model. These data related to assembly (transport, transfer, and assembly costs and size distribution of equipment used in assembling paddy), processing (storing, drying, and milling costs, capacities, and utilisation rates) and pricing systems (paddy quality, rice recovery rates, and prices of different grades of rice). Each of these areas of activity is described briefly below.

Assembly costs

A preliminary survey to obtain assembly cost data and physical characteristics of the paddy transport system was conducted in Tanjung Kerang during August–October 1985. The survey procedure was based upon Kerin's (1985)[2] study of assembly operations for grain in South Australia. Preliminary results of the survey were presented by Dr Mohd Ghazali Mohayidin and Dr Roslan Ghaffar at the January workshop in Adelaide. The main results of this preliminary survey were as follows:

(a) contract operators accounted for 93% of all deliveries of paddy at procurement centres and LPN complexes;
(b) queueing cost was positively related to the quantity of grain received and inversely related to the number of workers at each receival site,
(c) total road transport charges were positively related to trip distance, quantity of grain carried, and expected queueing cost; and
(d) congestion accounts on average for about 30% of total assembly costs.

Processing

Operations relating to drying, storing, and milling have been analysed by the Malaysian project team.

Literature relating to economics of drying and milling of paddy in Malaysia was reviewed by Dr Chew and Mr Loo at the 8th ASEAN Technical Seminar on Grain Post-Harvest Technology. Their review indicated that earlier unpublished work by Soo Lip Tan in 1971 on the locational pattern of dryers in the Muda region of Malaysia suggested an optimal spatial pattern of drying facilities tending towards decentralisation of drying facilities.

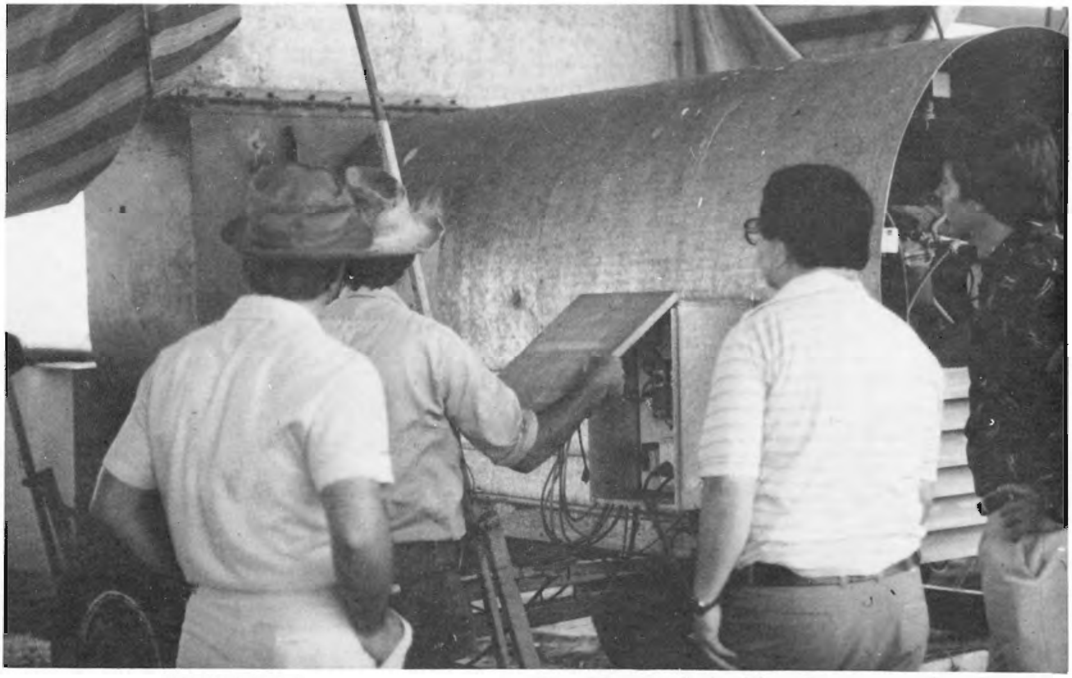
[2]South Australian Department of Agriculture Technical Reports 63, 68, and 80.

However, the optimal pattern in Soo's earlier study depended critically on availability of paddy. Chew and Loo also consider the issue of economic threshold levels of drying and how this may differ from the technical optimum. Their analysis indicates the inadequacy of empirical analysis in this area as there is a paucity of published information relating rice recovery rate to moisture content over a large range of observations on moisture content. This lack of suitable experimental data is currently being rectified by researchers in MARDI.

Dr Roslan Ghaffar and Mr Azman Hassan conducted a preliminary analysis of drying and milling costs. The results of this analysis were also presented at the 8th ASEAN Seminar on Grain Post-Harvest Technology. The study analysed the capital requirement and operating costs, in order to develop average cost curves for paddy drying and milling. Capital requirement for equipment alone ranges from M$200 000 to M$1.5 million for dryers, while mills range from M$150 000 to M$550 000. Incorporating the land, drying, and other structures, initial requirement for a drying and milling complex ranges from M$1.5 million to M$6.6 million. Mechanical dryers, which are of vital importance in reducing moisture content in paddy, cost from as low as M$30.66 to as high as M$79.63 per tonne to operate. Operating costs for milling range from M$35.09 to M$61.55 per tonne. The analysis suggests that drying and milling costs are more sensitive to throughput than capacity. However, there are several major deficiencies with the aggregate data upon which the preliminary empirical analysis was based. There was, for example, very little variation in the capacity and size of plants used in the analysis. The preliminary analysis revealed that depreciation and energy cost were the major components of cost.

Quality analysis and paddy pricing systems

Dr Chew Tek Ann and Dr Fatima Arshad are investigating the extent to which the Malaysian paddy pricing system reflects market failure, in that delivery of paddy to LPN procurement centres of higher moisture content is encouraged to the detriment of rice recovery rates. Dr Chew and Dr Roslan Ghaffar have shown that, under perfect competitive market conditions, weight deductions



During a visit to Australia in April 1986, Mr Loo Kau Fa visited the Mareeba rice-growing district in northern Queensland. He is seen here (second from right) at a demonstration of a mobile, on-farm flat bed dryer on the property of Mr Sam Adil, accompanied by Mr Brian Hansen (right) and Mr Adil and son.

for moisture should be related to rice recovery rates. Dr Chew is undertaking a comprehensive survey of paddy pricing systems in ASEAN countries to obtain an idea of the extent to which anomalies in the different systems occur. In addition, Drs Chew and Arshad have commissioned MARDI to conduct a number of experiments to obtain recovery rates for different paddy qualities as functions of moisture content and time (length of period paddy has been stored). These analyses will supply information which can be used to adjust the quality adjustment parameters specified in the model, as well as paddy prices. The extent to which different processing technologies (drying, storing, milling, and handling) affect quality and rice recovery rates is very much an empirical question.

Improved technologies may not only preserve quality (reduce losses) but at the same time increase recovery rates, i.e. the amount of head rice recovered per unit of paddy supplied.

Status of Economic Model

Pilot results have indicated that the model specified is characterising the actual paddy and rice movements through the handling network in Tanjung Kerang, Selangor. Results of the preliminary analysis suggest that very small changes in yield produce dramatic changes in net revenue, indicating the model can be used to solve the postharvest paddy/rice sectors planning problem of selectively investing in new grain handling facilities. Significantly, the model shows that payoffs from improving technical efficiencies in drying and milling operations are much less than those attributed to paddy pricing policy changes to reflect differing moisture levels (quality) in paddy at procurement. However, empirical results from the model regarding pricing policy, dryer location, and investment in bulk handling technology will become available only after the successful completion of data collection and analysis by the Malaysian team.

Project 8312

Program Development and Coordination

Commissioned organisation — CSIRO Division of Entomology

Introduction

Project 8312, contracted with the CSIRO Division of Entomology, covers program development and coordination. The objectives of the project are:

1. to develop and coordinate a program of research to ensure grain can be stored safely;
2. to develop a grain storage research information network with participation by all relevant organisations in Australia and overseas;
3. to publish a regular newsletter to disseminate information;
4. to provide a literature search and information retrieval facility;
5. to conduct seminars and workshops as appropriate in cooperation with local organisations and publish proceedings of these meetings;
6. to produce, as required, publications relevant to grain storage in developing countries.

Project 8312 provides an operational framework for the development and coordination of ACIAR's activities in the grain storage area. This is seen as an essential component of the program in maximising its effectiveness both in terms of use of resources and research output. The project had an initial duration of three years. It was renewed (as Project 8612) for a further two years following a review of the Grain Storage Research Program conducted during March 1986.

The Grain Storage Research Information Network and associated activities have materially increased the availability of information on existing technology to relevant organisations in Southeast Asia, expedited conduct of the ACIAR program, increased the impact of the program in overcoming storage problems in the area, and facilitated cooperative activities both within the ACIAR program and with other agencies concerned with postharvest research and technology.

Organisation and Staff

Dr B.R. Champ was seconded from the Division of Entomology to act as Research Program Coordinator for an initial period of three years from 7 April 1983.

Mr E. Highley, a communications consultant with knowledge of postharvest activities and issues, was contracted by the Division to edit and produce the biannual newsletter and other project publications. He was also proceedings co-editor and contributed to the organisation of the ACIAR/GASGA/LPN/MARDI/AFHB Seminar on Preserving Grain Quality by Aeration and In-store Drying, held in Kuala Lumpur from 9–11 October 1985, activities for which he was directly commissioned by ACIAR. Mr Highley participated in all internal workshops of program personnel held during the year, and in the program review.

Mrs R. Goodwin, Grain Storage Librarian in the Division of Entomology, spends 10 hours per week on ACIAR project activities, in particular providing the program's literature search and information retrieval facility.

Mrs J. Olditch provides part-time secretarial and administrative support to the program.

As Projects Officers for the Division, first Mr D. Rofe (to 12 August 1985), then Mr I. Rout (16 December 1985 to 3 March 1986), and subsequently Mr I. Lowth (from 6 March, 1986) provided administrative assistance during the year to all ACIAR projects in the Division of Entomology, including those in the Grain Storage Research Program. About half the Projects Officer's time was spent on ACIAR-related activities, encompassing:

- the preparation of annual estimates of expenditure for projects, including calculation of advance payments and acquittals of money expended;
- the monitoring of expenditure in each project;
- assistance with the development of systems and computer programs to facilitate the provision of estimates and financial control information;
- assistance with the preparation of new proposals; and
- assistance with the preparation and coordination of progress reports.

The Research Program Coordinator made frequent visits to projects overseas to facilitate conduct of the program. These visits were usually associated with other activities as listed in the later section on collaboration. In addition, periodic visits were made to the contracting organisations in Australia.

Internal Workshops

Workshops attended by project personnel are normally scheduled twice a year and hosted in turn by each of the project groups in Australia. One of the two meetings is designated the annual meeting for the purposes of reporting and is attended by all professional staff. The other meeting is generally attended by project leaders only. The general objectives of these workshops are:

1. to familiarise Australian participants in the ACIAR Grain Storage Research Program with

the full extent of current activities in the program;
2. to ensure maximum integration of project activities in Australia, including programming of interaction between projects, collaboration in necessary areas of common activity, and provision of facilities to other projects;
3. to discuss full exploitation of overseas resources for project activity, including cooperation between projects in the same area;
4. to present reports of activities for the previous half year and to discuss in detail the current status of each project and relevant research topics;
5. to discuss other matters that may have a bearing on the program; and
6. to inspect relevant research activity within the host organisation.

Three workshops were held during 1985–86, the first having been held over from the previous year until the earliest date that all project leaders could attend. This was 25 July 1985, and the workshop — the program's fourth — was held at the CSIRO Wheat Research Unit in Sydney. The Unit is the commissioned organisation for Project 8314.

The fifth workshop, which was the 1984–1985 Annual Meeting of all Australian scientific staff, was held at the CSIRO Division of Entomology on 18–19 September 1985.

Dr D.E. Evans, Officer-in-Charge of the Division's Stored Grain Research Laboratory, welcomed participants in the workshop and, as a prelude, Professor J.R. McWilliam, Director of ACIAR, gave a general talk on the development of the Centre and its research activities. He outlined how ACIAR selects projects and noted that the Centre was seeking to develop quantitative methods for assessing research priorities. These would embrace criteria such as the outcome of benefit/cost analyses, probabilities of success, availability of research expertise, expected rate of adoption of research findings, and likelihood of beneficial spill-over effects occurring. A model incorporating these criteria was being built.

With this introduction, participants then spent two days reviewing developments and progress in the projects over the year. Towards the end of the workshop, they also had the opportunity to tour the Stored Grain Research Laboratory and see something of its wide-ranging research, from fundamental studies of stored product insect pests to engineering aspects of the design of storages for controlled atmospheres and fumigation.

Grain Storage Research Program

Project 8312 Staff

CSIRO Division of Entomology
Dr B.R. Champ, Grain Storage Research Program Coordinator
Mrs R. Goodwin, Research Librarian
Mr E. Highley, Editor, Grain Storage Newsletter
Mr I. Lowth, Divisional Project Officer (from 6 March, 1986)
Mrs J. Olditch, Secretary
Mr D. Rofe, Divisional Project Officer (to 12 August, 1985)
Mr I. Rout, Divisional Project Officer (16 December 1985 to 3 March 1986)

The sixth internal workshop, for program leaders only, was also held at the Division of Entomology, on 3 March 1986. Professor McWilliam again attended this meeting, as did Mr A.W. Blewitt, ACIAR Centre Secretary, and Mr J.V. Moore, who had recently been appointed ASEAN Crops Post-Harvest Programme Technical Team Leader in the Philippines.

The venue for the Grain Storage Research Program's seventh internal workshop and 1985–86 Annual Meeting was Ricegrowers' Co-operative Ltd, at Leeton, New South Wales, The Co-operative is the commissioned organisation for application technology aspects of the bulk-grain drying project. During the two-day meeting from 23–24 July 1986, project leaders and staff reported on a year of solid progress in research in all participating countries. As some projects were nearing completion, there was considerable discussion on appropriate mechanisms for ensuring the application of research findings in grain storage practice in the region. Considerable attention was also given to assigning priorities for any extension of the program.

Research Information Network

A research information network built around specialist library and publications services is an integral part of the grain storage program. It serves primarily to strengthen contacts between the diverse projects and research groups spread through the four countries currently involved in the program, and between the program and other post-harvest groups. The network's functions are:

- to disseminate project and project-related information between program participants in ASEAN and Australia;

- to provide specialist information retrieval services to program participants;
- to maintain contact and foster collaboration with other grain storage research and development groups in the region and elsewhere;
- to respond to requests for information on program activities from other bodies; and
- to produce publications aimed at improving grain storage technology.

ACIAR Grain Storage Newsletter

A key element in the research information

The 1985–86 Annual Meeting was held at Ricegrowers' Co-operative Ltd, Leeton, New South Wales on 23–24 July 1986. Participants were (L–R): Mr P.C. Annis (CSIRO Entomology), Mr I. Lowth (CSIRO Entomology), Mr R. Parker (Queensland Department of Primary Industries), Mr J. Darby (Ricegrowers' Co-operative Ltd), Mr J. Wiseman (CSIRO Entomology), Dr T.V. Nguyen (CSIRO Chemical and Wood Technology), Mr J. Bryan (University of New South Wales), Dr P. Samson (Queensland Department of primary Industries), Dr G.J. Ryland (South Australian Department of Agriculture), Mr L.D. Bramall (Ricegrowers' Co-operative Ltd), Mr S. Wilson (CSIRO Chemical and Wood Technology), Dr P. Gras (CSIRO Wheat Research Unit), Dr G.R. Thorpe (CSIRO Chemical and Wood Technology), Dr D.E. Evans (CSIRO Entomology), Mr G. Sharpe (University of New South Wales), Dr B.R. Champ (ACIAR), Mr J. van S. Graver (CSIRO Entomology), Dr J.M. Desmarchelier (CSIRO Entomology), Mr G. Pym (Ricegrowers' Co-operative Ltd), Dr M. Bengston (Queensland Department of Primary Industries), Mr M. Bason (CSIRO Wheat Research Unit), Mr B. Hansen (South Australian Department of Agriculture), Dr R.H. Driscoll (University of New South Wales — partly obscured), Mr T.F. Ghaly (CSIRO Chemical and Wood Technology), Mr J.V. Moore (ASEAN Crops Post-Harvest Programme), Mr E. Highley (ACIAR), Mr T. Adamczak (University of New South Wales), Mr Omar Bin Yob (South Australian Department of Agriculture/LPN).

network is the *ACIAR Grain Storage Newsletter* published twice a year. During 1985–86, the policy was maintained of publishing details of project activities, of seminars and workshops held or planned, of new publications and information retrieval activities, and of the work of other groups tackling postharvest problems, as well as commissioning articles on topics likely to be of general interest to a wide cross section of its readers in various countries.

The second and third parts of Mr J.T. Snelson's comprehensive account of the regulation of pesticide residues in stored grain were published in the July 1985 and January 1986 issues of the newsletter (Numbers 3 and 4). Issue Number 4 also contained, among other things, reports on the ACIAR cosponsored seminar on 'Preserving Grain Quality by Aeration and In-store Drying', held in Kuala Lumpur from 9–11 October 1985 and of the 8th ACPHP Technical Seminar, held in Manila from 6–9 August of the same year.

Some 700 copies of each issue of the *ACIAR Grain Storage Newsletter* are now distributed via an expanding mailing list. Requests for publications and further information show that it now has readers in most parts of the developing world.

Databases and Information Retrieval Services

Project activities under this banner promote the spread of information on stored products research and applications by supplying bibliographic references and publications to participants in the program, in cooperation with other specialist libraries and by searching appropriate databases.

Demand for literature searches remains strong, and program participants and their associates clearly find this a useful service. The value of the service is also easily extendable to large numbers of postharvest workers by the simple expedient of announcing in the newsletter what searches have been undertaken and providing copies of the search results to all who are interested.

The following were among the topics submitted for literature searches during the year.

- Storage in Southeast Asia
- Chemical and biological changes in grains and legumes during storage
- Paddy pricing
- Economics of grain drying
- Computer control of grain drying
- Supplemental heating for rice drying
- Moisture adsorption and diffusion in rice
- Composition and analysis of yellow rice
- Rice bran stabilisation
- Extraction and refining of rice bran oil
- Germination of mung beans
- Drying and storage of soybeans
- Spontaneous heating of barley
- Grain protectant insecticides
- Methyl bromide residues in grains
- Deltamethrin — decay and inactivation
- Ethyl formate/methyl formate as fumigants for food products
- Insects infesting peas in storage
- *Reesa vespula*

Collaborative Activities

Participation in GASGA

ACIAR is the nominated Australian participant in the Group for Assistance on Systems relating to Grain After-harvest (GASGA) and is represented by Grain Storage Research Program Coordinator, Dr B.R. Champ. The 1985 Annual Executive Meeting was held in London from 30 June to 6 July 1985 and was hosted by the U.K. Tropical Development and Research Institute. The 1986 Meeting was held in Rome from 28–30 May 1986 and was hosted by FAO.

Attendance at International Conferences and Workshops

The ASEAN Crops Post-Harvest Programme's 8th Grain Post-Harvest Technical Seminar, held from 6–9 August 1985 in Manila, Philippines, was attended by a number of personnel associated with the Grain Storage Research Program. Dr Chew Tek Ann, Dr Roslan Gaffar, Mr Azman Hassan, Mr Loo Kau Fa, Dr G.J. Ryland, Mr Omar Bin Yob, and Mr B. Hansen, all participants in Project 8344, attended and presented a number of papers giving preliminary results of their work to develop a comprehensive model of the Malaysian rice economy. Further details are given in the section of the report covering the project.

Various staff from other projects also took part in the ACPHP seminar. They included Mr A. Rahim Muda (8309) and Mr Ong Seng Hok (8311) (Malaysian teams), and Mrs P. Sayaboc (8309) and Mr C. Mordido, Jr. (8311) (Philippine teams). Mr J. van S. Graver attended during a period of Project 8307 field work in the region. Other participants were Mr Mohd Mochtar (8308A) and the Research Program Coordinator.

ASEAN Food Handling Sub-committee, Grains Working Group

The Program Coordinator continued as consultant and ACIAR representative to the Grains Working Group and attended the 18th Meeting which was held in Jakarta from 1–3 April 1986.

Collaborative Activities in Thailand

The Program Coordinator participated in the MOAC–ACIAR Consultation Meeting on Agricultural Research Collaboration, held at the Central Forest Research Laboratory and Training Center in Bangkok on 21–22 November 1985. The current collaborative activities were reviewed and further initiatives discussed.

ACIAR/AFHB Working Party on Fumigation

The ACIAR/AFHB Working Party on Suggested Recommendations for Good Fumigation Practice in the ASEAN Region held its first meeting in Singapore in December 1985. This working party arose from a recommendation made at the ACIAR/NAPHIRE/AFHB Seminar on Pesticides and Humid Tropical Grain Storage Systems held earlier in the year in Manila.

At the Manila seminar, considerable concern was expressed on the problems associated with fumigation, particularly with phosphine, and at the likelihood of fumigant resistance appearing in the Southeast Asian region. Reference was made to the serious problem in Bangladesh and other parts of the world, where poor fumigation practices have generated high levels of resistance to phosphine in a range of pest species.

The ACIAR/AFHB Working Party consists of representatives of the national pesticide regulatory authorities in each of the ASEAN countries, together with personnel who were concerned with the development of a similar code of practice in Australia, and the research leaders of relevant ACIAR projects. It is convened by the ACIAR Grain Storage Research Program Coordinator. Its task is to draft for the region a suggested set of recommendations for fumigation that will include dose rates, exposure times, and requirements for gastightness of enclosures. The Working Party has the strong support of all appropriate organisations in ASEAN.

At the first meeting, the format for preparation of the recommendations was discussed and agreed upon, and preparation of a draft is under way. When this is complete, it will be circulated to all interested parties for comment.

Participation in the ASEAN Crops Post-Harvest Programme

In February 1986, Mr J.V. Moore, an Australian engineer with extensive experience in the design and construction of grain handling and storage facilities, was appointed to the Technical Team of the ASEAN Crops Post-Harvest Programme (ACPHP), based in Manila. Mr Moore was nominated for the position by ACIAR and the Australian Development Assistance Bureau. His appointment had been approved by the ACPHP Steering Committee at its 3rd Meeting, held in Singapore on 4–5 December 1985. He was subsequently appointed Team Leader.

The Program Coordinator attended the meeting of the ACPHP Steering Committee held in Singapore in December.

Other Aspects of Collaboration

During December 1985–January 1986, Dr G.R. Thorpe (Project 8310), on a visit cosponsored by ACIAR and the Commonwealth Fund for Technical Co-operation, held discussions in Thailand on a proposed joint project on solar grain cooling. Institutions visited included the Ministry of Agriculture in Thailand, the University of Chiang Mai, and the Asian Institute of Technology. During the same period of travel, Dr Thorpe helped to commission, on behalf of the Commonwealth Fund for Technical Co-operation, a fluidised-bed parboiled paddy dryer in Sri Lanka, and collated and analysed climatic data so that energy audits for grain cooling and drying can be carried out.

In December 1985, Mr James Darby (Project 8308B), was commissioned by FAO to present a series of lectures in China, at a training seminar on grain drying technology. Subsequently, and within the same program of seminars, Dr M. Bengston (Project 8309) and Dr J.M. Desmarchelier (Project 8311) participated in a workshop on pesticides in grain storage in April 1986, and Mr P.C. Annis (Project 8307) in a workshop on grain preservation with controlled atmospheres in May, June 1986.

The Program Coordinator was a member of the 1985/86 Joint Review Committee which, from 4–7 February 1986, assessed project activities funded by the Wheat Industry Research Council and the Barley Industry Research Council in the areas of grain storage, rodents, and insect pests.

A delegation from Malaysia visited Australia in April–May 1986. Mr Shaharuddin Hj. Haron, Director-General of LPN and Dr Yusof Hashim, Director, MARDI, visited the Burdekin rice-growing district of Queensland, accompanied by Dr G.J. Ryland (Project 8344).

A joint LPN/MARDI study team visited Australia from 7–19 July 1985 to investigate engineering design and management systems for sealed grain stores in Australia. Participants were Mr Dhiauddin Mohd Nour, Senior Research Officer (MARDI), Mr Teoh Inn Chek, Senior Engineer (LPN), and Mr Ibrahim Manan, Senior Warehouse Manager (LPN, Senawang). Their itinerary included visits to Ricegrowers' Cooperative Ltd, Leeton (Project 8308), and the CSIRO Division of Entomology's Stored Grain Research Laboratory (Projects 8307, 8311, 8312).

The ACIAR Liaison Scientist in the Philippines, Ms Leonarda Nallana, visited the CSIRO Division of Entomology's Stored Grain Research Laboratory on 30 October 1985. She discussed project activities in the Philippines, and familiarised herself with activities in Australia.

Mr L.D. Bramall (Project 8308B) visited TDRI and other research groups while in the U.K. in September 1985. He also inspected facilities in the USA and Canada before his return to Australia.

The Program Coordinator continues as Regional Editor for Australia and Asia of the *Journal of Stored Products Research* and as a member of the Permanent Committee of the International Working Conferences on Stored Product Protection.

Program Workshops and Seminars

Workshop on Paddy and Rice Bulk Handling

In collaboration with the ACIAR Socio-economics Program, a workshop on paddy and rice bulk handling was held in Adelaide on 14–15 January 1986. Organised by Project 8344, it was attended by project participants from Australia and Malaysia, and by delegates from Indonesia, the Philippines, and Thailand. Details of the workshop are given in the report on Project 8344.

Mr Chuwit Sukprakarn, Project 8307 Coordinator in Thailand, visited the CSIRO Stored Grain Research Laboratory in Canberra during April 1986. He is seen here discussing the Stored Products Reference Index with Mrs Rosalind Goodwin, the Program's Research Librarian.

International Seminar on Grain Drying and Aeration

The program's second international seminar, on the topic 'Preserving Grain Quality by Aeration and In-store Drying', was held in Kuala Lumpur, Malaysia, from 9–11 October 1985. It attracted some 150 participants. Seminar co-sponsors with ACIAR were GASGA, LPN, MARDI, and the ASEAN Food Handling Bureau.

The seminar's objectives were to review the current state of knowledge on the principles of aeration and in-store drying, and to assess, in technical and economic terms, the relevance to the handling of wet grain in the humid tropics of the various aeration and drying strategies available.

Aeration and in-store drying are well established techniques in grain storage technology in various parts of the world. The issue facing participants and their respective agencies was to begin to devise strategies for weaving appropriate drying technologies into the social and economic fabrics of the countries of the region.

Twenty-four papers were presented by post-harvest specialists from Australia, England, Indonesia, Korea, Malaysia, the Philippines, Thailand, the United States, and West Germany, 11 of them prepared by members of ACIAR-sponsored project teams. Other countries represented at the seminar were Italy, Kenya, Nepal, Singapore, and Sri Lanka.

A number of papers presented at the seminar showed quite clearly that we have the technology for drying wet grain in the humid tropics. It is possible to adapt, to such conditions, the aeration and in-store drying systems developed and used so successfully in temperate parts of the world. Even during the wet season, there are times of the day or night when air with properties suitable for aerating grain can be selected, with or without the addition of small amounts of supplemental heat, for the removal, in energy-efficient devices, of small amounts of moisture.

The seminar confirmed that there is a pressing need to reduce losses occurring immediately after harvest, by introducing appropriate drying technologies into the region. Given that most agencies have been readily acknowledging this, why has the rate of adoption of artificial or mechanical drying strategies been so low? The answer appears to rest on social and economic, rather than technical issues. In Malaysia, for example, it seems that there is no incentive built into the paddy procurement and pricing system to encourage farmers to dry their paddy. It costs farmers more to dry their grain than the extra return they get from doing so.

The seminar registered that a first step towards enhancing the rate of introduction of appropriate drying technology would be to introduce grain procurement and pricing policies that reward farmers delivering dry paddy for storage.

An important technical question raised at the seminar concerned the time at which the quality of harvested grain begins to deteriorate. In other words, for how long can harvested grain be left in the field or at a procurement centre before drying becomes imperative? There is clearly a need to determine, and distinguish between, damage that has its origins in events before the grain is dried and that which might occur during drying and storage. This information, apart from its intrinsic importance to the minimisation of postharvest losses, has a strong bearing on the valid assessment of the performance of aeration and in-store drying systems.

Publications

Journal Papers

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Research cooperation in Southeast Asia — Mr A.W. Blewitt, Secretary, ACIAR

Introductory remarks and objectives of the Seminar — Dr Mohd Yusof bin Hashim, Director-General, Malaysian Agricultural Research and Development Institute

Keynote Address — Y.B. En. Daud bin Dato' Taha, Deputy Minister of Public Enterprises, Malaysia

Objectives of Aeration and In-store Drying

Chairman — R.G. Bowrey; Rapporteur — K.F. Loo

Grain quality considerations in relation to aeration and in-store drying — R. Boxall and D.J.B. Calverley

In-store drying of grain: the state of the art — F.W. Bakker-Arkema and H.M. Salleh

Some fundamental principles and benefits of aeration of stored grain: requirements for drying high moisture content grain in Southeast Asia — D.B. de Padua

Basic Principles of Aeration and In-store Drying

Chairman — C.W. Bockhop; Rapporteur — B. Bohnstedt

Physical and thermal properties of grains — Do Sup Chung and Chong-Ho Lee

The application of psychrometrics to grain aeration — R.H. Driscoll

Modelling temperature and moisture changes resulting from natural convection in grain stores — T.V. Nguyen

Modelling of forced convection in in-store grain drying: the state of the art — F.W. Bakker-Arkema

Design of Aeration and In-store Drying Systems

Chairman — G.R. Thorpe; Rapporteur — Lim Boon Ka

Design parameters for storage and handling systems for grain — N. Teter

Design of air distribution systems and fan selection for grain aeration — A.J. Hunter

A procedure to estimate the supplemental heating needs for in-store drying of paddy — R.G. Bowrey and R.H. Driscoll

Control systems for the aeration and drying of grain — G.R. Pym and T. Adamczak

Economics of Aeration and In-store Drying

Chairman — Shaharuddin Hj. Haron; Rapporteur — Dhiauddin Mohd Nour/Jantan

Loss assessment — towards a fuller comprehension of postharvest loss — R. Boxall, D.J.B. Calverley, and P.S. Tyler

The economics of grain drying in the humid tropics — G.J. Ryland

Some economic aspects of drying of paddy by farmers in Selangor, Malaysia — T.A. Chew and R.A. Ghaffar

Cost implications of implementing grain drying systems — L.J. Fredericks and J.P. Mercader

Case studies

Chairman — D.B. de Padua; Rapporteur — J.P. Mercader

Silo storage in Malaysia — K.F. Loo

Storage and drying trials with unmilled rice in Indonesia — D.J.B. Calverley

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Grain aeration in Australia — J.W. Sutherland

Paddy drying in Australia — L.D. Bramall

Grain aeration and in-store drying in the U.S.A. — Do Sup Chung, Boma Kanujoso, L. Erickson, and Chong-Ho Lee

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Closing remarks — Dr Leo Fredericks, Director, ASEAN Food Handling Bureau

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