ACIAR Grain Storage Research Program

Research Report 1984–85

Australian Centre for International Agricultural Research

Canberra 1986

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ACIAR. 1986. Australian Centre for International Agricultural Research. Grain Storage Research Program. Research Report 1984–85. ACIAR Technical Reports 3, 85 p.

ISBN 0 949511 25 0

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Overview of the Program

Objectives and Organisation

ACIAR's commission is to encourage research aimed at identifying and finding solutions to agricultural problems in developing countries. Within its general postharvest activities, ACIAR has established a grain storage research program with a specific objective of safe storage of grain. This has been done in response to many requests for assistance in preventing the very substantial losses that are known to occur in the postharvest sector. The program seeks to achieve safe storage by facilitating research on high priority problems, such as grain drying and losses from pests, that have been identified as the major constraints to preserving grain quality after harvest. These problems exist because the research base is inadequate and the factors involved are not fully understood, either individually or in their interactions within storage systems. In dry temperate climates it is not difficult to store grain safely using ad hoc technology. In the humid tropics, however, where conditions are such that grain spoils rapidly, the problems are intensified and approaches based on expediency do not work.

There are immediate and pressing needs to improve grain storage technology in the region. The strategy adopted has been to seek these improvements in specific areas by a logical sequence of first understanding the processes involved and then using the information obtained to synthesise effective and reliable techniques for safe storage. An integral part of the strategy is the development of the research capacity of the overseas countries so that their individual programs are self-sustaining and can service their on-going research needs.

Problems in the central storage and handling systems have been the target of the program. It is in this sector that research needs are greatest and where Australia has the expertise that can be profitably exploited, where the likelihood of successful solutions to problems is highest, at least in the short term, and where the benefits accruing should be maximised for the resources expended. Moreover, the research results obtained would be transposable to smaller scale storage technology where sociological considerations have greater relative importance. These studies are designed to complement existing initiatives in the region, such as the work of the ASEAN Food Handling Bureau and various bilateral and multilateral activities which give particular emphasis to farm and village level problems.

The program thus has a defined set of practical goals that will improve storage technology in the region. It is building a sound research base and from this is devising storage systems that are compatible with the economic and social needs of the region. The demonstrable benefits of the new approaches to storage technology must be the prime catalyst to their widespread adoption, but this is being facilitated by the Research Information Network that has been developed to complement the program and ensure adequate diffusion of research findings to end users.

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 has an initial duration of 3 years.

The grain storage 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. 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. Agreement has been reached on specific activities in all countries and the cooperating institutions and individuals have been identified.

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 storages 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. The technology is not well-researched for application in the humid tropics and while the ACIAR program will provide information on which to base the necessary changes, detailed feasibility studies are essential if costly mistakes and losses of foodstuffs are to be avoided.

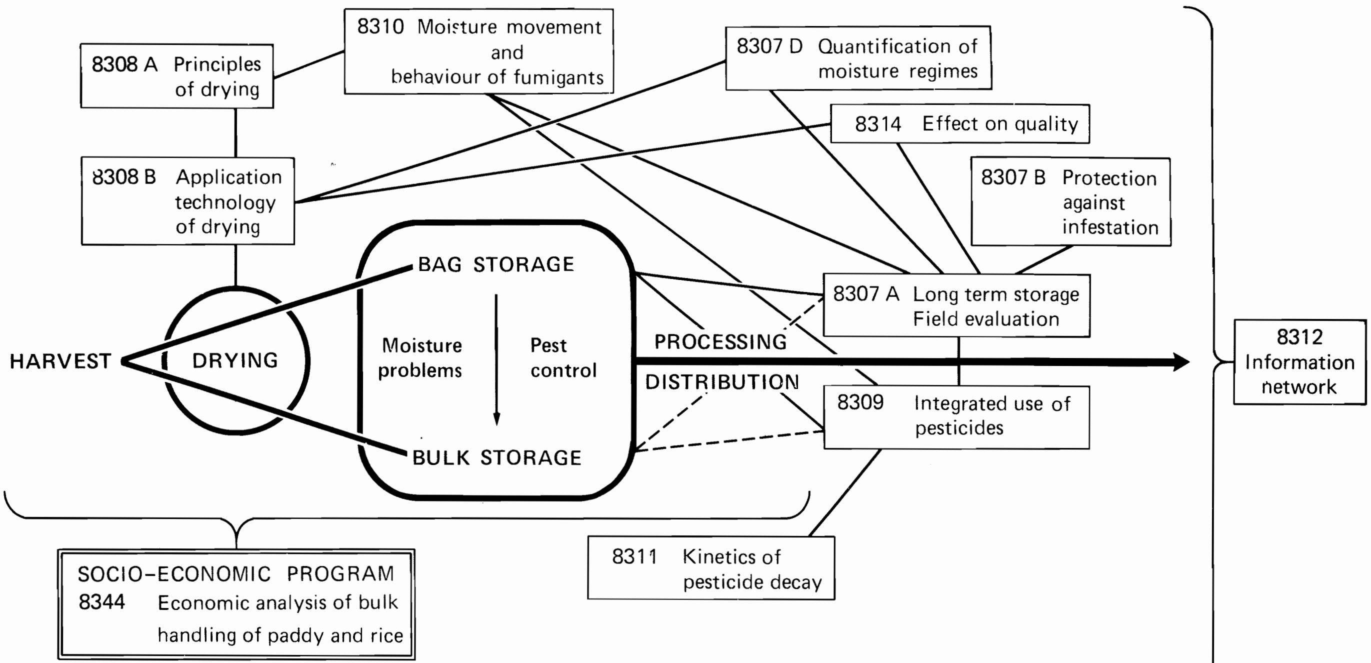
A project proposal for a study on the transition from bag to bulk handling of paddy (unhulled rice) and rice in Malaysia has been developed in association with the ACIAR Socioeconomics Program (Project 8344, South Australian Department

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

The Malaysian paddy handling industry faces difficult problems, particularly in the wet season. Delays in drying the harvested grain may lead to serious losses. ACIAR Project 8344 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.

of Agriculture). It is hoped to extend this, as opportunity permits, into the handling of other commodities in the Philippines.

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

The past year has seen considerable progress in the ACIAR Grain Storage Research Program. All arrangements have been finalised for the initial suite of core and support projects on drying, use of pesticides, and long term storage, and project activities are well advanced.

Definition of drying systems to maximise grain quality is now within reach, as are rational strategies for use of pesticides and other techniques for storage of grain to prevent the wastage of food and feedstuffs that occurs at present.

The economics of these operations are coming under close scrutiny and a very significant project has just been established in conjunction with ACIAR's socioeconomics program. This project will examine and provide a base for optimising the transition from bag to bulk handling of grain, which is a major dilemma confronting countries in the region.

As regards the administration of the program, significant progress has been made in providing an accounting and budget system that monitors expenditure and provides reliable forward estimates.

The research information network has received gratifying support and is materially assisting in bridging the communciations gap between Australian grain storage specialists and those in

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 in tropical climates	
	A. Principles — University of New South Wales, Australia	24/5/83
	B. Application technology — Ricegrowers' Co-operative Mills Ltd, Australia	25/3/83
	MARDI, Malaysia	25/11/84
	NAPHIRE, Philippines	23/8/83
	King Mongkut's Institute of Technology, Thonburi, Thailand	6/7/84
8309*, 8311	Integrated use of pesticides in grain storage 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	†
	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 grains	
	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[4]/LPN[5]/MARDI, Malaysia	23/7/85

* Core Project † Agreement not yet signed

1. Commonwealth Scientific and Industrial Research Organization
2. Malaysian Agricultural Research and Development Institute
3. National Post-Harvest Institute for Research and Extension
4. Universiti Pertanian Malaysia (Agricultural University of Malaysia)
5. Lembaga Padi dan Beras Negara (National Paddy and Rice Authority)

overseas countries, particularly in Australia's neighbours in Southeast Asia. The first international seminar in the program was held in Manila at the end of May. The topicality of the subject of this seminar — 'Pesticides and humid tropical grain storage systems' — was evidenced by the strong attendance of over 180 participants. The recommendations that came from discussions at the seminar not only confirmed the general thrust of ACIAR activities but also established where the most significant advances in application technology can be made. Chief among these was the proposed development, by countries in the region, of a code of practice for safe and effective use of fumigants.

There can be little doubt that the researchers in the ACIAR Grain Storage Research Program in the State Departments of Agriculture, CSIRO, the universities, and other instrumentalities, working together with their colleagues in Southeast Asia, are a resource that will build a grain storage technology for the humid tropics that will not only allow safe storage of grain to meet the individual requirements of the different countries in the region, but will also provide a research base that has application throughout the world.

Grain Drying Investigations

The theoretical objectives of the grain drying project (8308) have been accomplished. It has been shown that it is possible to dry wet-harvested grain in the conditions encountered in the humid tropics using existing technology. The practical application of the research findings is now being investigated in simulation studies. Pilot plants for grain drying investigations are in use in the Philippines and Thailand, and one is under construction in Malaysia. Substantial work on energy sources for supplemental heat for grain drying has been done by the research team in the Philippines, which has looked at the combustion of rice hulls in this regard, and by the team in Thailand, which has studied solar-assisted drying.

Pesticide Use

The prime objective of the pesticide projects (8309 and 8311) is to develop effective insecticide treatments for tropical stored grains. At the start of the projects, relatively little was known of the insecticide treatments needed at the higher moisture contents characteristic of the tropics and on grains such as paddy and maize.

Both moisture content and grain species have been found to influence insecticide efficacy, such that application rates have to be increased at higher moisture contents, and need to be greater on paddy relative to maize and wheat. Studies currently in progress will determine minimum effective application rates on maize and paddy stored at about 14% moisture content, the safe upper moisture limit.

The importance of the pesticide project has been emphasised by the results of resistance surveys conducted under its aegis in Southeast Asia. They have shown that resistance to malathion, the insecticide presently in routine use, is widespread. There is an urgent need for effective alternatives.

Studies of Moisture Movement

When commodities such as cereal grains and legumes are stored in bags or bulk, moisture migration from warm to cool regions may cause serious spoilage of the commodity. The major objective of the project on moisture movement (8310) is to develop an understanding of the mechanisms causing moisture migration in both aerated and unaerated grain.

Results already obtained have quantified the storage conditions needed to prevent harmful moisture migration. It has also proven possible to quantify the rate at which moisture migrates in unaerated grain. The effects of aeration on the grain moisture content and temperatures at the periphery of a grain store have also been quantified. It is anticipated that this will enable the effects of aeration on phenomena such as the rate of pesticide decay, insect population dynamics, grain quality, and respiration to be understood in far more detail than has hitherto been possible. A sound appreciation of the heat and mass transfer phenomena that occur in grain has enabled a systems study aimed at reducing postharvest losses to be initiated.

Storage Under Plastic Covers

The results of work on moisture movement have direct bearing on the project to assess the potential of carbon dioxide atmospheres and sealed plastic enclosures for long term storage of bagged commodities. Pilot studies in this project (8307) are currently being conducted in Malaysia and Thailand, and will be extended to the Philippines. A preliminary experiment in Thailand confirmed the importance of the use of appropriate sealing technology in the manufacture of the enclosure. Support studies on moisture measurement (8307D) and quality (8314) are well under way.

Grain Storage Research Program

Research Team Contact Addresses

Australia

Mr P.C. Annis
Stored Grain Research Laboratory
CSIRO Division of Entomology
G.P.O. Box 1700
Canberra, ACT 2601
Ph 062 465860 Tx 62309
(Project 8307A/B)

Mr J.R. Wiseman
Stored Grain Research Laboratory
CSIRO Division of Entomology
G.P.O. Box 1700
Canberra, ACT 2601
Ph 062 465021 Tx 62309
(Project 8307D)

Dr R.H. Driscoll
School of Food Science and Technology
University of New South Wales
P.O. Box 1
Kensington, NSW 2033
Ph 062 6974357 Tx 26054
(Project 8308A)

Mr L.D. Bramall
Technical Services Manager
Ricegrowers' Co-operative Ltd
P.O. Box 561
Leeton, NSW 2705
Ph 069 530439 Tx 69992
(Project 8308B)

Dr P.W. Gras
CSIRO Wheat Research Unit
c/- Bread Research Institute
Private Bag
North Ryde, NSW 2113
Ph 02 8889600 Tx 20003
(Project 8314)

Dr M. Bengston
Entomology Branch
Department of Primary Industries
Meiers Road
Indooroopilly, Qld 4068
Ph 07 3779351 Tx 41620
(Project 8309)

Dr G.R. Thorpe
Agricultural Engineering Group
c/- CSIRO Division of Energy Technology
P.O. Box 26
Highett, Vic. 3190
Ph 03 5562634 Tx 37130
(Project 8310)

Dr J.M. Desmarchelier
Stored Grain Research Laboratory
CSIRO Division of Entomology
G.P.O. Box 1700
Canberra, ACT 2601
Ph 062 465337 Tx 62309
(Project 8311)

Dr G.J. Ryland
Sagric International Pty Ltd
G.P.O. Box 1671
Adelaide, SA 5001
Ph 08 2273039 Tx 88422
(Project 8344)

Dr B.R. Champ
c/- CSIRO Division of Entomology
G.P.O. Box 1700
Canberra, ACT 2601
Ph 062 465340 Tx 62309
(Project 8312)

Malaysia

Mr Ahmad Robin Wahab
MARDI
G.P.O. Box 12301
Kuala Lumpur
Ph 356401 Tx 37115
(Project 8307)

Mr Loo Kau Fa
National Paddy and Rice Authority
P.O. Box 108
Kuala Lumpur
Ph 934367 Tx 30992
(Project 8308)

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Mr A. Rahim Muda
Food Technology Division
MARDI
G.P.O. Box 12301
Kuala Lumpur
Ph 356401 Tx 37115
(Project 8309)

Mr Ong Seng Hock
Central Research Laboratory
MARDI
G.P.O. Box 12301
Kuala Lumpur
Ph 356401 Tx 37115
(Project 8311)

Dr Mohd. Ghazali Mohayidin
Faculty of Resource Economics and Agri-Business
Universiti Pertanian Malaysia
Serdang, Selangor
Ph 586101 Tx 37454
(Project 8344)

Philippines

Mrs Glory Sabio
NAPHIRE
3rd Floor, FTI Administration Building
Taguig, Metro Manila
Ph 8287551 Tx 45575
(Project 8307)

Mr Justin Tumambing
NAPHIRE
3rd Floor, FTI Administration Building
Taguig, Metro Manila
Ph 8287551 Tx 45575
(Project 8308)

Mr C. Mordido, Jr
NAPHIRE
3rd Floor, FTI Administration Building
Taguig, Metro Manila
Ph 8287551 Tx 45575
(Projects 8309 and 8314)

Thailand

Mr Montri Rumakom
Entomology and Zoology Division
Department of Agriculture
Bangkhen, Bangkok 10900
Ph 5798540 Tx 84478
(Project 8307)

Dr Somchart Soponronnarit
King Mongkut's Institute of Technology
Thonburi Campus
Bangmod, Rasburana
Bangkok
(Project 8308)

Socioeconomic Studies

On the economic front, a project (8344) to elucidate the cost implications of the introduction of paddy drying systems is in progress in the Tanjung Kerang rice-growing district of Malaysia. There are four areas of investigation: grading systems and paddy pricing; cost analysis; physical data; and development and specification of a system model. This project aims to determine the economic feasibility of the grain-drying strategies that have been shown through the program to be technologically feasible.

Research Information Network

The research information network provides specialist library and publications services to program participants and other postharvest researchers in the region. A key strand in the network is the ACIAR Grain Storage Newsletter published twice a year.

There was a substantial increase in demand for the program's library and information services during the year. For the first time in the program, requests for literature searches were received from overseas participants, following extensive coverage of these services in the newsletter. Twenty-seven specialist searches were performed, almost half of them requested by members of the various country research teams. There was also an increase in demand for copies of earlier searches, particularly from overseas workers.

There was also a substantial increase in the number of requests for publications with well over 300 requests being satisfied. Most of the requests from overseas were for ACIAR and CSIRO publications.

An important element of the program's library resources is its possession of the sole copy of the U.K. Ministry of Agriculture, Fisheries and Food's Stored Products Reference Index. An exciting development during the year has been the progress made towards computerisation of the index. Trials have been performed on a subset of the database using the STATUS retrieval language running on MAFF Prime computers. The research information network is liaising with the MAFF library to ensure the earliest possible access to the machine-readable form of the database for program participants.

By a judicious blend of projects concerned with theory and practice, and the wider social implications of technological change, the ACIAR Grain Storage Research Program is making a unique contribution to the solution of grain storage problems in Southeast Asia. No less a factor in the progress of the program is the breadth of expertise of the research staff selected to participate in it. Discussions are now under way as to the most effective procedure for taking the results of the research into the developmental stage.

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. Nevertheless, results obtained to date have confirmed that the method is practical under normal warehouse conditions in Southeast Asia.

Background

Summary

Most stocks of grain and similar commodities in Southeast Asia are held in warehouses as uncovered stacks of bagged commodity. Reliable insect control in such stacks is a difficult and often expensive procedure, which usually consists of several fumigations and regular spraying or fogging with insecticides. Project 8307 is concerned with investigating the reliability and limits of applicability of a method which relies on an initial disinfestation using carbon dioxide followed by long term 'insect-proof' storage in a sealed plastic enclosure. 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, by extensive replication of field treatments, the reliability of the overall method and to investigate some of the practical limitations to its use (Project 8307A). To support this work, laboratory studies are being conducted to determine the dosage of carbon dioxide needed to ensure a complete initial disinfestation of insects (Project 8307B).

Currently, methyl bromide and phosphine are the only widely available fumigants. Both materials are effective and acceptable in most parts of the world but there are specific locations where for various reasons either one or the other is not used, or if used, is not fully effective. 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 being maintained with related work in Indonesia, Papua New Guinea, and Singapore.

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

- *Australia*
  CSIRO Division of Entomology
  Research Leader: 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)
  Team Leader: Mr A. Robin Wahab
  LPN Coordinator: Mr Ahmad Ilham
- *Philippines*
  National Post-Harvest Institute for Research and Extension (NAPHIRE)
  Team Leader: Mrs G. Sabio
- *Thailand*
  Department of Agriculture, Entomology and Zoology Division
  Team Leader: Mr Montri Rumakom

Delays occurred in finalising agreements for project operations in Southeast Asia. Activities effectively commenced in January 1985 in all three countries, although some preparatory work was carried out before this. These delays were compounded after the commencement of work by problems with availability of enclosures for the stacks. These problems have now been overcome and it is expected that the major objective of obtaining a measure of the reliability of the carbon dioxide/sealed sheeting method of insect control will be realised within the revised time frame.

All field trials in the project are being carried out in Southeast Asia. A preliminary trial in Thailand, using locally supplied stack enclosures, has shown that the special skills required to fabricate these to the sealing standards required are not readily available in Thailand and that, for the present, enclosures should be imported.

A further trial in Thailand using phosphine rather than carbon dioxide indicated that this material has potential as a replacement for carbon dioxide in short term storage.

The series of substantive field trials planned for the project commenced in June 1985 and it is too early to be able to report any results.

The laboratory studies on the toxicity of carbon dioxide to grain pests are on schedule. Results to date using 40% carbon dioxide, the highest concentration included in the tests, indicate that the currently recommended treatment schedule for use of carbon dioxide for disinfestation may be marginal. This schedule requires an initial concentration of 70%, with 10 or more days with a concentration greater than 35%. This does not create a problem in properly sealed bag stacks, where concentrations typically remain greater than 35% for 30 days. However, it is apparent there can be no

reduction in the standard of sealing from that which is currently required.

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

This project provides for an evaluation of the reliability of the method over the wide range of conditions that would be encountered in commercial use, 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 is to concern bagged paddy, 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).
(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, activities would be expanded 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.

To achieve these objectives, a series of replicated trials with storage times between 3 and 12 months will be carried out in each of the overseas participating countries.

Stacks (each 100–200 tonnes) of bagged grain, mainly milled rice but including paddy and maize, will be used for evaluation of the enclosure techniques. Samples of the grain will be analysed for pre-trial quality and insect infestation. The stacks will then be sheeted and, following tests of the level of sealing, fumigated with carbon dioxide. Batches of test insects for bioassay will be included as appropriate.

During the storage period, the enclosure fabric will be inspected regularly and carbon dioxide levels, temperature, and relative humidity recorded within the stack. Insect trapping will take place in covered treated and untreated stacks to assess the reinfestation pressures after carbon dioxide concentrations have fallen below a nominal level.

Batches of stacks will be opened at predetermined intervals and assessed for changes in quality (moisture, mycotoxins, and user assessment) and insect infestation. If the quality is unchanged at a given opening time, the balance of the stacks will remain sealed until the next opening time. Comparison of the covered stacks with unsealed stacks will give an objective measure of the advantages of the method. If reinfestation occurs, the relationship between degree of gastightness and reinfestation will be examined.

The effective commencement date for project activities in Southeast Asia was January 1985. The proposed activities are outlined in the accompanying research schedule.

The schedule of trials has been amended from that originally proposed to conform with availability of grain and enclosures for the stacks in the various countries.

The enclosures for the first series of trials in each country were to be fabricated in Australia, where the equipment and technology are available. Substantial delays were experienced in the manufacture, shipping and, in one case, the clearance through customs of enclosures sent to Southeast Asia. Enclosures reached Thailand and Malaysia in April 1985. They were opened and inspected and were ready for trials which started in June 1985. Enclosures for the Philippines were delayed both in shipping and during clearance in Manila. Trials in the Philippines are now expected to start in about September 1985.

In Malaysia, trials will commence with rice and be extended later to paddy. Stacks of 200 tonnes will be used throughout. The first of the series of trials will commence in June 1985 and will involve storage for 3–6 months. Initially, a single stack will be held for approximately 6 months from June to November 1985. After examination of this preliminary experiment, 10 further stacks will be constructed progressively between November 1985 and July 1986 giving stacks with a range of storage times up to six months available for examination in July 1986. This trial will be followed by a longer-term trial between July 1986 and July 1987, involving six stacks and storage times ranging from 6–12 months. The first trial with paddy will commence in July 1986 and will use four stacks to examine storage for 3–6 months. This will be

Project 8307 field studies in Southeast Asia began in June 1985. The first trials in the Philippines are on bagged stacks of maize in an NFA warehouse at Cebu City. They are shown here. In the background are the unsealed control stacks.

followed in December 1986 by a similar trial with paddy, examining storage for 6–12 months. These trials will be carried out in the LPN storage complex at Pasir Gudang, Johore Bahru.

In the Philippines, the studies will involve paddy, rice, and maize. All stacks will contain 200 tonnes of grain. The trials with paddy and rice will be similar and carried out at the same time. Four stacks of each grain will be used in each trial. The series of trials will commence with short term trials with a duration up to six months, followed progressively in March 1986 with medium term trials with a duration of 6–9 months, and in December 1986 with long term trials with a duration of 9–12 months. With maize, the first trials will commence in November 1985 and continue to June 1986, followed by similar trials commencing in June 1986 and March 1987. Only two stacks will be used in each trial. The trials on paddy and rice will be carried out in the NFA storage complex at Isabela and on maize at the NFA complex at Cebu.

In Thailand, only rice will be used and storage times will nominally be up to six months. Stacks will be limited to 100 tonnes and three per trial. The first trial will commence in June 1985 and run until December 1985. The second trial will commence in March 1986 when more rice is available and continue provisionally until September 1986, but will be extended if appropriate until December. A final trial in the series will commence in December 1986. An additional large scale trial using a single stack of 200 tonnes of rice is proposed for the period May to November 1986, with a repeat commencing in December if possible. These trials will be carried out at the Mah Boonkrong Rice Mill in Pathumthani Province.

Trapping studies will be carried out in the Philippines only and will commence in December 1986.

Additional stacks, as available, will be fully instrumented for measurement of temperature and moisture profiles, which will be used in the development of models for moisture movement (Project 8310) with the object of determining optimal storage conditions.

The proposed trials in Malaysia and Thailand have been commenced and conform with the revised schedule of operations.

Laboratory Studies

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.

These objectives will be achieved by a series of experiments carried out in Australia and complemented with similar, but less comprehensive studies on other species, undertaken by NAPHIRE in the Philippines.

The data from Australia will be based on the responses of *Sitophilus oryzae* over a range of carbon dioxide contents between 10% and 40%. Batches of insects of known age will be exposed on grain in the laboratory to constant carbon dioxide contents for various time periods. The effects of this treatment will be assessed in terms of mortality, delay in adult emergence, and changes in fecundity.

Four laboratory experiments will be conducted sequentially, each involving the exposure of insects to one of four treatments: 40%, 30%, 20%, and 10% carbon dioxide. Each experiment will take about eight months to complete. Results obtained midway through each experiment will be tested under field conditions using caged test cultures introduced into those stacks in the field trials whose carbon dioxide contents have decayed to the appropriate level.

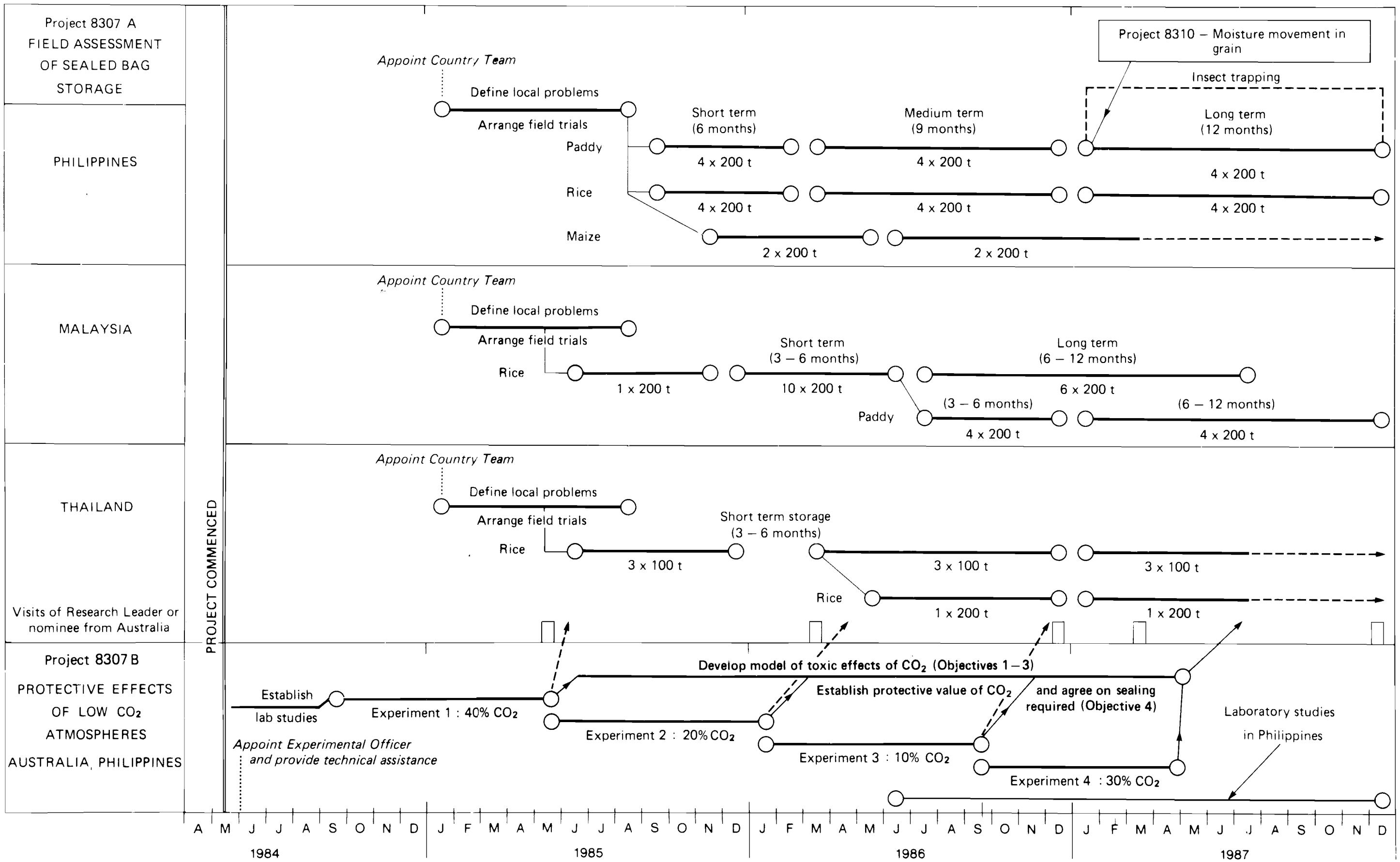
The experiments using 40% carbon dioxide are now complete and those with 20% carbon dioxide are in progress. This conforms with the agreed research schedule.

Organisation and Staff

The Record of Understanding between ACIAR and CSIRO was signed on 4 November 1983 but 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.

ACIAR GRAIN STORAGE RESEARCH PROGRAM

Project 8307 — Long term storage of grain under plastic covers



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

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. Mr Ahmad Robin Wahab of MARDI was confirmed as Team Leader. Other staff assigned to the project were Mr A. Rahim Muda, Entomologist from MARDI, and Mr Ahmad Ilham, Coordinator, Mr Idris Abas, Engineer, and Mr Lee Chin Hin, 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. The original nominee as Team Leader, Mr Enrico Corvera, was succeeded by Mrs Glory Sabio previously Entomologist in the Project. She is supported by Research Assistants, Mr Don David Julian and Mr Fernando Lingan, and Research Aide, Mr Dionisio Alvinda.

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, was confirmed as Team Leader and Mr Chuwit Sukprakarn as Entomologist and Project Coordinator. Other staff assigned to the project were Ms Kruawan Attaviriyasook, Agricultural Researcher, Mrs Kanjana Bhudhasamai, Seed Pathologist, Ms Lamaimaat Khowchaimaha, Agricultural Researcher, and Mrs Boodsara Promsatit, Entomologist.

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 Ahmad Robin Wahab, Team Leader
Mr Abdul Rahim Muda, Entomologist
Mr Dhiauddin Mohd Nour, Engineer

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

Philippines (NAPHIRE)
Mr Dionisio Alvinda, Research Aide
Mr Don David Julian, Research Assistant
Mr Fernando Lingan, Research Assistant
Mrs Glory Sabio, Team Leader, Entomologist

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

Research Activities in Australia

All research activities in Project 8307A are located in Southeast Asia and will be reported 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.

Effect of Carbon Dioxide on Developmental Stages of *Sitophilus oryzae*

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 *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 are now complete. These have shown that most stages of *S. oryzae* are killed easily, but that the prepupae/pupae require a long exposure (greater than 20 days) to ensure complete mortality. Experimental exposures to 20% carbon dioxide are now in progress but it is too early for any clear trends to be apparent.

The natural tolerance of *S. oryzae* pupae to carbon dioxide implies that the currently recommended treatment schedule for a carbon dioxide disinfestation (an initial concentration of 70% or more followed by 10 days above 35% carbon dioxide) may be marginal. In sealed sheeted bag stacks, this does not create a major problem as, in a typical treatment, carbon dioxide concentration remains greater than 35% for over 30 days.

However, the finding shows that there can be no reduction in the standard of sealing from that which is currently obtained.

Research Activities in Southeast Asia

Project 8307A comprises a series of field trials in Malaysia, the Philippines, and Thailand to develop methods for long term storage of grain under plastic covers. After some delays, the program has been established with trials underway in Malaysia and Thailand and scheduled for the Philippines in September 1985. The trials involve paddy, rice, and maize and are planned as a series of short, medium, and long term experiments to be carried out over a three year period.

Project 8307B concerns laboratory studies that will be carried out in major part in Australia with limited studies in the Philippines which are scheduled to commence in June 1986.

Mr P.C. Annis, the Australian Research Leader, visited Indonesia from 26 April to 1 May 1985 to follow up progress made by BULOG and the Tropical Development and Research Institute on the development of the sealed stack/carbon dioxide treatment method. He inspected a site near Jakarta where there was a long term semi-commercial trial of this method involving the storage of about 2000 tonnes of milled rice and gave a talk to BULOG grain storage scientists on some of the problems that needed resolving before the technique could be recommended for widespread commercial use.

Mr Annis also visited Singapore on 25–26 April 1985 for discussions with representatives of the Ministry of Trade and Intraco on progress towards carbon dioxide disinfestation and sealed storage of milled rice in Singapore. He had further discussions in Singapore on 14 June 1985.

Malaysia

Mr J. van Graver visited Malaysia from 19–28 August 1984 for preliminary discussions on project activities in Malaysia in anticipation of the agreement for these activities being finalised between the governments of Malaysia and Australia. During this visit, he participated in the ASEAN Crops Post-Harvest Programme 1984 Grains Post-Harvest Workshop held in Kuala Lumpur from 20–23 August.

The Australian Research Leader, Mr P.C. Annis, visited Malaysia from 7–14 June 1985 to assist in establishing the first of the stack trials scheduled for Malaysia.

The Team Leader, Mr Ahmad Robin Wahab, Mr Dhiauddin Mohd Nour, and Mr A. Rahim Muda also participated in the 1984 ASEAN Grains Post-Harvest Workshop. Mr Ahmad Robin Wahab and Mr A. Rahim Muda attended the ACIAR/NAPHIRE/AFHB Seminar on Pesticides and Humid Tropical Grain Storage Storage Systems held in Manila from 27–30 May 1985.

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. One stack of 200 tonnes was used initially with further stacks being brought in to give the total of 10 planned for the 12 months of the trial.

Philippines

Mr J. van Graver visited the Philippines from 1–7 August 1984 for discussions on project activities and to make arrangements for commencement of field trials. Mr van Graver, together with the Australian Research Leader, Mr P.C. Annis, visited the Philippines again from 25 May to 2 June 1985 to discuss project activities and to attend the ACIAR/NAPHIRE/AFHB Seminar on Pesticides and Humid Tropical Grain Storage Systems in Manila. Mr Annis presented a joint paper with Mr van Graver on 'Use of carbon dioxide and sealed storage to control insects in bagged grain and similar commodities' and Mr van Graver acted as rapporteur for the session on 'Framework for use of pesticides'.

Mr Annis held a Team Leaders' meeting during the seminar and also convened a discussion group on 28 May to discuss interpretation of quality assessments of grain stored under plastic covers.

Mr van Graver remained in the Philippines after the seminar to assist in arrangements for establishing the field trials.

The Philippine Team Leader, Mrs G. Sabio, participated in the ASEAN Crops Post-Harvest Programme 1984 Grains Post-Harvest Workshop held in Kuala Lumpur from 21–24 August 1984 and the ACIAR/NAPHIRE/AFHB Seminar on Pesticides and Humid Tropical Grain Storage Systems held in Manila from 27–30 May 1985.

Field trials

Trials on short term storage of paddy and rice are expected to commence in September 1985 and on maize in November 1985.

Thailand

Mr J. van Graver visited Thailand from 28 August to 1 September 1984 to prepare for the series of trials using stack enclosures fabricated in Australia. The Australian Research Leader, Mr P.C. Annis, assisted local staff when the first of these trials was established in June 1985. His visit from 2–7 June also allowed opportunity for discussions on the future program.

Mr Chuwit Sukprakarn participated in the ASEAN Crops Post-Harvest Programme 1984 Grains Post-Harvest Workshop held in Kuala Lumpur from 21–24 August 1984.

The Team Leader, Mr Montri Rumakom, Miss Lamaimaat Khowchaimaha, and Mr Chuwit Sukprakarn, attended the ACIAR/NAPHIRE/AFHB Seminar on Pesticides and Humid Tropical Grain Storage Systems held in Manila from 27–30 May 1985. Mr Chuwit Sukprakarn presented a paper entitled 'Pest problems and use of pesticides in grain storage in Thailand'.

Field trials

A preliminary trial was carried out at the Mah Boonkrong Rice Mill in Pathumthani Province between June and August 1984 to test whether it was feasible to fabricate sealed enclosures at the storage site.[1]

Two stacks, each of 88 tonnes of bagged milled rice, were built on wooden pallets over a PVC floor sheet. The stacks were covered with locally made plastic enclosures which were bonded to the floor sheet with double-sided adhesive tape. Carbon dioxide was then introduced to give average concentrations of 81 and 83%. Readings taken after 24 hours indicated concentrations of carbon dioxide less than 35%, signalling failure of the sealing and no prospect of insecticidal activity. This was confirmed when the stacks were opened 30 and 60 days later and large numbers of living insects were found. These included psocids, *Sitophilus oryzae*, *Tribolium castaneum*, and *Oryzaephilus surinamensis*. The trial showed that it was not possible to fabricate an adequately sealed enclosure on site with locally available equipment and that this operation should be carried out where proper facilities and equipment are available. A manufacturer with such facilities could not be found in Thailand and, in the short term, the enclosures will have to be imported.

A second trial was carried out at the same site from 13 December 1984 to 8 February 1985, using phosphine fumigation for the initial disinfestation treatment1. Two stacks of bagged off-season milled rice each of 50 tonnes were built on wooden pallets over a concrete floor and covered with 0.375 mm sheeting which was held to the floor with sand snakes. Phosphine generating tablets were placed beneath the pallets before final sealing. A dose rate of 2.2 g phosphine/tonne was used. The stacks were opened 30 and 60 days later. On sampling, no live insects were detected but fungal infection was increasing with storage time. The quality of the rice did not change markedly and all samples were acceptable. It was concluded that phosphine could be used to preserve milled rice in storage for periods up to two months.

The first of a series of trials storing milled rice in 100 tonne bag stacks commenced at the Mah Boonkrong Rice Mill in June 1985 using enclosures imported from Australia. Three stacks were used and the planned storage periods ranged to 6 months.

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[1] Montri Rumakom, Chuwit Sukprakarn, Kruawan Attaviriyasook, Kanjana Bhudhasamai, Lamaimaat Khowchaimaha, and Boodsara Promsatit 1985. Long term storage of grain under plastic covers. (Trial 1. Carbon dioxide, Trial 2. Phosphine). Reports of ACIAR Research Projects in MOAC–ACIAR Consultative Meeting on Agricultural Research Collaboration, 20–22 November 1985. Thailand, Department of Agriculture, 1–32.

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 is being established to offer programmable temperature and moisture regimes for commodity samples and accurate measurement of moisture interaction between samples and their environments. Grain moisture sensors have been developed for in situ monitoring of 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 rapid deterioration particularly from the activity of insects and moulds, whose proliferation is intimately associated with high temperatures and humidities. Despite this, moisture related characteristics of many commodities and their associated organisms are poorly understood.

Generally, moisture interchange occurs in bulk, particulate commodities through the intermediary of 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. It is through this microenvironment that pest management procedures are imposed.

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 biological variability, the effects of hysteresis, and the inappropriateness of static analysis of dynamic systems, but also the difficulty of measuring moisture and the consequent diversity of experimental methods that have been employed.

While the moisture content of commodities themselves rather than that of their interstitial microenvironments 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.

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. Moreover, successful conduct of the ACIAR program's field trials on storage of bagged (Project 8307) and bulk grain (Project 8308) depends on adequate monitoring of conditions in the commodities, as indeed will any commercial developments of storage technique.

Project 8307D is providing a better understanding of grain moisture phenomena by clarifying and evaluating existing data and rectifying deficiencies. A grain moisture sensor has been developed that will enable 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.

For a number of reasons, progress has been slower than intended. Nevertheless, it is expected that the project can be brought to fruition within the planned three year time span but from the effective date of commencement. In view of the opportunities for expanded study offered by the new technique, there may be grounds for extending the project into other areas at the end of this period.

Expected Benefits

Much of the inconsistency in published information on moisture related properties of bulk-stored food products arises from differences in experimental and measurement procedures. Existing data will become far more valuable when they are rendered more accessible, their information content is critically appraised, and the information is expressed systematically in standardised forms.

The test facility will allow relatively fast collection of data in a standardised manner to rectify present inadequacies and generally to expand our understanding of moisture related phenomena. It will rely 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.

It is axiomatic that research leading to 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.

The specific objectives of this project include the following:

1. (a) A comprehensive catalogue will be compiled 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 will be 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 will be established and used to rectify deficiencies in the information emerging from the above and to improve its quality. Attention will concentrate 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 will be 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. To liaise closely 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.

Delays in the appointment of Mr S.A. Rogers, as Technical Officer resulted in the project effectively commencing about six months later than intended. Difficulties in acquiring equipment also contributed delays and it has become clear that the amount of professional input required during the development phase was seriously underestimated. It is unlikely that the six month lag can be reduced.

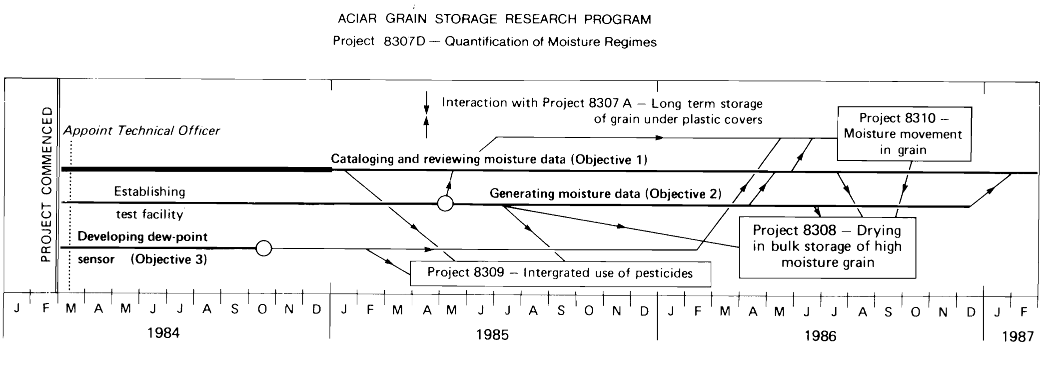
Organisation and Staff

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 1983–84: Mr J.R. Wiseman as Research Leader and Mr S.A. Rogers as Technical Officer.

Research Activities in Australia

Commodity Moisture Characteristics Data Bank

Data are being assembled on the moisture characteristics of a diverse range of agricultural commodities. These data have been scattered through the literature and obtained by numerous researchers using differing apparatus and techniques. To render this bank of information accessible, database techniques are being used to consolidate the material into a systematic form.



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

Grain Storage Research Program
Project 8307D Staff

Australia (CSIRO Division of Entomology)
Mr S.A. Rogers, Technical Officer
Mr J.R. Wiseman, Research Leader

Generation of Commodity Moisture Characteristics Data

Components of the moisture interaction equipment, central to the second objective, have been operated at prototype level, the measurement/control concepts proved, and much of the software written. This equipment consists (initially) of eight chambers and a microcomputer which monitors their temperatures and, using peltier heat pumps, precisely maintains or modifies them in accordance with the test program. Alternate chambers house commodity samples, the remainder being used in generating atmospheres having programmed humidities. The required atmosphere is fed through a precise dewpoint meter, through the sample, and then to a second dewpoint meter. Differences between the two dewpoint readings provide a very sensitive measure of moisture exchange between sample and atmosphere. 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.

The development of this equipment has suffered delays. The sensitive moisture meters on which the project relies were delivered some months late and modifying them to suit this application has proved unexpectedly time consuming. An erratic hardware fault in the controlling microcomputer has resulted in much of the calibration having to be repeated. In the light of this and other experiences it is apparent that the project relies too heavily on the single microcomputer and that a more powerful machine is required to share what has proved to be a substantial load. It is anticipated that full operations will commence in October 1985, several months later than planned.

Development of Remote Measuring Sensors

The development of the remote moisture sensor has followed two lines. Simple peltier cooled devices for measuring the humidity of intergranular air have been investigated and, although very promising, they would be too costly for widespread use. A cheap capacitance sensitive device responding to water in its vicinity has been developed. It also provides temperature readings. Laboratory studies indicate that the devices, though not precision instruments, are adequately stable, and particularly sensitive to changes in commodity moisture content. Their absolute accuracy in wheat at maximum commercial moisture content is within 1% m.c. and once installed in a static bulk, they reliably detect changes of less than 0.2% m.c.

About 20 of these sensors were evaluated in Queensland storages in cooperation with Dr M. Bengston (Project 8309). In one case, a heating front and the leading edge of a moisture front were detected before the bin was emptied to deal with an associated insect infestation. The same sensors are to be evaluated in rice by Mr J. Darby of Ricegrowers' Co-operative Ltd (Project 8308B).

There has been considerable demand from researchers for the sensors, and to meet that demand and to confirm that standard production practices will yield devices offering reproducible results, a small commercial production run is contemplated. A multichannel measuring instrument suitable for general field use is also required, and it is probable that this too could be produced commercially in Australia.

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 theoretical objectives of the project were to study the movement of moisture and temperature profiles through aerated bulk grain and develop models to describe this. These have been accomplished. Pilot drying facilities to determine optimum drying strategies are operational in Australia, the Philippines, and Thailand, and under construction in Malaysia. Quality studies are an integral part of these investigations. The results obtained indicate that in-store drying will be feasible in the humid tropics.

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 seeks to extend this technology into the humid tropics. The research strategy is to develop a thorough understanding of grain deterioration in tropical climates and a robust drying model that will predict both thermophysical drying relationships and the resultant effect on quality for any set of drying conditions. This information, together with pilot plant and field evaluations in Southeast Asia, is being used to develop aeration and drying systems appropriate for the region.

The project is being implemented by a joint research arrangement between the School 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 — School 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
- *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

Studies at the University of New South Wales on heat and mass transfer in a grain bulk have provided a sound theoretical basis for understanding the rice-drying process in a deep bed. The basic inputs required for accurate prediction of the drying rate of a mass of rice are the drying rate of a thin layer of rice, the isothermal data, and information on the physical bulk properties. Simulations of a rice bed have been used in conjunction with meteorological data to design rice bed dimensions. With this procedure, the optimum drying strategy for particular meteorological conditions can be identified.

Considerable research has gone into testing and proving the dependability and accuracy of the simulation model under tropical conditions. A significant defect in the rice drying model is lack of drying rate and isothermal data for Southeast Asian rice varieties, and collection of these data is currently a major component of the research work in Southeast Asia. This additional information will add to the reliability of the model's predictions. The drying model will also be tested for its accuracy under field conditions, with field trials on large grain stores planned for the last year of the current project.

The studies at Ricegrowers' Co-operative 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.

Considerable emphasis has been placed on optimising drying strategies. This includes evaluation of two-stage drying systems to counter the rapid rate of deterioration of grain that can result from the high receival moisture contents of grains at drying facilities, and the high ambient temperatures and humidities in the tropics, particularly during the wet season. In order to prevent substantial losses, grain moisture content must be reduced to 18–19% maximum within 24 hours of harvesting. In order to gain the maximum advantage of the cost and quality gains of the ambient air drying methods used in Australia, it is therefore necessary to dry the grain in two stages. The first is a fast drying stage using conventional high energy input dryers. The second stage removes the moisture at a sufficiently slow rate to conserve quality, and costs about one tenth of the cost of the fast drying stage on a dollars per tonne basis for each percentage point of moisture removed.

Much of the basic data required for developing drying strategies are generated in scaled-down pilot plants which simulate conditions in commercial-scale facilities. The value of the pilot plant is twofold: firstly, to demonstrate safe drying techniques; and secondly, to test and develop improved drying strategies. The control system used allows the implementation of a variety of control strategies, such as controlled inlet humidity, air-selection on the basis of relative humidity, and constant supplementary heating. Parameters such as grain depth and air speed can also be controlled. Each drying run may be accompanied by detailed grain quality appraisals involving physical analysis (dry matter loss, grain purity, moisture content, milling recovery, damaged grain), biological assay (microbial infection, identification of pests), and chemical analysis (mycotoxin, free fatty acid and ergosterol levels). Tests can also be made on the plant energy efficiency, drying efficiency, overall thermal efficiency, and economic viability.

Activities in the *Philippines*, now in their second year, have progressed satisfactorily and at June 1985 were on schedule. Work carried out during the past year included assessment of equilibrium moisture contents of six local rice varieties and construction of the pilot plant dryer facilities, which were completed in December 1984, preliminary pilot plant drying trials conducted in January and February 1985, and dry season pilot plant drying trials conducted in April to June 1985.

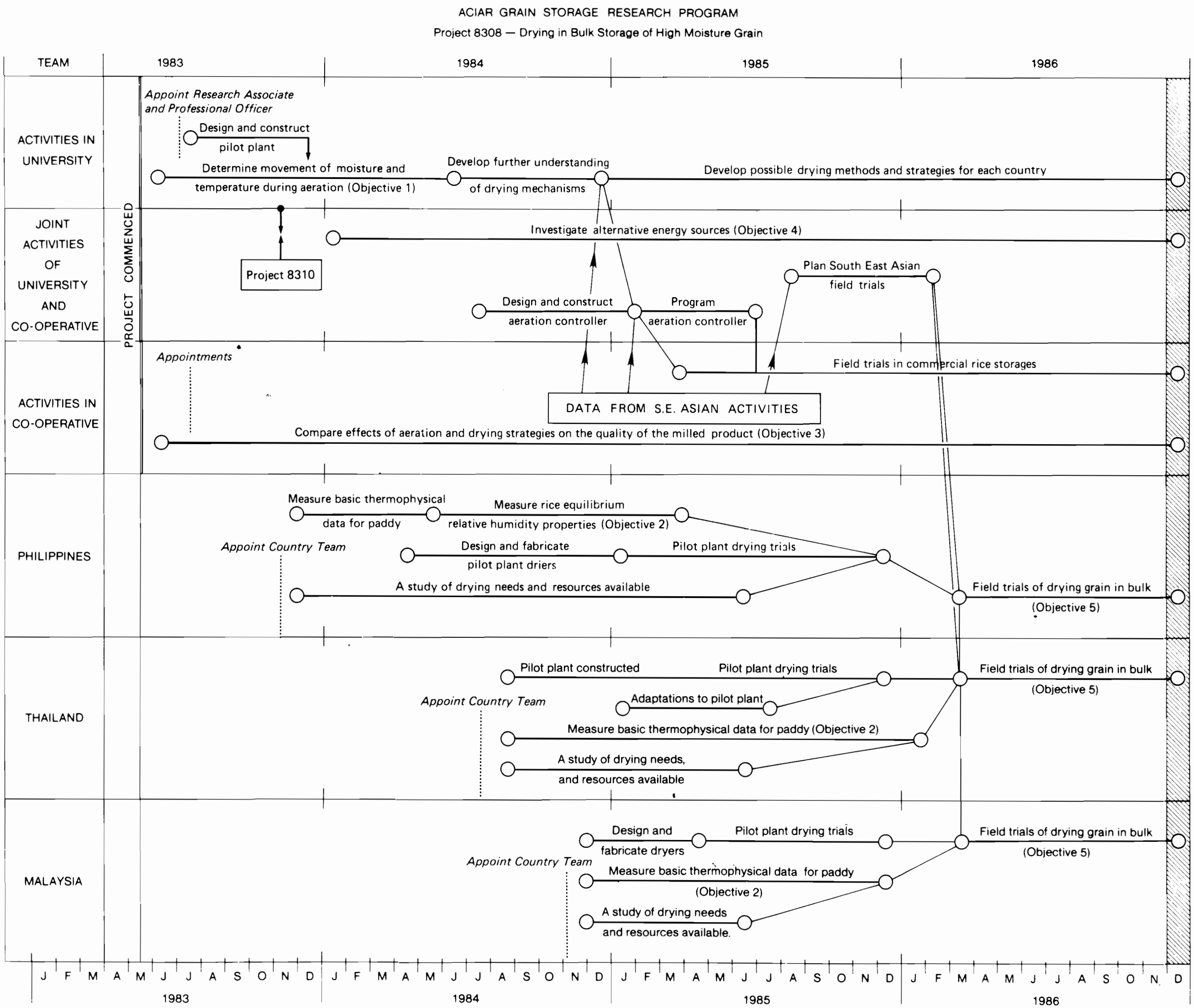
The equilibrium moisture content studies have shown that values vary significantly with varieties and that drying air relative humidities up to 80% may be used to reduce moisture contents to 14% wet basis (w.b.) in some varieties.

In the dry season pilot plant trials, ambient air with supplemental heat from fan compression has been used successfully for in-store drying. Paddy in beds of 2.0–2.3 m depth has been dried safely from an initial moisture content of 18–25% w.b. to about 14% w.b. in 60–158 hours, equivalent to 5–17 days drying period. An airflow rate of 1.9 $m^3/min/m^3$ paddy (4 m/min air velocity) was found suitable for paddy with 18% w.b. initial moisture content while an airflow rate of 3.6 $m^3/min/m^3$ paddy was suitable for paddy with 23–25% w.b. initial moisture content. Specific energy costs were PHP7.20–30.15 per tonne. Quality analysis of in-store dried paddy samples indicated no difference from naturally dried control samples in terms of brown rice and germination rate, while quality was improved in terms of crack ratio and head rice yield and recovery. Head rice yield was in the range of 45.7–59.4% of paddy weight, equivalent to head rice recovery of 70.1–89.3% of milled rice weight. Crack ratio varies from 0.0025 to 0.22 depending upon the history of grain. The highest value of yellow rice obtained was 1.95%, below the tolerable limit of 2–3% for premium grade. Dry matter loss was within the tolerable limit in the range of 0.05–0.87%. No visible growth of moulds was found in the dried samples.

The pilot plant drying experiments will be carried out again during the wet season harvest (September–December 1985) and the in-store drying strategy appropriate to wet season drying needs will be investigated. Field trials will commence in 1986 after the pilot plant trials.

Project work in *Thailand* included the design and construction of the pilot plant, three experiments on drying paddy in bulk storage, development of simulation models of rice drying (logarithmic and near-equilibrium), and analysis of drying strategies. Paddy at an initial moisture content of 18–22% w.b. was successfully dried to 14% under tropical, wet season conditions, with no apparent loss of quality or viability. It was found that, of the three drying methods tested, continuous ventilation with heating of the inlet air to attain a relative humidity of 65% was the most economical. A solar hut dryer has been developed. The hut takes advantage of sun-heated air to dry rice at farm level, and has proved successful in trials.

Activities in *Malaysia* are at an earlier stage than in the Philippines and Thailand because of the later start in November 1984. Nevertheless, thermo-



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

physical data on local rice varieties are being assembled and arrangements for provision of pilot drying facilities are well advanced.

In the remaining year of the project, a large part of the research effort will be devoted to the implementation of field trials in the Philippines, Malaysia, and Australia. The aim of these field trials is to demonstrate, on a commercial scale, successful strategies for drying grain in the humid tropics, developed from the pilot plant drying experiments and simulation studies. Existing silos and storage bins will be used. The field trials are being designed in such a way as to monitor the chosen rice storage facility closely. The inlet air and outlet air will be monitored continuously. At various levels within the grain, the dry and wet bulb temperatures will also be monitored. The complete records can then be analysed to show the position and extent of drying fronts as they propagate through the bed. At the end of the drying process, the grain quality will be measured using milling trials and estimates of the degree of yellowing and mould growth.

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 preheating of ambient air is required.
5. Potential for development of central monitoring systems for storage conditions and stock assessment.

In addressing specific issues in project activities, a thorough practical and technical understanding will be achieved of rice breakage, yellowing, and mould growth under tropical conditions. From this, it will be possible to arrest quality deterioration, with commensurate increases in food availability through decrease in dry matter loss and elimination of low quality grain. Similar benefits would accrue with maize and other grains, reducing economic losses and operational expenses generally.

Grain Storage Research Program
Project 8308 Staff

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

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, Collaborator

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

Thailand (King Mongkut's Institute of Technology)
Dr Ratana Chirarattananon, Assistant
Mr Chatchai Karnjanaboon, Research Student
Miss Petchara Prechakool, Research Student
Dr Somchart Soponronnarit, Team Leader

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.

After harvest, grain deteriorates rapidly in the humid tropics, and safe and timely methods of drying grain are essential. The drying methods developed must be efficient, cost-effective, and reliable. They must be soundly based to be applicable throughout the region under diverse conditions and to a range of commodities.

For these reasons, a sound theoretical understanding of the heat and mass transfer processes occurring in a grain bed is required and it is necessary to simulate the movement of drying fronts in computer models. These simulations must be compared with data obtained from rice drying in pilot plants, and with basic data relating to grain properties such as water activity levels, drying rates of thin layers of grain, physical properties such as grain size, grain types, and with weather records from the various tropical countries. These data are the input for the models to optimise rate of movement of moisture drying fronts and so development of safe drying methods.

The objectives of the project thus include the following.

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

By the end of the third year, it is anticipated that grain will 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 have necessitated some compression of the research schedules, particularly in Malaysia. These delays have not affected progress of the theoretical research developments at the University and the quality studies at the Co-operative. At present, considerable effort is being directed towards the construction of pilot plants in Malaysia, in time for the wet season harvests later this year. By then, it is anticipated that all countries will have constructed pilot plants, received and fitted control equipment, and have them operational ready for the wet season harvests. On that basis, project activities will be on schedule and the field trials of drying grain in bulk in the third year (Objective 5) will be realised. It is anticipated that the project as a whole will have achieved its objectives and be within the approved budget by December 1986, in accordance with the research schedule.

Organisation and Staff

Dr R.H. Driscoll, the Research Leader of Project 8308B, was appointed as Lecturer in Food Technology in the School of Food Science and Technology of the University of New South Wales on 15 February 1985. Although no longer funded by ACIAR, his responsibilities as Research Leader remain unchanged. Mr K. Thong Do was appointed as a Professional Officer on 1 April 1985 to assist with pilot plant development and computing studies. Mrs Paula Koussa was appointed on 4 March 1985 to provide part-time administrative assistance to the project.

Agreements for overseas operations were finalised between the University of New South Wales and all participating countries during 1984. The Memorandum of Understanding between the governments of Thailand and Australia was signed on 6 July 1984, nominating King Mongkut's Institute of Technology, Thonburi as the implementing agency in Thailand and the Project Document covering activities in Malaysia was signed for the Government of Malaysia on 26 November 1984, nominating the National Paddy and Rice Authority (LPN) as the implementing agency in that country. The agreement for collaborative activities with NAPHIRE in the Philippines had been finalised on 22 November 1983.

Dr Ratana Putranon was confirmed as Team Leader in Thailand and Mr Loo Kau Fa in Malaysia. Dr Somchart Soponronnarit replaced Dr Ratana Chirarattananon (nee Putranon) as Team Leader in Thailand on 3 December 1984. Dr Ratana will continue working in the project.

The Team Leader in the Philippines is Mr Justin Tumambing. Mr Manolito Bulaong, an agricultural engineer, was appointed as full-time research associate in the project.

Research Activities in Australia

Drying Strategy

A major area of theoretical research at present is in designing methods of approaching the diversity of drying situations found in Southeast Asia. The large number of factors involved, such as farm size, receival moisture content, availability of energy sources, and range of weather suitability for drying, means that there is no unique solution to the acute wet season harvest problem. One possible general approach being investigated at present for large drying facilities, such as at a mill or procurement centre, is the possibility of dividing the drying process into two distinct stages. The first would have the sole purpose of reducing the moisture content of the grain quickly, while avoiding overdrying or rewetting of the grain, in order to protect the quality of the rice. The semi-dried rice could then be transferred to a slow drying facility, where the bound moisture is removed at a more economical rate in large aeration/drying bins, in which the dried grain could be stored for milling. Simulation studies have indicated large reductions in drying costs are possible by using this two-stage method. The first stage of drying could be done by conventional column driers, spouted or fluidised beds, LSU-type driers, or any other type of simple fast dryer where a certain percentage of the moisture is removed with each pass.

Further developments of the rice drying principles are currently being pursued by pilot plant experiments in the four countries. Each country is studying slightly different approaches to the same wet season harvest problem.

Current research efforts have also been devoted towards investigating drying facilities at a medium mill-level operation. Simulation studies are planned for small-scale and larger scale operations, in order to study a diversity of Asian situations. To ensure that the results are meaningful, studies of rice postharvest infrastructure are being pursued in various countries. The data from these studies will be a major contribution to the bulk storage project in Malaysia (Project 8344).

A further direction for research is into the area of bulk grain cooling as a short-term quality preservation measure. Studies on mill drying facilities at present include the possibility of a receival bin fitted with a refrigeration unit, which could be used to hold grain arriving at the mill in poor condition, when inadequate drying facilities are present. The major current objection to this method is the high cost of cooling the grain. However, economical methods of cooling are being investigated in other projects of the ACIAR program, and the benefits of saving poor grain may well outweigh in some situations the cost of total loss of that grain.

Economic studies are also proceeding on bed dryers and other fast and slow- drying methods, including those using spouted and fluidised bed technology, in order to determine the relative economies of alternative drying methods. Further research is also needed on alternative energy sources, such as wind and solar power, and combustion of rice hulls.

Simulation Models of Grain Drying

The development of computer simulations of grain-drying behaviour is a prerequisite for studying drying methods. The models can be used to test drying strategies, and hence to make detailed recommendations on the best methods of drying grain in particular localities.

Following evaluation of the different computer simulation models reported previously, an improved drying model has been incorporated into the slow-drying simulation model RICE. The model has been developed for Australian conditions and has been tested only with Australian varieties, for which it gives accurate shape and speed predictions. Data are being collected from overseas for a specifically Asian rice model. The main data required are rice isotherms and thin-layer drying rates.

Program RICE has been incorporated into a more general program that allows selection of weather data from Indonesia, Thailand, Malaysia, Darwin, Queensland, or New South Wales. There are currently 60MB of raw weather data available on computer tapes at the University, of which 8MB are reserved for simulation use. Rice drying simulations for the various regions can therefore be run quickly. The program is currently being extended to include economic evaluations of running costs.

RICE has also been adapted and incorporated into a program called MILL, designed for simulating mill-site stationary drying facilities. The paddy is received into a storage bin. Preliminary drying is performed with batch dryers and completed in a deep-bed dryer. The grain is then transferred to an aerated storage bin which supplies the mill. Simulation studies indicate the technological feasibility of this strategy, especially at high paddy receival moisture contents. It may be advantageous to provide both the receival and aeration storage bins with air cooling units, to lower the temperature of the grain and so reduce grain deterioration during the holding periods.

Pilot Drying Bin Studies

The University of New South Wales pilot-plant bin has been operated over the last year using 250 to 500 kg of rice per experiment. The experimental results have proven to be sufficiently accurate to allow assessment of the theoretical model. The following points relate to the comparisons between theory and experimental results.

1. The predictions of B-zone conditions are extremely accurate. The B zone is the area of the bed which has been passed by the heat front but has not yet been reached by the moisture front during constant drying operations.
2. The predictions of the moisture front speeds are also accurate. Predictions of the position of the middle of the drying front (corresponding to a moisture ratio of 0.5) are generally exact, as are those of the outlet relative humidity.
3. The moisture front profiles are predicted accurately over the tail, but not the leading edge of the front. The discrepancy at the leading edge

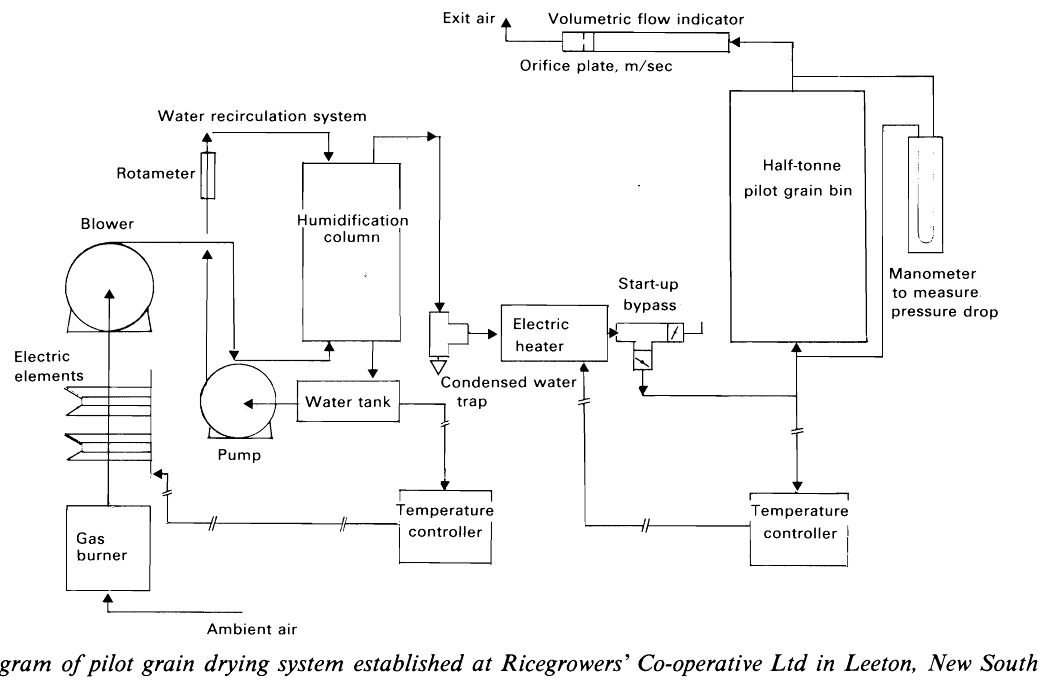


Diagram of pilot grain drying system established at Ricegrowers' Co-operative Ltd in Leeton, New South Wales. The drying bin holds 500 kg of grain.

may be due to heat transfer effects not included in the model, but in any case does not significantly affect the final predictions of the model.

The model has been confirmed at speeds up to 15 m/min, and temperatures varying from temperate to tropical.

A new method for wetting experimental rice was tested, but proved unsuccessful as it led to localised wet spots and mould growth. Because a satisfactory method for wetting large amounts of grain to the moisture content required for an experiment has not been found, future experiments will be performed using a smaller diameter bin. The smaller amounts of rice involved should lead to more accurate experimental results.

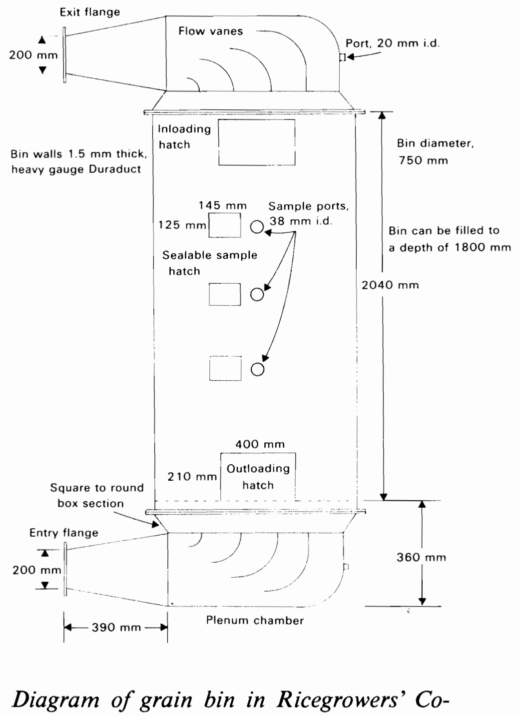


Diagram of grain bin in Ricegrowers' Co-operative 500 kg pilot drying system.

Effect of Aeration and Drying Strategies on Quality

Following earlier studies at the Ricegrowers' Co-operative using a series of 5 kg test beds of paddy to examine the effects of aeration on quality, a 500 kg pilot drying system has been commissioned to extend these studies, particularly as related to kernel breakage. The system can generate the full range of ASEAN and Australian weather conditions with flow rates capable of fluidising paddy rice. Computer control and data logging are directly on line. The new system will enable drying strategies with and without heated air to be examined and flow rate and burner controller trials to be performed.

Initial experiments on discoloration of rice have been completed. The results confirmed the dependence of yellowing on time, temperature, and grain moisture content. The results, however, were not quantifiable to the extent required for mathematical simulation in the theoretical models being developed. A constraint to these studies has been the apparent absence from the Australian industry of a species of mould that has consistently been reported in connection with yellowing of rice in Asia.

Collection of data on the hygroscopic properties of rice varieties and their relationship to air conditions and previous moisture history has continued.

Breakage of Rice

The literature on rice kernel breakage has been reviewed to determine the critical variables known to affect breakage. From this information, a mathematical description has been derived of the changing moisture gradient within a single rice kernel during wetting and drying. The relevance of this parameter to kernel breakage and its mathematical relationship to air and grain conditions have been examined using the 500 kg drying system. The data obtained indicated that the milling quality of rice was not directly affected by the rate of drying but by the post-drying treatment imposed on the grain. The parameter thus appears less significant as an index of kernel breakage than was originally thought.

It was of particular significance that rapid drying minimally affected the finished product whole grain yield and that the control of the conditions presented to the grain for up to the next four weeks was most critical. These results have a vital influence on the design of rapid drying facilities in tropical climates and will set the design parameters of the dryers and the control strategy for post-drying bulk storage systems. The field trials in Southeast Asia are planned to verify this.

GLC Analysis of Ergosterol in Rice Moulds

A method has been developed by collaborators in the Department of Analytical Chemistry of the University of New South Wales for determining the biomass of mould present in rice grain based on gas-liquid chromatographic (GLC) estimation of ergosterol.

The ergosterol was estimated by the following method.

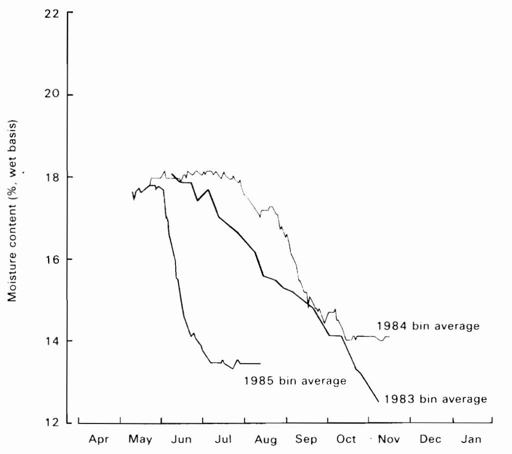
Dried samples of rice were ground and extracted several times with methanol. The extract was centrifuged and the supernatant concentrated before hydrolysis with ethanolic postassium hydroxide. The ergosterol and other unhydrolysed organic materials were then extracted from the reaction mixture with petroleum ether, the solution dried, decanted, and the petroleum ether replaced with chloroform before clean-up in an alumina column. After removal of the chloroform, the extract was weighed and either injected directly into the GLC, or after dilution with chloroform.

GLC separations were done with dinitrogen carrier gas flowing through a standard packed OV-17 column at 295°C. The ergosterol was measured with a flame ionisation detector over the range of 0.2–50 μg.

Field Trials in Australia on Commercial Paddy Stores

The field trial planned for the Australian 1985 harvest was not carried out as essential control equipment was not available on time from the suppliers.

A new version of the automatic control hardware was installed in some of the Co-operative's stores in association with expansion of LPG burner installations. Evaluation of these installations and the continuous adjustment of drying strategies has particular significance in raising the efficiency of the in-store drying operation as illustrated in an accompanying graph.



Plots of moisture content vs. time, showing improvement in management of drying of bulk paddy in Australia with progressive retirement of aeration controller operation.

Research Activities in Southeast Asia

Meetings between Australian project personnel and the Team Leaders from Malaysia, the Philippines, and Thailand were held in Kuala Lumpur on 22 August 1984 and in Australia from 16–19 April 1985 to compare research results and plan on-going activities.

Assessments have been made in each country of the nature of the problem of drying grain to safe storage levels and data have been assembled on local weather conditions and the physical properties of the varieties of paddy produced. Pilot plant drying experiments have been carried out during the dry season harvests in the Philippines and Thailand and trials will commence soon in Malaysia. Currently, similar activities are being planned for the wet season harvests at the end of 1985.

Malaysia

The Australian Project Leaders, Dr R.H. Driscoll and Mr L.D. Bramall, together with Mr G. Pym (Project 8308B) and the Program Coordinator, visited Malaysia from 18–26 August 1984 for discussions on implementation of Project 8308 in Malaysia in anticipation of the agreement for project activities being finalised between the governments of Malaysia and Australia. They also participated at Alor Setar and Tanjung Kerang in project formulation discussions for Project 8344 on bulk handling of paddy in Malaysia and attended the ASEAN Crops Post-Harvest Programme 1984 Grains Post-Harvest Workshop, which was held in Kuala Lumpur from 20–23 August. A meeting of the Team Leaders of Project 8308 was convened during the ACPHP Workshop.

The agreement for project activities in Malaysia was finalised on 25 November 1984.

The Malaysian Team Leader, Mr Loo Kau Fa, held discussions on project implementation with Australian project personnel during a visit to Leeton on 12–14 August 1984 to participate in project formulation discussions on Project 8344 on bulk handling of paddy in Malaysia. He also participated in Team Leaders' meetings held in Kuala Lumpur on 22 August 1984, in Australia from 16–19 April 1985, and at the 1984 ASEAN

Grains Post-Harvest Workshop. Mr Dhiauddin Mohd Nour also attended this workshop.

Currently, attention is being given to assembling chemicophysical data on Malaysian rice varieties and providing a pilot drying plant to evaluate methods of drying under local conditions.

Rice postproduction systems

A report entitled 'Introduction of paddy bulk handling in Malaysia: problems and development needs' was prepared by the Malaysian team. The report outlined the current situation in Malaysia with respect to wet season harvests and underlined the need for the country to move rapidly towards bulk handling methods in grain postharvest operations. Rice production trends over the last two decades were analysed, along with rice imports and the distribution of rice growing areas in terms of needs and production.

Pilot drying bin studies

A design for a pilot drying plant has been developed jointly by the University and the Malaysian Team. It is based on the recommendations included in a report ('Pilot plant: proposal for Malaysia') prepared by the University of New South Wales. The first section of the report is a theoretical justification of the pilot plant design, in which the weather patterns for Malaysia are analysed with regard to their rice-drying capabilities, and a basic strategy for drying grain in tropical countries is suggested. The second section of the report is devoted to the actual design of a pilot plant for Malaysia. The drying bin will have a bed depth of grain of 0.3 to 1 m and will operate at initial grain moisture contents of 23 to 30% w.b. Inlet air speeds will be variable between 10 to 20 m/min and supplementary heating can be provided over the range +10°C to +30°C. It has been proposed that the plant be located at Anak Bukit near Alor Setar where a research laboratory for LPN is under construction. Quotes have been received for construction of the pilot plant, and work should be completed within the next one to two months in time for the wet season harvest.

Philippines

The Australian Project Leaders, Dr R.H. Driscoll and Mr L.D. Bramall, together with Mr G. Pym (Project 8308B), visited the Philippines from 15–18 August 1984 for discussions with the

These deep bed drying bins in Malaysia are to have computer controllers fitted to their fans and burners for studies forming part of Project 8308.

local Team Leader Mr Justin Tumambing, and to inspect facilities for drying trials at NAPHIRE and in the field. They also visited the International Rice Research Institute.

The Team Leader, Mr Tumambing, attended the ASEAN Grains Post-Harvest Workshop which was held from 21–24 August 1984 in Kuala Lumpur, Malaysia, and presented a paper entitled 'Testing and evaluation of rice hull-fired furnaces for grain drying'. He also attended the Project 8308 Team Leaders' meeting that was convened during the Workshop.

Mr Tumambing attended the further Team Leaders' meeting that was held in Australia from 12–20 April 1985 and the ACIAR/NAPHIRE/AFHB Seminar on Pesticides and Humid Tropical Grain Storage Systems, which was held in Manila from 27–30 May 1985.

Equilibrium moisture content of local rice varieties

Equilibrium moisture contents (e.m.c.) of six local rice varieties (equilibrated over supersaturated salt solutions) were measured at three temperatures and a range of relative humidities (21.1°C — 52.9, 59.0, 75.4, 88.8, 92.9% RH; 26.7°C — 27.5, 58.0, 75.3, 86.6, 91.5% RH; 32.2°C — 25.0, 56.0, 75.2, 84.3, 90.1% RH).

At 90% RH and below, the moisture contents decreased as the temperature increased from 21.1 to 32.2°C except for IR50 and IR56. At 75% RH, moisture contents ranged from 12.98 to 14.06% at 21.1°C, from 12.52 to 13.67% at 26.7°C, and from 12.18 to 13.26% at 32.2°C. These results indicate that, based on the recommended 14% final grain moisture content after drying, some rice varieties may be exposed to drying air with a relative humidity slightly higher than 75%. This would be particularly so for ambient air drying. Sinang Domeng, IR42, and IR52 varieties exhibited relatively higher e.m.c. values than the IR50, IR56, and IR58 varieties. The former varieties have lower amylose/amylopectin ratios and are more glutinous than the latter which is presumably the reason for their higher e.m.c. values.

Isotherm curves derived for the different varieties at the three temperatures demonstrated that the effect of temperature is more pronounced at lower relative humidities.

Pilot drying bin studies

The pilot drying bin facilities were based on the two-stage 'combination dryer' system using high speed primary drying to remove moisture rapidly down to 18% m.c. followed by slower in-store drying from 18 to 14% m.c. to preserve milling quality.

For high speed drying, a circular steel bin measuring 1.0 m in diameter by 0.86 m in height, was fabricated with a perforated metal sheet floor 0.30 m from the bottom of the bin. Its capacity was 165 kg of paddy at a grain depth of 0.36 m A backward curve centrifugal fan driven by a 1.5 kW electric motor was fitted to the bin and heat supplied by a 5.0 kW rated electric heating element. The fans and heaters could be operated manually or automatically by microprocessor control in three modes: (i) using inlet air of constant relative humidity achieved by raising the inlet air temperature; (ii) using inlet air adjusted by a fixed temperature rise at a given airflow rate; and (iii) using ambient air adjusted only by the heat generated from the fan blades.

For in-store drying, a circular steel bin of the same diameter and floor configuration but 2.7 m in height was used. Its capacity was 1000 kg of paddy at a grain depth of 2.20 m. The fan and motor were similar but the heating element was rated at 2.5 kW. As before, the system could be operated manually or automatically and was designed with a fixed heater setting and a relative humidity upper limit cutoff.

Construction of the pilot bins at the National Food Authority grain complex at Isabela was completed in December 1984. During the dry months of January and February 1985, three preliminary runs were made with the in-store drying bin, using ambient air below 75% RH and medium and long grain IR varieties of rice grown in the Isabela area. The moisture contents ranged from 20–25% w.b.

During the dry season harvest in April to June 1985, six experimental runs were conducted using similar paddy. Three of the runs involved primary high speed drying to reduce the grain moisture content to about 18% w.b. before final in-store drying to 14% w.b. In the high speed drying stage, air velocity was maintained at 30 m/min using air slightly heated from the compression of the fan in two of the runs and air heated by the 5 kW heater in the third. In the in-store drying stage, ventilation occurred only at selected times during the day. Air velocities were 8 m/min with ambient air and 4 m/min for the heated air. The other three runs used in-store drying only, with ventilation at selected hours of the day in two of the runs and continuously in the third. Air velocities were again 8 m/min.

Pilot grain drying facility constructed at Isabela in the Philippines as part of Project 8308.

Ambient air conditions over the period of these dry-season trials were typically hot and dry during the day and cool and humid at night. In January–February 1985, temperatures ranged from 22–33°C and relative humidities from 54–96% RH. In April–June 1985, the corresponding values were 24–35°C and 43–97% RH, indicating higher temperatures and lower relative humidities during the harvest period in April to June.

The following conclusions were reached from these trials:

1. Under local conditions and using ambient air, paddy with an initial moisture content up to 25% w.b. and in beds of 2.2 m depth could be dried intermittently in-store to a safe moisture content in about 110 hours fan operating time in a 11 days drying period using an airflow rate of 3.6 $m^3/min/m^3$ paddy (8 m/min equivalent air velocity). At an initial moisture content of 18% w.b., an airflow rate of 1.9 $m^3/min/m^3$ paddy (4 m/min equivalent air velocity) was satisfactory.
2. Intermittent drying appeared to be more energy efficient than continuous drying, provided the drying time is within the allowable storage time of the paddy.
3. Quality tests showed that in-store drying has no detrimental effects upon milled rice recovery, head rice yield, crack ratio, yellowing, dry matter loss, and germination rate. When compared with naturally dried samples, some improvements were noted in crack ratio and head rice yield. Quality of dried paddy did not vary significantly between layers in the grain bed.
4. The energy costs are substantially less than for conventional high-temperature dryers and much lower than the cost of sun drying.
5. Grain temperature is a good indication of where the moisture front (drying front) is located.
6. Under climatic conditions in Isabela during the dry season months of January to June, in-store drying is a feasible drying strategy for high moisture grains. It appears that in-store drying can be a genuine alternative to the conventional high-temperature dryers, i.e. batch and continuous flow dryers, for dry season drying in terms of its energy requirements, costs, and

the quality of the dried paddy. A significant reduction in labour input can also be derived.

The pilot plant drying experiments will continue at Isabela during the wet season harvest in September to December 1985 and experiments will be carried out on the drying rate of local rice varieties.

These studies will include evaluation of two-stage drying methods appropriate to local conditions. This involves proper matching of airflow rates, degrees of supplementary heating, and rice receival moisture contents with the ambient conditions. The drying strategies will then be evaluated in terms of their drying efficiency, quality of stored product, and cost effectiveness. Field trials of these drying strategies will be carried out for both dry season and wet season harvests in 1986.

Testing and evaluation of rice hull-fired furnaces for grain drying

Three furnace and grain drying tests were done to evaluate the burning efficiency, furnace efficiency, heat utilisation, and drying system efficiency of six locally manufactured, rice hull-fired furnaces.

The horizontal grate and air-suspended types of furnace showed the highest burning efficiencies of 99.12% and 98.61%, respectively. On the other hand, the combined vertical and inclined step grate furnace obtained the highest furnace efficiency of 71.39%, the lowest heat utilisation of 2697 kJ/kg and the highest drying system efficiency of 60.92%.

The flatbed dryer using the inclined step grate furnace was the most economically viable with a return on investment of 45.8%, a payback period of 1.18 years, and a break-even point of 154 tonnes.

All furnaces tested needed improvements, especially on the choice of materials to lengthen durability and minimise heat losses. Other modifications needed were in the grate system design for better burning of rice hulls.

Thailand

The Thailand Team Leader, Dr Ratana Putranon, attended the ASEAN Crops Post-Harvest Programme 1984 Grains Post-Harvest Workshop held in Kuala Lumpur from 20–23 August 1984 and participated in the Project 8308 Team Leaders' meeting held in conjunction with the ACPHP Workshop. Dr Somchart Soponronnarit who replaced Dr Ratana as Team Leader in December 1984, attended the second Team Leaders' meeting held in Australia from 12–20 April 1985.

Pilot drying bin studies

Feasibility studies of drying in bulk storage commenced with evaluations in a pilot scale drying bin. Design of the bin was based on simulations of paddy drying in bulk storage in the Bangkok area, using the models of Hukill for drying and that of Seib and others for dry matter loss. Airflow rates of 1.8, 5.5, and 15.2 $m^3/min/m^3$ of grain were required to dry paddy from an initial moisture content of 20, 22, and 24% w.b. respectively, to a final moisture content of 14% w.b. with a dry matter loss of 0.5%. The corresponding drying times were 315, 126, and 54 hours, respectively. It was calculated that air had to be heated by up to 5–6°C for the worst month of 30 year weather data.

The bin was fabricated from 1.5 mm galvanised steel sheet with a diameter of 0.75 m and a height of 2.75 m. It was insulated with glass wool 25 mm thick and then covered with aluminium sheet. A backward curve centrifugal fan driven by a 1.5 kW electric motor delivered air to a plenum formed by a perforated steel sheet inserted near the base of silo. Supplemental heat was supplied by three 0.5 kW electric heating elements.

Three experiments drying paddy of variety RD21 were conducted during the wet season in July–August 1984. The paddy was kept in cut panicles laid in the field for one day and as threshed grain in sacks for a second day before drying began. The initial moisture contents were 18–22% w.b. Ambient air was passed continuously through the 1.6 m deep paddy bed using airflow rates from 2.3–4.6 $m^3/min/m^3$ of grain. No supplemental heat was used apart from that from the fan. The paddy dried within 90–120 hours. No significant moulding or yellowing of grain was observed and head yields after milling and seed germinations were 51–60% and 96–98%, respectively. These head yields compared very favourably with those reported elsewhere for field-dried paddy in Thailand — 40–50% in the wet season and less than 40% in the dry season. There was no significant difference in paddy quality between grains at different depths in the test beds.

It was concluded from these results that in-store drying of bulk paddy with an initial moisture content up to 22% w.b. was feasible in Thailand and that grain quality can be significantly improved using this method.

Drying strategy

Following the pilot bin studies, investigations were carried out to determine a strategy for drying grain if its receival moisture was below 22% w.b. Different methods of drying paddy in bulk storage were evaluated. These methods may involve continuous ventilation or ventilation at times when ambient conditions are favourable. Supplementary heating may also be provided to control inlet air temperatures and/or relative humidity. Selection of the most appropriate method will depend on the initial moisture content, weather conditions, energy consumption, and the moisture gradient in the grain bed.

Three methods were investigated:

1. continuous ventilation with constant heating or without heating if the air condition is favourable, based on a moisture content ratio (derived from the initial and the required grain moisture contents and the equilibrium moisture content of the inlet air) that is equal to or higher than 0.1
2. continuous ventilation with relative humidity controlled to 65% if ambient air is above a predetermined level (75 or 85% RH)
3. ventilation when air conditions are favourable (below a predetermined relative humidity).

A simulation model of drying was developed to assist in selection of the most appropriate method. The model was a composite of the 1968 model of Thompson, Peart, and Foster for grain drying, the 1980 model of Seib and others for dry matter loss, the 1978 equation of Wang and Singh for thin-layer drying, and the 1980 equation of Segal for equilibrium moisture content.

Drying rates calculated from the model were compared with those established from the pilot drying bin trials. Although the simulated drying rates were slightly lower, differences between average moisture content at any drying time never exceeded 1% w.b. On this basis, the simulation model was used to compare the different methods for drying.

It was concluded from simulation of the three methods that continuous ventilation with relative humidity controlled to 65% if ambient air relative humidities exceeded 75% was the most economical option.

Solar hut dryer

An integrated paddy drying and storage solar hut was constructed and tested at a farmer's house in Kampangsaen, Nakornpathom province. The maximum loading of paddy for drying was 2.6 tonnes and the drying rate was about one tonne per day (approximately 10 hours). No supplemental heat was used. The storage capacity for paddy was 10.4 tonnes. In operation, air was sucked by a centrifugal fan from a bare plate solar air heater in the roof and delivered through a perforated iron sheet beneath the drying bed. The unit was easy to construct and operate. It cost about THB27 600 of which THB21 600 was material cost (except engine) and the remainder was labour cost. The engine from a walking tractor may be used or an electric motor if electricity is available. When a diesel engine was used to drive the fan, it used about 1.1 litres of diesel oil per tonne of dry paddy for each one percent wet basis of moisture reduced.

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 inclusion in pest control programs for grains stored in the humid tropics. Both moisture content and grain species have been found to influence insecticide efficacy, such that application rates have to be increased at higher moisture contents, and need to be greater on paddy rice than on maize and wheat. Studies to determine minimum effective application rates on maize and paddy stored at the safe upper limit of moisture content (about 14%) are continuing. Surveys in Southeast Asia show widespread resistance to malathion, the insecticide presently in routine use, proving the urgent need for alternative insecticide treatments.

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. These studies have primarily concerned wheat stored under dry conditions. In comparison, relatively little is known of the insecticide treatments needed on grains such as paddy rice and maize at the higher moisture contents characteristic of the tropics. Projects 8309 and 8311 aim to develop effective pesticide treatments for such grains in the humid tropics. Project 8309, which has been commissioned in the Queensland Department of Primary Industries, is concerned with biological and toxicological aspects of the investigations. Project 8311, which has been 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.

In Australia, the effect of relative humidity on the potency of insecticide deposits on filter paper substrates was measured. This work defined the need for precise control of relative humidity during insecticide resistance tests using a standard impregnated-paper assay. Organophosphate insecticides were more potent at higher relative humidities, but the effect was minimal when a non-volatile mineral oil such as Risella was used as a carrier for the insecticide, as recommended by FAO.

When the organophosphorus insecticide fenitrothion was applied to maize, potency was much lower at higher moisture levels (i.e. the reverse effect to that occurring on filter papers). The mechanism is thought to be reduced availability of the residue for pick-up by insects, perhaps caused by rapid penetration of the deposit into the kernels at high moisture contents. Loss of potency occurred very rapidly, within a few hours or days of insecticide application, and seemed to be irreversible. This indicates that fenitrothion may be of limited use on maize unless moisture content can be controlled from the time of treatment onwards. The apparent irreversibility of the effect means that any drying of grain should be done before fenitrothion is applied.

In a comparison of insecticide efficacy on different grain species, the relative potency of fresh deposits of 10 compounds on maize and paddy rice varied depending on the insect species used for biological assay. Potency was about equal on the two grains when tested against *Rhyzopertha dominica*, but was several times greater on maize when tested against *Tribolium castaneum*. *A. priori*, greater efficacy was expected on maize because of the smaller surface area to weight ratio of individual maize kernels and consequently greater effective concentration of insecticide on the kernel surface. Regardless of test species, effectiveness was lost more rapidly during subsequent storage on paddy rather than maize. The data suggest minimum effective application rates will need to be higher on paddy than on maize under comparable moisture conditions.

Minimum effective application rates of the 10 insecticides are being determined on maize and paddy for storage of up to 9 months. The data will be interpreted according to the basic studies above, and will be used to suggest rates for laboratory testing in Southeast Asia and to set rates for testing in later field trials in Australia.

Surveys of insecticide resistance are under way in Malaysia and completed in the Philippines. Resistance to malathion is widespread in *T. castaneum* and *R. dominica*, indicating that alternative insecticide treatments are needed urgently.

Scheduled work in Australia during 1985–86 will include further investigation of the effect of grain moisture content on insecticide efficacy, particularly the effect of moisture content of grain species other than maize on insecticides other than fenitrothion. Comparative studies of efficacy on

different grains will be extended to a wide range of species. Estimates of minimum effective application rates on maize and paddy will be verified by field trials.

In the Philippines and Malaysia, minimum effective application rates estimated in Australia will be laboratory tested under local conditions. Field trials on maize and paddy in the Philippines, and on paddy in Malaysia, are also planned for 1985–86.

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 the technology.
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.

Grain Storage Research Program

Project 8309/8311 Staff

Australia (Queensland Department of Primary Industries)
Dr M. Bengston, Research Leader, 8309
Ms A.L. Jones, Laboratory Technician
Ms J.A. Keating, Laboratory Technician
Mr R.J. Parker, Laboratory Technician
Dr P.R. Samson, Entomologist
Australia (CSIRO Division of Entomology)
Dr J.M. Desmarchelier, Research Leader, 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, 8309
Mr Zulkilfli Zainudin, Assistant Research Officer, 8311, MARDI
Philippines (NAPHIRE)
Ms M. Amoranto, Entomologist
Mr C. Mordido Jr., Team Leader, 8311
Mrs P. Sayaboc, Team Leader, 8309

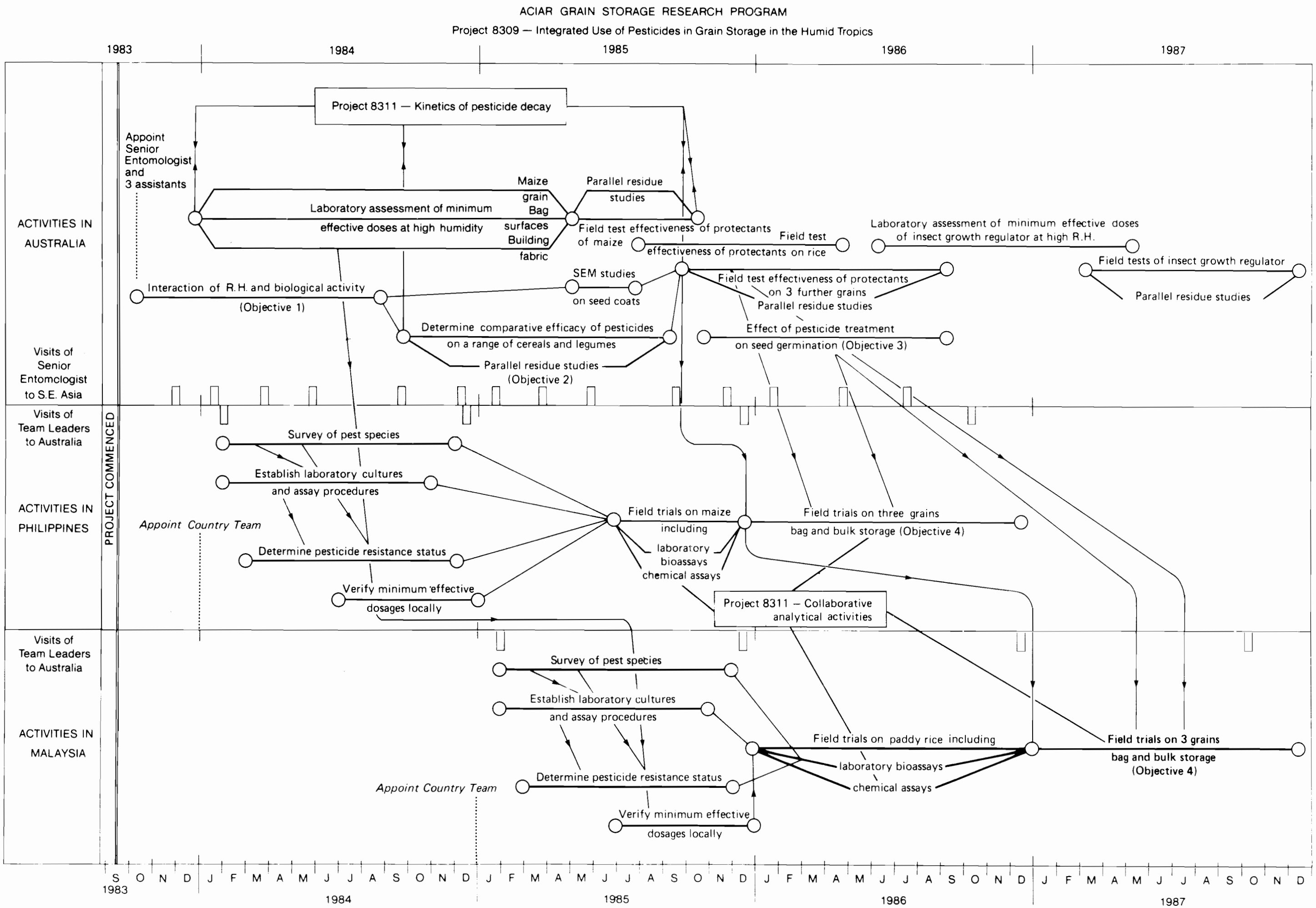
Project Objectives and Operational Schedules

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 comparative effect of a range of cereal and legume species on biological activity of grain protectants.
3. Determination of the effect of phosphine on germination of seed fumigated at high moisture levels.
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 is to provide support data from a laboratory study of the kinetics of loss of insecticides during storage and processing, is monitoring pesticide residue behaviour, and will otherwise service 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



Research schedule — Projects 8309 and 8311 (shaded area indicates work completed) can be calculated for each commodity, having regard to storage period, temperature, relative humidity, and method of processing.

The specific objectives of Project 8311, running on from those of Project 8309, are as follows.

5. Establishment of suitable procedures for analysis.
6. Laboratory studies on the effects of such parameters as temperature and moisture content on the stability of various insecticides during storage.
7. Laboratory studies on the effects of processing on the stability of various insecticides.
8. Laboratory studies on model compounds, relating stability in storage and processing to physical parameters such as partition coefficients.
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.

Field trials in Australia scheduled for May 1985 have been deferred owing to a harvest failure in southern Queensland. It is expected that these trials will now commence in October (maize) and January (paddy).

Overall, the project is realising its 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 CSIRO (Division of Entomology) for Project 8311 was signed on 30 July 1984, complementing the previous agreement between ACIAR and the Queensland Department of Primary Industries for Project 8309, signed on 5 April 1983.

Dr J.M. Desmarchelier was appointed by CSIRO as Research Leader of Project 8311 and negotiations are in progress with the University of New South Wales for the laboratory studies on the kinetics of decay of the pesticides, to be carried out by postgraduate students.

Arrangements for operations in NAPHIRE in the Philippines which had become effective in January 1984 for Project 8309 were completed when the agreement with CSIRO for Project 8311 was signed on 30 July 1984. Mr C. Mordido Jr. was confirmed as Team Leader for Project 8311.

In Malaysia, arrangements for both Projects 8309 and 8311 were finalised with signing of agreements between ACIAR and the Government of Malaysia on 25 November 1984. Mr Tee Sze Peng, originally nominated as Team Leader for Project 8309, resigned from MARDI in November 1984 and was replaced by Mr A. Rahim Muda. Mr Jumali Juratman was appointed Chemist to the project and Mrs Jamiah Jaafar and Mr Rasali Musa assigned as Technical Assistants. Mr Wang Yung Shyen of the Marketing Division, Quality Control, LPN was nominated as the prime contact with that organisation for field activities.

Mr Ong Seng Hock replaced Dr Abu Bakar Hussin as Team Leader for Project 8311. Mr Zulkilfli Zainudin, an Assistant Research Officer, and Mrs Siti Rahmah, a Research Assistant, were also assigned to the project.

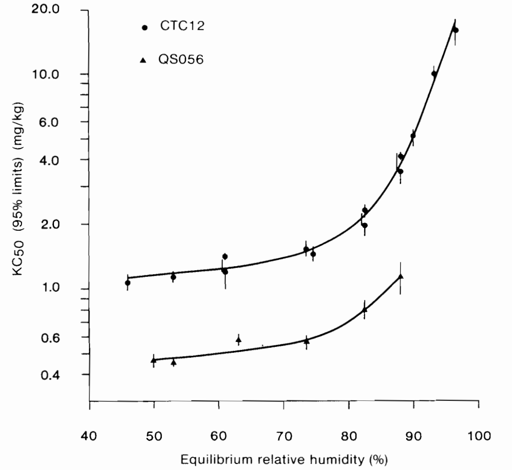
In Australia, Ms G.B. Marshall resigned as Laboratory Technician in Project 8309 and was replaced by Ms A.L. Jones on 11 February 1985.

Research Activities in Australia

Moisture and Biological Activity of Insecticides

The effect of different grain moisture contents on the biological activity of fenitrothion on maize was investigated by biological assay using adults of several species of Coleoptera. Activity declined by about 15 times with increasing grain moisture content (m.c.) in the range 10–24%, with the greatest change occurring at moisture contents above 14%. The reduction in potency at high grain moisture is relatively constant for the major species. For example, the relative potency of fenitrothion on maize at 18% m.c. compared with 14% m.c. was 0.33 for *T. castaneum*, 0.38 for *Sitophilus oryzae*, 0.20 for *R. dominica*, and 0.35 for *Oryzaephilus surinamensis*. This occurred regardless of whether maize was treated with fenitrothion when moist or was moistened after treatment, and it was not reversed by drying the treated grain. Differences in activity between moisture contents could not be explained by the chemical residues. The suggested mechanism is a reduction in the availability of fenitrothion residues for pick-up by insects.

The way fenitrothion availability changed with time was measured by chemical extraction of available and unavailable residues and by biological assay. Results of the two types of measurement were in general agreement. At higher moisture contents, the availability of fenitrothion was reduced within a few hours of insecticide application. The greatest change in availability between moisture levels occurred within a few days of application, and there was little change thereafter during storage of up to 6 months when allowance was made for different rates of decay at the different moisture contents.



Effect of the equilibrium relative humidity of maize on the biological activity of fenitrothion against Tribolium castaneum *(CTC12) and* Sitophilus oryzae *(QSOS6) (3-day exposure of adults to treated grain at 25°C, 1 day after treatment).*

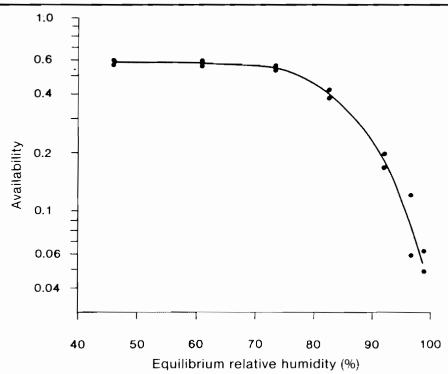
An assessment was made of the need for precise control of relative humidity during resistance tests using the impregnated-paper method recommended by FAO[1], in which insecticides are dissolved in a mixture of Risella oil, petroleum ether, and acetone. Four organophosphorus insecticides were more potent at a higher humidity (i.e. the converse to that on grain) but the effect was slight, with relative potencies being less than 2 between 93% and 30% RH. The potencies of two pyrethroids were unaffected by humidity. When the organophosphorus compound, fenitrothion, was applied to filter papers without Risella oil, relative potencies between 90% and 40% RH were 7 with acetone plus petroleum spirit as the solvent and 17 with acetone alone. When fenitrothion was applied as an aqueous emulsion, the relative potency was greater than 200. When fenitrothion was applied topically, however, consistent differences in toxicity were not found at different humidities. It was concluded that relative humidity affects the potency of organophosphorus insecticide residues on filter papers by altering the availability of the insecticide for pick-up, and that this effect is minimal when insecticides are applied according to the FAO-recommended method.

Grain Species and Biological Activity of Insecticides

The activities of 10 insecticides on maize and paddy rice conditioned to 70% equilibrium relative humidity were compared at both 1 day and 3 months after application, by bioassay with two species of Coleoptera.

One day after application, the potencies of deltamethrin, pirimiphos-methyl, chlorpyrifos-methyl, fenitrothion, and methacrifos against *T. castaneum* were 2–4 times greater on maize than on paddy. On the other hand, the potencies of bioresmethrin, fenvalerate, permethrin, d-phenothrin, and carbaryl against *R. dominica* were about equal on maize and paddy, while deltamethrin was less potent on maize. When deltamethrin and methacrifos were tested simultaneously with both species, potencies on maize relative to paddy were 2–3 times greater when tested with *T. castaneum* rather than *R. dominica*. This suggests that the initial difference between relative potencies was probably a consequence of the different test insects rather than any variability in behaviour of the insecticides.

The surface area to weight ratio of paddy kernels was determined to be about 3 times greater than that of maize, and so equal insecticide residues



Effect of the equilibrium relative humidity of maize at 25°C on the availability of fenitrothion (10 mg/kg) 4 days after treatment. Availbability was defined as the proportion of the total recovered residue that was extracted by soaking grain in methanol for 1 minute. The curve was fitted by eye.

[1]Anon. 1974. Recommended methods for the detection and measurement of resistance of agricultural pests to pesticides. FAO Method No. 15. Plant Protection Bulletin FAO, 22, 127–137.

should represent effective concentrations per unit of kernel surface about 3 times higher on maize. This factor could account for the greater biological activity on maize of those compounds tested against *T. castaneum*. Further work is needed to determine why the use of different test species gives different results.

After 3 months storage, the potencies of most insecticides on maize relative to paddy were 2 or more times greater than the corresponding values for freshly applied deposits. This implies that initial deposits lost potency more rapidly on paddy than on maize. It is not yet known whether the insecticides decay faster on paddy or whether the remaining residues lose activity more rapidly.

Application Rates for Protectants for Maize and Paddy Rice

Maize and paddy rice of about 70% equilibrium relative humidity were treated with each of 10 candidate protectants at six or more application rates and stored at 30°C. The protectants trialled were fenitrothion, pirimiphos-methyl, chlorpyrifos-methyl, methacrifos, fenvalerate, permethrin, d-phenothrin, bioresmethrin, deltamethrin, and carbaryl. Samples into which test insects were placed were taken every 6 weeks. Parent mortality and the numbers of F1 and F2 progeny were assessed. Studies on maize are almost complete, and sampling at 4.5/2 months has been done for paddy. These data will allow selection of the minimum effective application rates needed to prevent insect breeding during the required storage period for each grain.

Research Activities in Southeast Asia

The schedule of work proposed for the initial stages of the projects in Southeast Asia required that the country teams prepare reports on the current situation in pest control in the rice and maize industries in their respective countries. These reports have been completed. Surveys of pesticide resistance are in progress, as are laboratory studies to determine minimum effective dosage rates for grain protectants for local use.

Mrs F.M. Caliboso and Mr A. Rahim Muda, nominees from Project 8309 in NAPHIRE and MARDI respectively, visited Australia for two weeks from 19 November 1984 to discuss project activities and to study bioassay techniques and spray application methods at the laboratories of the Queensland Department of Primary Industries. Visits were made to the CSIRO Stored Grain Research Laboratory in Canberra (Project 8307), Ricegrowers' Co-operative at Leeton and Griffith (Project 8308), and the CSIRO Wheat Research Unit (Project 8314) in Sydney.

Malaysia

The Australian Leader of Project 8309, Dr M. Bengston, together with Dr P.R. Samson, held discussions with MARDI and LPN during the week of 20–24 August 1984, in conjunction with attendance at the 1984 ASEAN Grains Post-Harvest Workshop. These discussions covered arrangements to permit an early start of project activities on finalisation of the formal agreement between Australia and Malaysia. After signing of this agreement in November 1984, Dr Samson again visited MARDI from 22–28 February 1985 to assist in establishing the laboratory testing program. Dr Bengston and Dr Samson visited Malaysia from 4–10 June 1985 to inspect progress at the MARDI laboratories and a rice field-trial site at Sekincen, Selangor, and to discuss pesticide regulations and legislation with the Department of Agriculture.

The Malaysian Team Leaders of Projects 8309 and 8311, Mr A. Rahim Muda and Mr Ong Seng Hock, attended the 1984 ASEAN Grains Post-Harvest Workshop held in Kuala Lumpur from 21–24 August and the ACIAR/NAPHIRE/AFHB Seminar on Pesticides and Humid Tropical Grain Storage Systems, held in Manila from 27–30 May 1985. Mr Muda presented a paper entitled 'Pest problems and the use of pesticides in grain storage in Malaysia' at the latter seminar. Mr Wang Yung Shyen also attended the seminar.

The report on the current situation in pest control in rice in Malaysia has been completed and laboratory toxicity testing and the survey of pesticide resistance in Malaysia are in progress.

Postharvest systems for storage and protection of rice

Malaysia's requirement for milled rice in 1984 was estimated at 1.9 million tonnes, of which 77.2% was produced locally. The balance of some 430 000 tonnes was imported from Thailand (83%), Burma (5.7%), Pakistan (11.1%), and Australia (0.2%).

An account of current storage and pest control systems in rice in Malaysia has been prepared[2]. This report outlines the various components of post-

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[2] Rahim Muda, A. 1985. Current storage and pest control in rice in Malaysia. 6 p. Kuala Lumpur, Malaysian Agricultural Research and Development Institute.

harvest activities in the rice industry, with particular reference to the pest problems. Attention is given to production areas, harvest times, procurement and drying, the storage intervals at the farm, private miller, and government (LPN integrated complex) levels, pest infestation and losses from this cause, as well as the pesticides in use and the legislation covering pesticide use. A list of insect pests associated with stored paddy and rice in Malaysia is appended to the report.

Survey of pesticide resistance

Insect material has been collected from 10 of the 13 States of Malaysia and monitored for resistance to malathion and lindane using the impregnated-paper assay recommended by FAO.

Tests have been completed for *T. castaneum* and *Sitophilus* spp. from five States, and *O. surinamensis* from two States. All *T. castaneum* were resistant to malathion, those from Kedah, Perlis, and Selangor showing non-specific resistance. Malathion resistance was detected in strains of *Sitophilus* spp. from Malacca, North Sembilan, and Johore, and in all strains of *O. surinamensis* which concerned Selangor and N. Sembilan only. The survey of resistance will continue in the second year of the project, and a survey of fumigant resistance will be commenced. The identity of the species in the *Sitophilus* spp. strains will be determined by examination of genitalia.

Philippines

Following the signing of the agreement for Project 8309 in the Philippines on 30 July 1984, Mr R.J. Parker from the Queensland Department of Primary Industries visited NAPHIRE from 5–12 August 1984 to provide on-site training in laboratory procedures for insect culturing and resistance monitoring. The Australian Leader for Project 8309, Dr M. Bengston, together with Dr P.R. Samson and the Program Coordinator then visited the Philippines from 26–31 August 1984 for discussions with NAPHIRE and to inspect maize field-trial sites at General Santos and Cebu City. Dr Samson made a further scheduled visit to NAPHIRE from 17–22 February 1985 to assist with laboratory work.

The ACIAR/NAPHIRE/AFHB Seminar on Pesticides and Humid Tropical Grain Storage Systems was held in association with Projects 8309 and 8311 in Manila from 27–30 May 1985. The Philippine Team Leaders of these projects, Mrs P. Sayaboc and Mr C. Mordido Jr., together with Ms M. Amoranto, attended the seminar. A joint paper by Mrs F.M. Caliboso, Mrs Sayaboc, and Ms Amoranto entitled 'Pest problems and the use of pesticides in grain storage in the Philippines' was presented by Mrs Caliboso. The Australian and Malaysian Leaders of these projects, together with Dr Samson and the Program Coordinator, also attended the seminar. Dr Bengston presented papers on 'Principles of integrated use of chemicals in grain storage in the humid tropics' and 'Grain protectants'. He also chaired the session on 'Fumigants' and acted as rapporteur for the session on 'Integration of chemicals into storage systems'. The Research Leader for Project 8311, Dr J.M. Desmarchelier presented papers on 'Behaviour of pesticide residues on stored grain' and 'Quality control and methods of application of pesticides to stored grain' and Dr P.R. Samson presented a paper on 'Biological efficacy of residual pesticides in stored grain at high humidities and moisture contents'. During their stay in the Philippines, Dr Bengston and Dr Samson inspected a rice field-trial site at Santiago, Isabela, and Dr Desmarchelier held discussions with NAPHIRE staff concerning Project 8311.

The Philippine Team Leader, Mrs P. Sayaboc, attended the 1984 ASEAN Grains Post-Harvest Workshop in Kuala Lumpur from 21–24 August.

Reports on 'Post-harvest systems for storage and protection of maize' and 'Pesticide usage in warehouses', and preliminary data on the survey of pesticide resistance were presented in the 1983–84 Research Report. Studies in the Philippines have now progressed to the point where the large-scale field trials will be under way before the end of 1985.

Survey of pesticide resistance

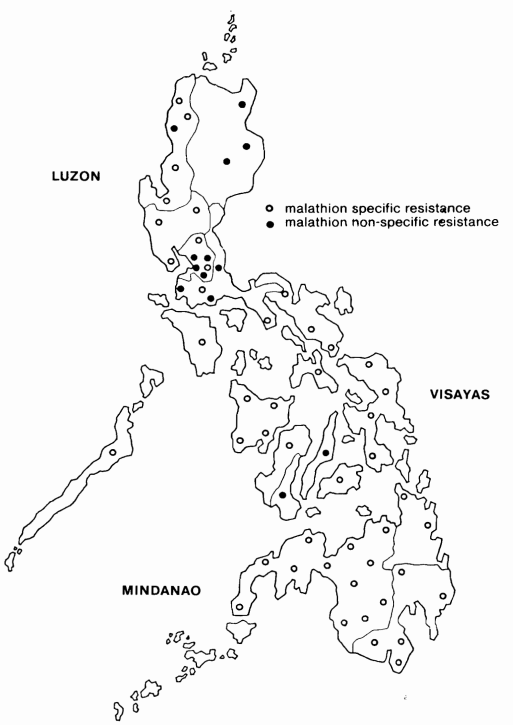
Insects collected from stores in the Philippines have been monitored for resistance to malathion and pirimiphos-methyl using the impregnated-paper assay recommended by FAO.

All strains of *T. castaneum* collected (61) were resistant to malathion. Thirteen exhibited non-specific resistance with a degree of resistance to pirimiphos-methyl. The dominant weevil collected was *Sitophilus zeamais*, and all 38 strains were susceptible to both malathion and pirimiphos-methyl. Few strains of the lesser grain borer *R. dominica* were collected, probably because paddy rice, the commodity usually infested, was in short supply during the collection period. Of five strains, four were resistant to malathion, and one of these was also resistant to pirimiphos-methyl. Preliminary work was also done to establish methods for testing resistance in other species.

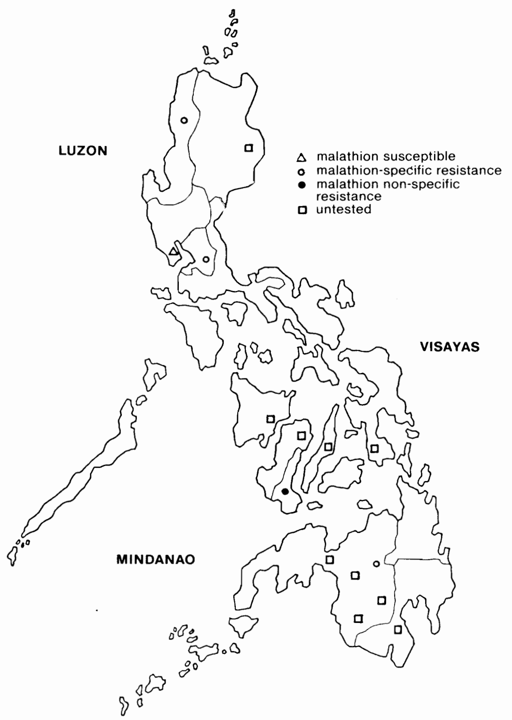
Minimum effective application rates on maize and rice

Acute toxicity tests with candidate protectants for maize were carried out using grain at 14% m.c. against three major pest species including *T. castaneum* (multi-resistant) and *S. zeamais*. The materials used were chlorpyrifos-methyl, fenitrothion, methacrifos, pirimiphos-methyl, and deltamethrin. Deltamethrin was the most toxic and methacrifos the least toxic to both species. A further series of tests is in progress using methacrifos, bioresmethrin, deltamethrin, fenvalerate, permethrin, and carbaryl against *R. dominica* in maize and paddy. The results will be compared with Australian values, to allow minimum effective application rates determined in Australia to be adapted to Philippine circumstances.

Aged grain studies have been commenced using fenitrothion, pirimiphos-methyl, chlorpyrifos-methyl, and methacrifos on maize at three application rates (between 4 and 20 ppm).



Occurrence of malathion-resistant strains of Tribolium castaneum *in the Philippines, as determined from surveys in Project 8309.*



Occurrence of malathion resistance in Rhyzopertha dominica *in the Philippines, as determined from surveys in Project 8309.*

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 commodities such as cereal grains and legumes are stored in bags or bulk, moisture migration from warm to cool regions causes serious spoilage of the commodity. Observations in Australia have shown that the initial grain temperature is the single most important factor in determining the rate of moisture migration. Heat liberated by insects or respiration of the commodity causes steeper temperature gradients to occur and spoilage is accelerated. In the humid tropics, the climatic conditions are almost optimal for insect development and grains are often harvested wet. These circumstances compound already severe difficulties.

A principal objective of ACIAR Project 8310 is to develop an understanding of the fundamental mechanisms that result in moisture migration in both aerated and unaerated grain. To date, considerable progress has been made in quantifying the factors that cause moisture migration, and this will have practical significance in ACIAR Project 8307 (Long term storage of grain under plastic covers) and in Project 8308 (The drying in bulk storage of high moisture grains in the humid tropics). Work carried out as part of ACIAR Project 8310 has also resulted in the rationalisation of moisture sorption data. The results of ACIAR studies on moisture movement in grain are therefore proving to be of great significance in terms of both theory and practice.

Powerful mathematical models of moisture movement in non-aerated grain bulks have been formulated. The models have been used to quantify the rate at which moisture migrates under a range of initial grain and boundary conditions. When combined with the experimental data on moisture movement in aerated and unaerated grain that have been generated, they enable the stored grain ecosystem to be closely defined and the safe storage conditions that are required to prevent harmful moisture migration to be quantified for grain being stored for prolonged periods. The effect of aeration on the grain moisture content and on temperatures at the periphery of a grain store is now under investigation. It is anticipated that this will enable the effects of aeration on the processes operating in grain bulks to be understood in far more detail than hitherto possible. Before Project 8310 is concluded it is planned to carry out further laboratory experiments to validate the mathematical models of moisture migration by both free and forced convection. The models will be extended to incorporate a quantification of insect population dynamics, grain quality loss, respiration, and the rate of pesticide decay. This sound appreciation of the heat and mass transfer phenomena that occur in grain will enable a systems study aimed at reducing postharvest losses to be initiated.

In recognition of the importance of this work, CSIRO has awarded Dr T.V. Nguyen, the ACIAR Research Fellow concerned, a $15 000 CSIRO Computing Grant to assist in the studies on the movement of moisture and fumigants in a three-dimensional bulk of grain.

Laboratory and numerical experiments on an open-cycle, solar regenerated grain cooling system have established that it is possible to reduce the enthalpy (heat content) of ambient air by over 20 kJ/kg. It is anticipated that the system will be be highly effective in cooling grains and preventing moisture migration in tropical climates. Its energy requirements are exceedingly low.

Future research activities planned include studies on the behaviour of fumigants in grain, the interaction of the physical and biological processes that occur in stored grain, and the systems studies previously mentioned.

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 thus:

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 microenvironment.
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, in conjunction with Project 8307, monitor their performance as measured by grain quality and the insect population indices.

It has become clear from studies of the problems of storing warm, damp grains that a systems approach must be adopted to the handling and storage of such grain. If such an approach is not taken, then grain spoilage by insect attack, respiration, and moisture movement will be severe. Hence, as Project 8310 has progressed another objective has been added, namely:

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.

This last objective will be met in close collaboration with Project 8308.

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).

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.

Grain Storage Research Program
Project 8310 Staff

CSIRO Division of Chemical and Wood Technology

Mr T.F. Ghaly, Experimental Scientist
Dr A.J. Hunter, Principal Research Scientist
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 in Australia

Mathematical Modelling of Temperature and Moisture Changes by Natural Convection

The study of moisture movement in stored grain by natural convection involves the analysis of simultaneous heat and mass exchange between a hygroscopic porous medium and a fluid mixture. The equations describing the conservation of momentum, energy, and mass in the numerical model are coupled and non-linear. The coupling occurs since heat is released or absorbed as the porous medium sorbs a fluid component, and also the equilibrium concentration of the moisture in the medium depends on its temperature. For example, the transient equations describing the airflow pattern are written in dimensionless form,

$$f\frac{\partial \zeta}{\partial t} = -\,Ra\frac{\partial T}{\partial x} - \zeta$$

$$O = \nabla^2\psi + \zeta$$

where ζ and ψ are vorticity and stream functions respectively, f and Ra are parameters which relate to isotropic porous media, i.e. paddy, wheat, sorghum, etc.

The grain and air moisture contents and the temperature distribution as functions of time, t, and spatial coordinates (x,y) may be written as

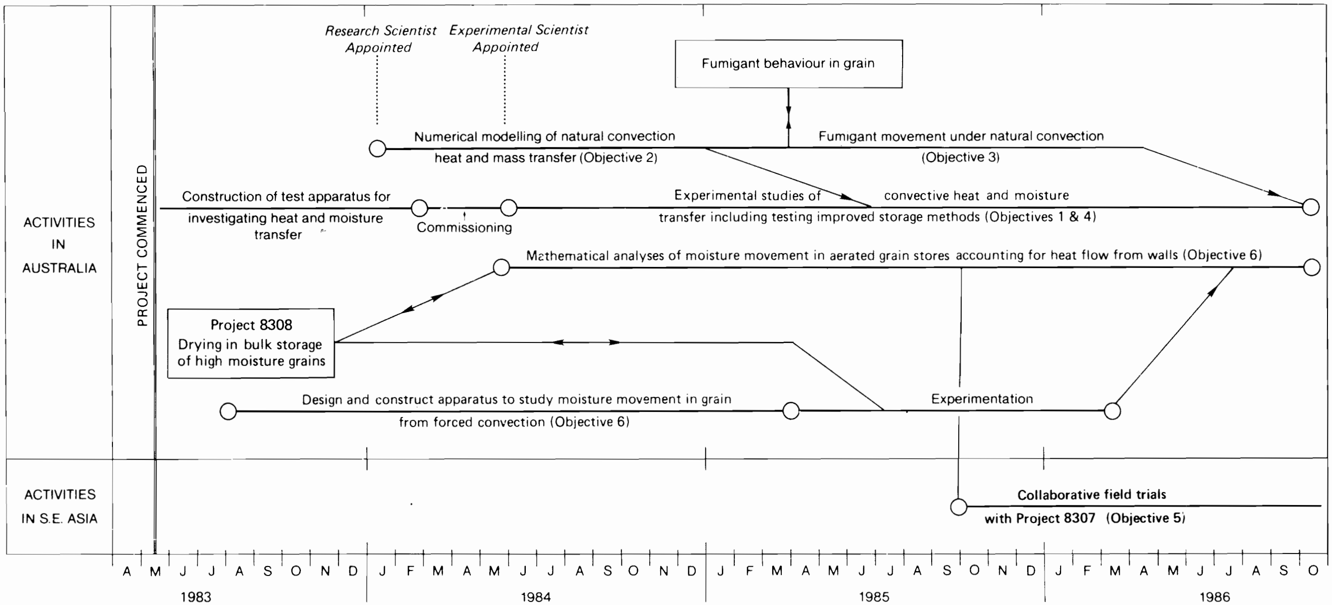
$$O = \epsilon\frac{\partial w}{\partial t} + \gamma\frac{\partial W}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y}$$

$$\frac{\partial T}{\partial t} = \phi_1(W)\{\phi_2(\triangle T,H,L)(u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y}) - \phi_3(w,H,L)(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}) + \nabla^2 T\}$$

where γ, ϕ_1, ϕ_2, and ϕ_3 are functions of grain properties, u and v are horizontal and vertical

ACIAR GRAIN STORAGE RESEARCH PROGRAM

Project 8310 — Moisture Movement in Grain



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

velocities, and H and L are the height and length of the grain store.

Solutions have been obtained for various storage structures using powerful numerical methods such as the Alternating Direction Implicit method and the Fourier Analysis — Fast Fourier Transforms direct method. Some typical predictions for a bunker-type storage are shown in Figs 1 and 2. The grain bulk is initially at 40°C and at 10% and 12% moisture contents. Under similar thermal boundary conditions, after 12 months of storage, the region of wet grain at the top of the bunker with 12% initial moisture content (Fig. 2(d)) contains grain at 20.8% moisture content which is much worse than the bunker with 10% initial moisture content.

Numerical Modelling of Forced Convection Using Finite Differences

(a) Heat Transfer Only. Good progress has been made toward solving forced convection heat transfer in cylindrical grain stores with heated isothermal side walls. Forced convection generates strong gradients and, in order to accurately resolve these gradients, it has been necessary to introduce a coordinate transformation into the finite difference mesh which exponentially compresses it at the entrance of the cylinder and to then stabilise this solution using quadratic upstream interpolation for the convective heat transfer. This single-phase model has been extended to enable calculation of both the fluid and solid temperatures by solving

$$\frac{\partial T_f}{\partial t} = \frac{k_f^*}{\epsilon(\rho C_p)_f U_o D} \nabla^2_{axis} T_f - \frac{1}{\epsilon} U.\nabla T - \frac{Nu}{Pe_f} \frac{aD}{\epsilon} (T_f - T_s)$$

$$\frac{dT_s}{dt} = \frac{k_s^*}{(1-\epsilon)(\rho C_p)_s U_o D} \nabla^2_{axis} T_s \frac{Nu}{Pe_f} \frac{(\rho C_p)_f}{(\rho C_p)_s} \frac{aD}{1-\epsilon} (T_s - T_f)$$

From this two-phase model it has been shown that for the small particle sizes found in most cereal grains ($D_p < 3$ mm) the single-phase model is sufficiently accurate.

(b) Combined Heat and Mass Transfer in Cereal Grains. Great progress has been made in deriving new equations which are completely rigorous and do not involve the previous approximations and/or elimination of terms.

Additionally, because forced convection results in high mass transfer rates, a non-equilibrium mass transfer model has been incorporated. The equations to be solved are:

$$\frac{dT}{dt} = \frac{1}{Pe^*} \nabla^2_{ax} T - \frac{(\rho C_p)_f}{(\rho C_p)^*} U \nabla T - \frac{\rho_f \frac{dh}{dw}}{(\rho C_p)^* \triangle T} U.\nabla w - \frac{(1-\epsilon)\rho_s \frac{dH}{dw} kD}{(\rho C_p)^* \nabla T U_o} (W_e - W) - \frac{\epsilon \rho_f \frac{dh}{dw}}{(\rho C_p)^* \triangle T} \frac{dw}{dt}$$

$$\frac{dw}{dt} = \frac{D_{aw}}{DU_o} \nabla^2_{axis} w - \frac{\gamma k D}{U_o} (W_e - W) - \frac{1}{\epsilon} U \nabla w$$

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

A program to solve these equations is currently being developed.

List of Symbols

C_p	specific heat capacity at constant pressure
D*	effective diffusivity of water vapour in air
D	cylinder diameter
f	effective conductivity factor
H	enthalpy of moist grain
h	enthalpy of moist air
L	height of grain bed
Pe*	effective Peclet number
Ra	modified Rayleigh number
t	time
T	temperature
U	axial velocity
u	velocity in x direction
v	velocity in y direction
w	air moisture content
x, y	coordinates
w	grain moisture content
∇T_2	temperature difference
∇_{ax}	axi-symmetric Laplacian operator
ϵ	void fraction of grain bed
γ	density ratio
ζ	vorticity
ψ	stream function

Subscripts

e	equilibrium
f	fluid phase
s	solid phase

Superscript

*	effective value

Experimental Studies on Forced Convection

An experimental apparatus has been commissioned enabling temperature and moisture measurement in an aerated cylindrical grain bed having a heated isothermal wall. Typical temperature profiles for a bed of glass beads are shown in Fig. 3. In order to better control the velocity profile at the entry to the bed and to enable experiments at very low flow rates involving simultaneous forced and natural convection, the entrance region of the apparatus is now being modified to include what is effectively an 'open circuit, low-speed wind tunnel'.

A Systems Approach to Minimising Moisture Migration

An important variable that affects moisture migration is the intergranular water vapour pressure. This is in turn a function of grain moisture content and temperature, and the vapour pressure can be lowered by reducing either or both of these variables. ACIAR Project 8308 is concerned with in-store drying of grains, a process necessary to prevent rapid deterioration. Drying is nonetheless an energy intensive process, and grain preservation may also be achieved by cooling. A component of Project 8310 is therefore concerned with carrying out a systems study aimed at determining an optimum grain storage strategy that involves both drying and cooling. In one situation, cooling is achieved by means of an open-cycle, solar regenerated desiccant bed system.

The principal elements of the cooling device are shown in Fig. 4. During the air drying and cooling process, night air from the aeration fan enters the first heat exchanger, HE1, and some of the heat of compression is lost to atmosphere by convection and radiation to the night sky. The cool, humid air then enters desiccant bed, DB1, where it is dried iso-enthalpically. As a consequence of this process the air increases in temperature and it is subsequently cooled in the second heat exchanger, HE2. The air is further dried in the second desiccant bed, DB2, before being finally cooled in the third heat exchanger, HE3.

The desiccant is regenerated by designing the heat exchangers HE1 and HE3 as effective solar collectors. Hence, during the day ambient air leaving the fan is heated in the heat exchangers,

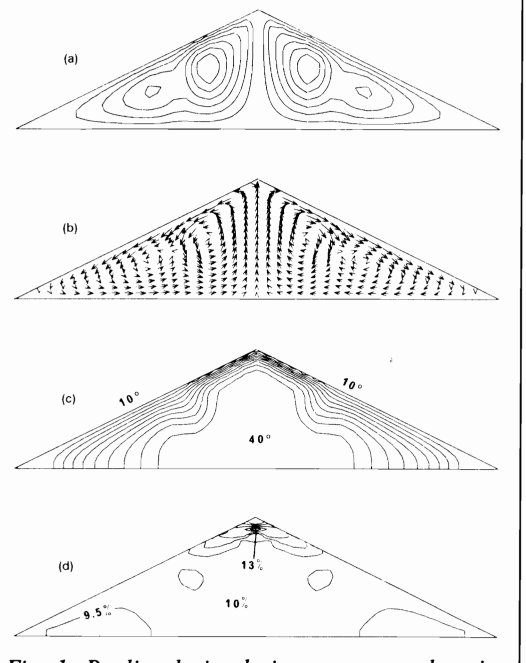


Fig. 1. Predicted circulation pattern and moisture build-up in a bunker-type store of grain initially at 40°C and 10% m.c. after 12 months storage: (a) streamlines; (b) velocity vector plot; (c) isotherms; (d) moisture distribution.

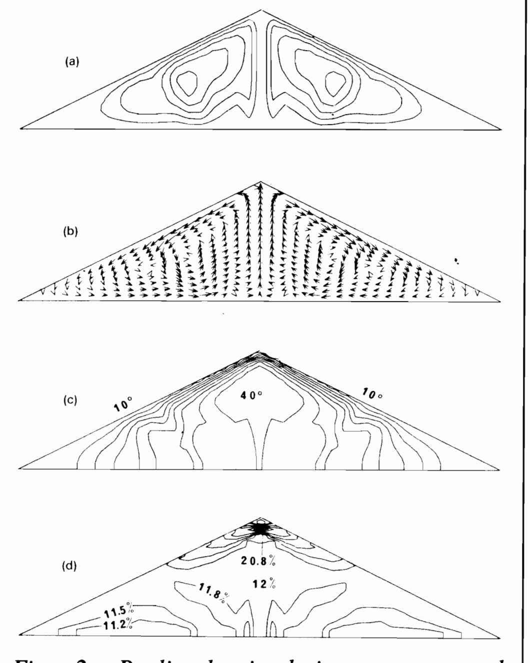


Fig. 2. Predicted circulation pattern and moisture build-up in a bunker-type store of grain initially at 40°C and 12% m.c. after 12 months storage: (a) streamlines; (b) velocity vector plot; (c) isotherms; (d) moisture distribution.

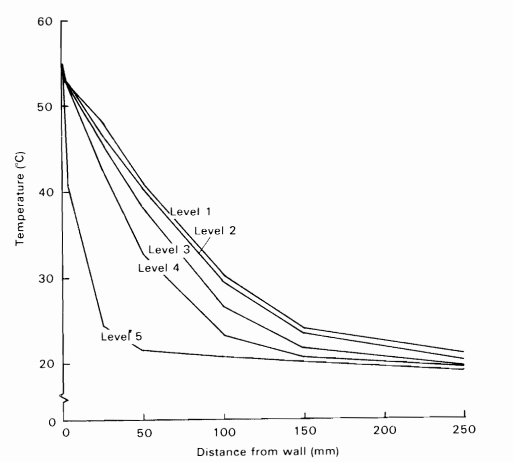


Fig. 3. Temperature profiles in experimental grain silo fitted with heated external wall.

thereby reducing its relative humidity so that the desiccant beds are regenerated for the night cycle.

The underlying principles of operation of the stage-wise system can be understood from the psychrometric chart (Fig. 5). Cool ambient air with a high relative humidity, state 1, is compressed by the fan to state 2. It is this air that would normally be used for ventilating grain in ambient aeration systems, but because of its high enthalpy it has limited cooling capacity. In the desiccant bed cooling system the air is cooled from state 2 to state 3 in the first heat exchanger, HE1. The air on entering the first desiccant bed, DB1, leaves at state 4, whence it is cooled by the atmosphere to state 5. Now this represents a reduction in enthalpy compared with natural aeration systems, but a further reduction is obtained by passing the air through the second desiccant bed, DB2, bringing it to state 6, before finally cooling it to state 7. It is this air that is used to cool the grain. An experimental single cooling stage is shown in Fig. 6.

The system is still at the developmental stage. However, computer modelling and experimental results indicate that under tropical conditions the enthalpy of ambient air can be reduced by about 20 kJ/kg. This means that grain cooled with ambient air to 26°C could be cooled to less than 20°C with air leaving the desiccant bed system. To summarise then the solar regenerated open-cycle desiccant bed grain cooling system has the following attributes:

- It is very simple to construct from readily available materials and its fabrication requires only basic sheet metal working skills.
- It achieves a significant reduction in the heat content of ambient air, hence considerably lower grain temperatures can be achieved.
- Apart from a solenoid valve, no more moving parts are required than for a conventional aeration system.
- It may prove possible to use renewable desiccants, such as cereal grains themselves.

It is planned to test the device in a tropical environment.

Sorption Studies

An essential component of a study of moisture migration in grain is a thorough knowlege of the

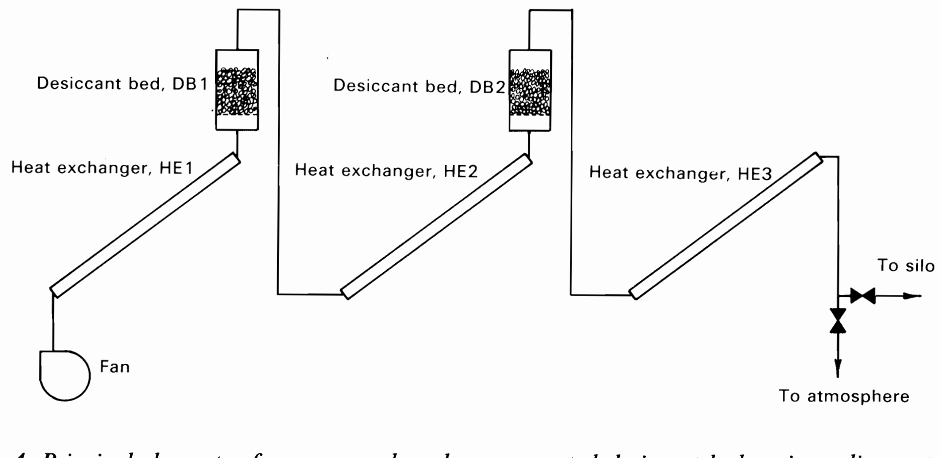


Fig. 4. Principal elements of an open cycle, solar regenerated desiccant bed grain cooling system.

thermodynamics of sorption. From the thermodynamics of equilibrium, it is possible to derive that the relative humidity, r, of intergranular air is given by

$$r = k(p_s)^{h_s/h_v - 1}$$

where p_s is the saturated vapour pressure of water, h_s/h_v is the ratio of the latent heats of bound and free water, and k is a constant. By fitting the above equation to empirical data it was found that (h_s/h_v-1) is a transcendental function of the grain moisture content. By this means an accurate isostere equation has been derived for barley, maize, rapeseed, rice, sorghum, soybeans, sunflower seeds, and wheat.

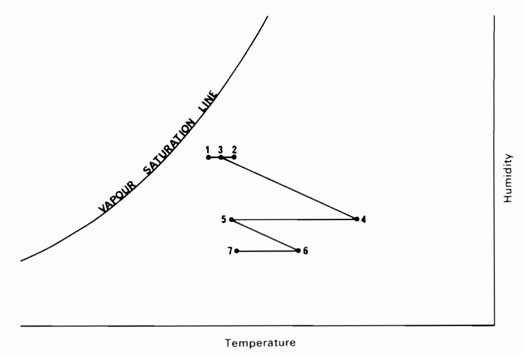


Fig. 5. Air states attained in a solar grain cooler.

Rapid Drying of Rice

As part of a program of studies aimed at developing an integrated approach to the handling and storage of wet grains, the CSIRO Division of Chemical and Wood Technology is devising energy-efficient methods of grain drying. One promising method of rapidly drying paddy is by means of intermittent heating in a fluidised bed.

In this work, Calrose (medium grain) and Inga (long grain) rice of 11.7 and 11.3% m.c. (wet basis) respectively, were heat treated in a small batch, fluidised-bed rig using ambient and air of 40°–80°C at 5°C increments and heating times of 5, 10, and 20 minutes. Also, freshly harvested Calrose and Inga of 20.3 and 21.8% m.c. respectively, were dried in the same apparatus to approximately 14% m.c., using ambient and air of 35°–80°C at 5°C increments for periods of between 11.5 and 29.1 minutes depending on temperature and variety. Germination and head rice yields were used as indexes of heat damage.

For the low moisture content rice, germination was adversely affected at temperatures greater than

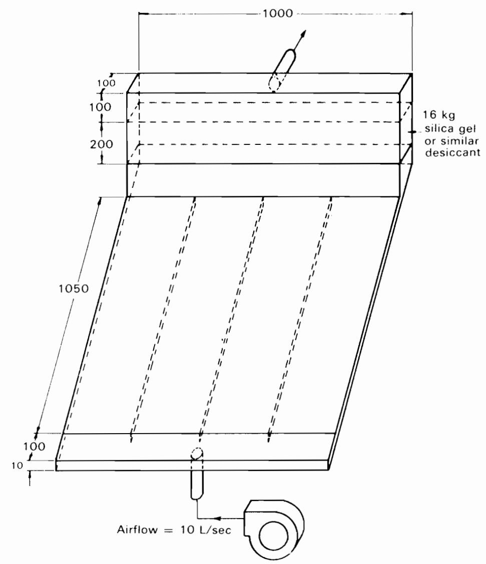


Fig. 6. Typical single stage grain cooler needed to cool 20 t of wheat.

70°C for Calrose and greater than 75°C for Inga. Head yield was adversely affected at temperatures greater than 60°C for both varieties. The effect of heating time was highly significant.

For the high moisture content rice, germination was adversely affected at temperatures greater than 60°C for both varieties. All heat treatments significantly affected the head yield which fell by 9–100%, depending on the temperature. In both cases, Calrose was more susceptible to heat damage than Inga with regard to head yield.

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. Only preliminary results are available. These indicate that low oxygen atmospheres reduce loss of germinability in rice and sorghum and discoloration in rice. Carbon dioxide (60%) has the converse effect on rice.

Background

Summary

Large amounts of grain and similar foodstuffs in tropical countries are held in warehouses as stacks of bagged products. Preservation of these commodities is a difficult and expensive operation and losses have been high. Attention to the problem has been given a high priority by international agencies such as FAO and by the relevant authorities in the developing countries of Southeast Asia, particularly the Philippines.

Project 8314 is closely linked to Project 8307, which is concerned with developing the technology for storing grain under plastic covers. It also interfaces with other projects in the ACIAR Grain Storage Research Program the objective of which is to develop systems of safe storage for grain in the difficult storage environment of the humid tropics. Project 8307 addresses specifically the questions relating to the effects of storage on quality which must be answered if protection of foodstuffs by enclosing them in large plastic envelopes is to be recommended and brought into widespread use. These questions have been raised by the developing country institutions interested in developing the technique for local use and were given high priority for attention by participants in the 1983 Grains Post-Harvest Workshop of the ASEAN Crops Post-Harvest Programme. The Philippines has indicated a desire to take a lead in this research.

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.

Assessments of quality are being carried out in Australia and the Philippines, in the latter case by the National Post-Harvest Institute for Research and Extension (NAPHIRE), which provides the research support for the National Food Authority (NFA). NFA is responsible for the procurement, safe storage, and distribution of foodstuffs throughout the country. The quality assessment team will also service other ACIAR grain storage projects in the Philippines and provides a model for the type of facility which could support the ongoing research programs in that country.

Only preliminary results are available. They indicate that low oxygen atmospheres reduce loss of germinability in rice and sorghum and discoloration in rice. Carbon dioxide (60%) has the converse effect on rice.

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.

Accelerated storage tests are being used to evaluate various combinations of commodity and storage atmosphere to enable models to be developed of the effects of storage factors on grain quality. These models will in turn be incorporated into more comprehensive models on heat and moisture balance in storage systems to enable rational design of storage containers and management procedures.

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 11 grains, 3 spices, 2 pulses, and coffee. 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 will be 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, and microbial activity.

Eight 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.

Further experiments will be carried out over a six-month period to determine the effect of carbon dioxide and other storage gases on water activity in closed systems. Water output of grains will be measured in the presence of various levels of carbon dioxide at 14% m.c. and 30°C using the following atmospheres: air; 10, 30, and 60% carbon dioxide in air; 10% carbon dioxide + 10% O_2, balance nitrogen; and one reference concentration of phosphine, 0.5 g PH_3/m^3 in air. Plate counts of fungi will be run and water output of unsterilised and surface-sterilised samples will be compared. These studies will be undertaken at the CSIRO Division of Entomology in collaboration with ACIAR Project 8307.

It is estimated that three years will be required to complete the series of experiments previously outlined.

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 A. Morris, Technical Assistant, to support these activities.

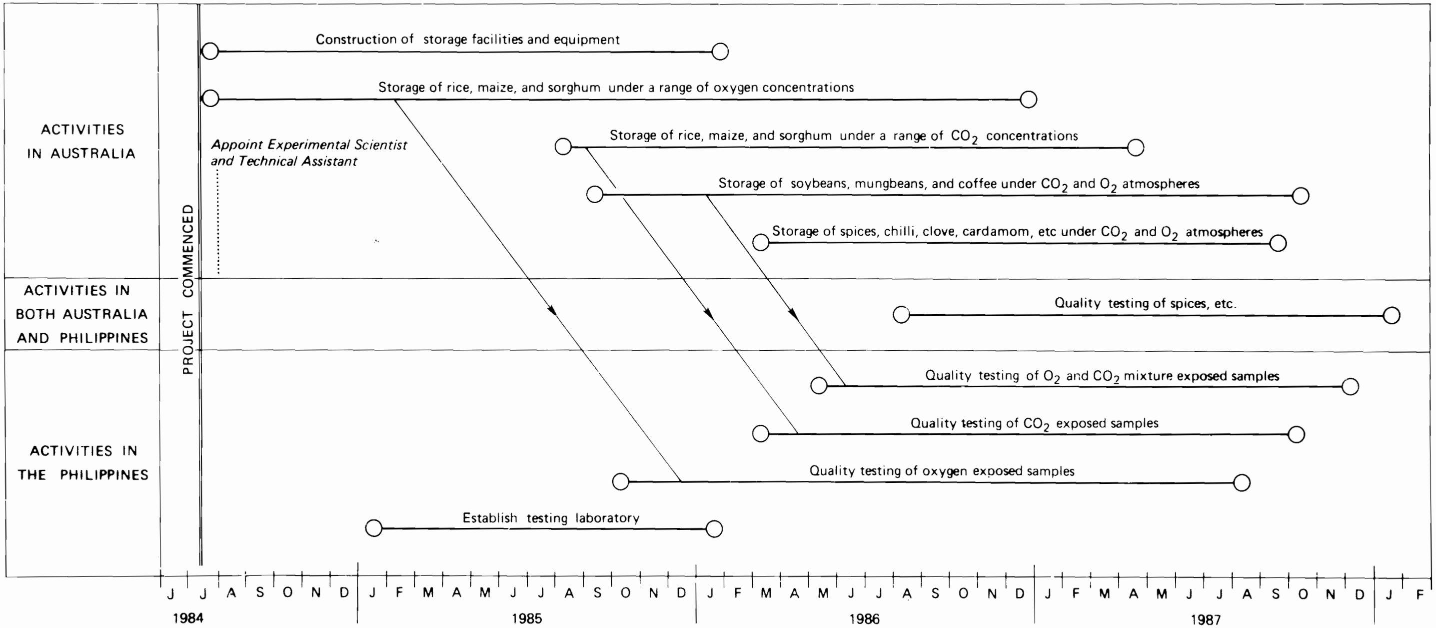
Grain Storage Research Program
Project 8314 Staff

CSIRO Wheat Research Unit
Mr M. Bason, Experimental Scientist
Dr I. Batey } Research Leaders
Dr P. Gras
Miss A. Morris, Technical Assistant

NAPHIRE
Mr C. Mordido, Jr., Team Leader

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)

Proposed grains and conditions for controlled atmosphere storage experiments. Proposed experiments are indicated by a cross; completed experiments 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 Calrose		×	×		14.0	×	×	×	×	×	10.0	×
Milled Calrose		×	×		×	×	×	×	14.5	×	10.4	×
Milled Inga					×	×		×	×			
Maize												
Manning White		×	×		×	14.7	×	×	×	×	×	×
Hickory King		×	×		×	×	×	×	×	×	×	×
Manning Pride								×				
'Cornflake #1'		×	×		×	14.9	×	×	×	×	×	×
'Cornflake #2'								×				
Leaming								×				
Golden Superb								×				
Other												
Sorghum		×	×		×	×	×	×	14.5	×	10.2	×
Soybean		×	×		×	×	×	×	×	×	×	×
Mung Bean		×	×		×	×	×	×	×	×	×	×
Coffee		×	×		×	×	×	×	×	×	×	×
Spices												
Chilli		×	×		×	×	×	×	×	×	×	×
Cardamom		×	×		×	×	×	×	×	×	×	×
Cloves		×	×		×	×	×	×	×	×	×	×

The Memorandum of Agreement between ACIAR and the Philippine Council for Agriculture and Resources Research and Development for collaborative activities with NAPHIRE was also finalised on 14 July 1984. NAPHIRE nominated Mr Cris Mordido Jr. as Team Leader in the Philippines. Mr Mordido is also involved in Project 8311.

Research Activities in Australia and Southeast Asia

The Australian Research Leader, Dr P. Gras, visited Malaysia from 19–25 August 1984 for joint discussions with Project 8309 personnel on quality assessment of rice in their field trials. While in Malaysia he attended the ASEAN Crops Post Harvest Programme 1984 Grains Post-Harvest Workshop, which was held in Kuala Lumpur from 21–24 August 1984. He then visited the Philippines from 25 August to 3 September for discussions on implementation of Project 8314 in NAPHIRE.

Mr M. Bason attended the ACIAR/NAPHIRE/AFHB Seminar on Pesticides and Humid Tropical Grain Storage Systems held in Manila from 27–30 May 1985. He stayed on for discussions with NAPHIRE concerning project activities.

The Philippine Team Leader, Mr Cris Mordido Jr., visited Australia from 11–21 April 1985. As well as obtaining experience in experimental procedures at the CSIRO Wheat Research Unit in Sydney, he inspected facilities and had discussions with ACIAR project personnel at Ricegrowers' Co-operative Ltd at Griffith, the Department of Agriculture's Rice Research Institute at Yanco, and the CSIRO Stored Grain Research Laboratory in Canberra.

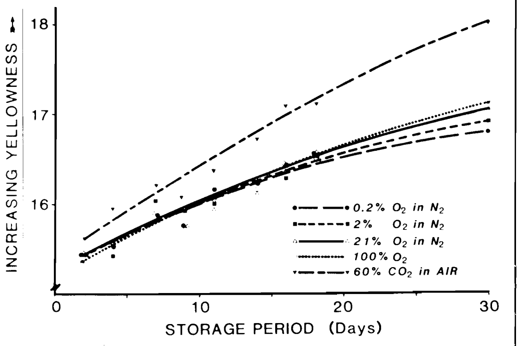
Grain Moisture Content Determination

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 these experiments.

Effect of Controlled Atmospheres on Quality

Experiments completed to date have concerned paddy, maize, and sorghum. Germination data have been obtained from six of these experiments. Although the results are as yet far from conclusive, trends so far observed in paddy are similar to results obtained for wheat. That is, storage life is increased with decreased oxygen levels, and carbon dioxide (60%) markedly reduces germinability for high moisture grain. The same result with carbon dioxide has been observed with sorghum, but not yet noticeably with maize. Low oxygen atmospheres (2%) are also correlating with increased storage life in sorghum and maize.

Preliminary results on discoloration of milled rice under controlled atmospheres indicate that greying and yellowing are a function of storage period and storage atmosphere. Storage in low oxygen atmospheres slightly reduced the rate of development of discoloration relative to that found in air, whereas storage in carbon dioxide significantly increased the overall yellowness and decreased the lightness of rice stored at 47°C and 80% RH, and also significantly increased the yellowness of rice stored at 60°C and 60% RH. This is illustrated in an accompanying diagram. The yellowing referred to here was an equal discoloration of all kernels and, because it occurred at high temperatures, it is unlikely to be due to mould growth. The results suggest that carbon dioxide may exacerbate the development of yellowing of rice in storage.



Relationship between yellowing in polished Calrose rice and the composition of the storage atmosphere at 47°C and 80% RH.

Project 8344

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

Commissioned organisation — South Australian Department of Agriculture

Abstract

The basic objective of the project is 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.

Background

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, has requested assistance from and collaboration with Australian institutions involved in researching similar problems.

The request for participation by Australia in a study of the transition from bag to bulk handling in Malaysia originated from the 1979 ADAB Research for Development Seminar on grain storage research[1]. The Director of Research of Lembaga Padi dan Beras Negara (LPN) identified the problems associated with bulk handling as an area where Australian expertise would be useful. At a meeting convened by the Malaysian Agricultural Research and Development Institute (MARDI) in April 1983, to discuss Malaysian participation in the ACIAR Grain Storage Research Program, MARDI and LPN unilaterally made reference to the high priority given to the development of a bulk-handling capacity in Malaysia and requested ACIAR to give consideration to cooperative work in developing an appropriate bulk-handling system for Malaysia. A proposal for handling wet paddy in bulk was tendered for ACIAR's consideration. In essence, the proposal involved a systems analysis of grain handling in Malaysia, from harvesting of paddy through to processing and distribution of rice. The discussion confirmed this intent. The matter of Australian involvement was raised again the next day by the Deputy Director-General of LPN at a meeting of the Programme Steering Committee of the ASEAN Crops Post-Harvest Programme in Singapore and soon afterwards by the Director-General during a workshop on Bulk Handling of Paddy in Malaysia in June 1983.

Clearly, a study of the economics of postharvest handling of paddy and rice in Malaysia has been accorded a very high priority and the desirability of Australian participation has been stressed by all the Malaysian authorities concerned.

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.

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

The basic objective of the project is to develop a model of the Malaysian rice economy which inte-

[1]Champ, B.R., and Highley, E., ed. 1981. Grain storage research and its application in Australia. Canberra, CSIRO Division of Entomology, 267 p.

grates 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, 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 core component of the project is the development and specification of a mathematical programming model. This work will be carried out by the South Australian Department of Agriculture in Adelaide under the general supervision of the Australian Project Leader.

The Malaysian research team will be responsible for assembly of the database and for placing the data in a form suitable for subsequent processing in the model.

There will be close collaboration between other institutions engaged in the ACIAR Grain Storage Research Program. In particular, the research group in Ricegrowers' Co-operative Limited (RCL), which is already undertaking Project 8308 on grain drying in Malaysia, will provide advice on the technical feasibility of improved bulk handling, drying, and milling equipment. Similarly, the Malaysian research team will be a consortium of Universiti Pertanian Malaysia (UPM) and MARDI as the primary economic and technical research institutions concerned with the rice industry in Malaysia, in collaboration with LPN.

The proposed schedule of major events is shown in the project flow diagram. Key elements are the development of the model in Australia and the field survey work in Malaysia needed to obtain data for input into the model.

Organisation and Staff

A Project Formulation Meeting was held at Ricegrowers' Co-operative Ltd in Leeton on Friday 13 July 1984. Its objectives were:

1. to discuss the scope and objectives of the proposed project;
2. to determine an operational framework for the activities, including delegation of responsibility; and
3. to draw up a definitive schedule of operations.

The meeting was attended by: Dr J.G. Ryan, Deputy Director, ACIAR (Chairman); Dr Ismail Shamsudin, Director-General, LPN; Mr Zainuddin Dato Awang Ngah, Deputy Secretary-General, Ministry of Public Enterprises, Malaysia; Mr Ahmad Ilham Abdul Samada, State Director, Kedah and Perlis, LPN; Mr Loo Kau Fa, Chief Engineer, LPN; Mr H. Baird, Deputy General Manager, RCL; Mr J. Kennedy, Export Manager, RCL; Mr S. Dunn, Operations Manager, RCL; Mr L. Bramall, Technical Manager, RCL (Project 8308B); Mr B. Bourne, Engineering Manager, RCL; Mr P. Martin, Research and Development Manager, RCL; Mr G. Pym, Storage Research Manager, RCL (Project 8308B); Mr P.C. Annis, CSIRO Division of Entomology (Project 8307A, B); Dr M. Bengston, Deputy Director, Entomology Branch, Queensland Department of Primary Industries (Project 8309); Dr J.H. Johnston, Senior Economist, N.S.W. Department of Agriculture; Dr G.J. Ryland, Chief Agricultural Economist, S.A. Department of Agriculture; Mr T. Adamczak, Professional Officer, University of N.S.W. (Project 8308A); Dr B.R. Champ, Research Program Coordinator, ACIAR.

Before discussion on the detailed arrangements for the proposed project, the following position and background papers were presented to the meeting:

'The ACIAR Grain Storage Research Program: perspectives and current activities', by Dr B.R. Champ;

'Economic research on grain-handling, storage, and marketing in Australia', by Dr J.H. Johnston;

'Development of a bulk-handling system for paddy and rice in Australia', by Mr H. Baird;

'Paddy receival, storage and management in New South Wales, Australia', by Mr L. Bramall;

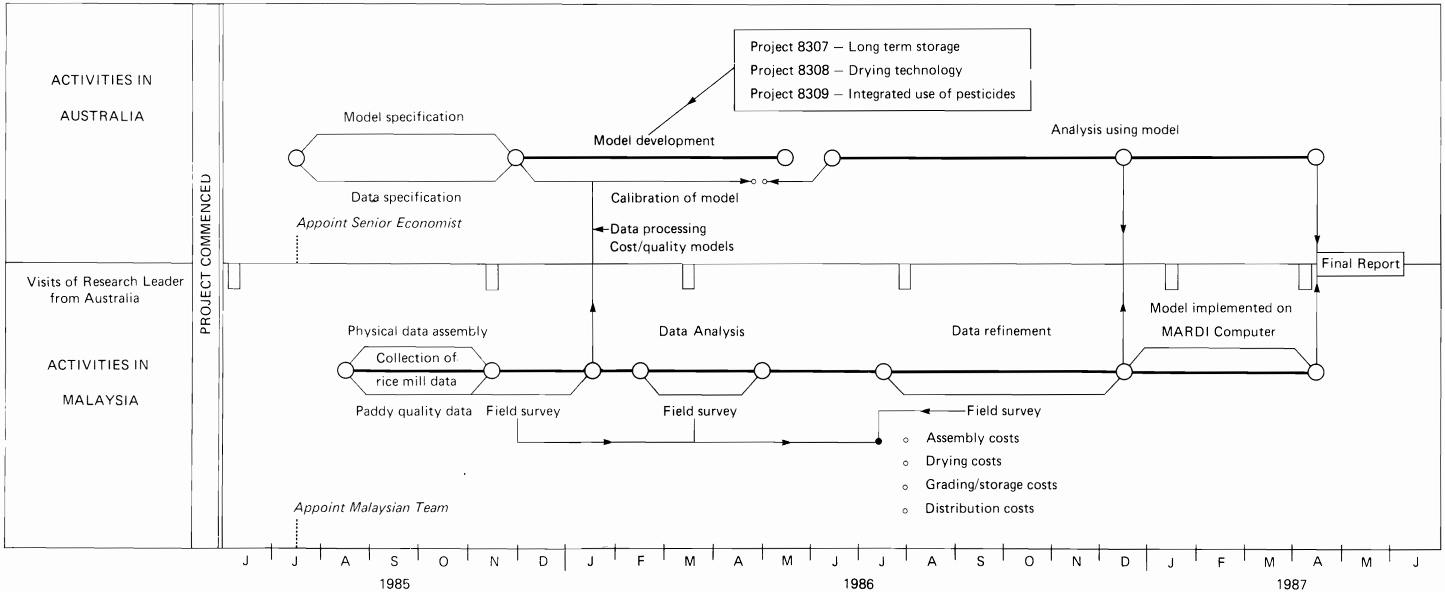
'Current status of harvesting, handling, transport, and marketing of paddy and rice in Malaysia', by Dr Ismail Shamsudin; and

'Changeover options for developing countries: some appropriate models', by Mr J. Kennedy.

An approach was made after the meeting to the South Australian Department of Agriculture to draw up a firm proposal on 'Bulk Handling of

ACIAR GRAIN STORAGE RESEARCH PROGRAM

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



Research schedule — Project 8344

The formulation of Project 8344, as with all ACIAR projects, involved many discussions between research and operational groups in Australia and participating countries.

Paddy and Rice in Malaysia: an Economic Analysis'.

Further discussions on the draft proposal were held in Malaysia on 19–20 August 1984 in conjunction with attendance at the ASEAN Crops Post-Harvest Programme 1984 Grains Post-Harvest Workshop in Kuala Lumpur. The first meeting was held in Alor Setar on 19 August. LPN was represented by Dr Ismail Shamsudin, Mr Loo Kau Fa, and Mr Teoh Inn Chek, Senior Engineer from LPN Head Office and Mr Ahmad Samad and his Deputy Director of the Kedah and Perlis State Office, Mr Mohd Dashilah Alang Mohd. ACIAR representatives were Dr G. Ryland, Dr J. Johnston, Dr R. Driscoll (Project 8308A), Mr L. Bramall (Project 8308B), Mr G. Pym (Project 8308B), Mr E. Highley (Project 8312), and the Program Coordinator. Inspections were then made of field activities in the Muda II Farm Development Project at Tambun Tulang. The following day, the party inspected the North West Selangor Development Project at Tajung Kerang which had been nominated by LPN as the project study area. A final meeting between representatives of ACIAR, LPN, and MARDI, was held on 22 August in Kuala Lumpur to discuss project implementation.

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, has been nominated by the South Australian Department of Agriculture as Research Leader. A Senior Research Economist, Mr B. Hansen, has been appointed to work with Dr Ryland. They will be supported by Mr Omar Bin Yob, a Malaysian Research Economist from LPN who will be based in Australia, with provision to undertake post-graduate training within the project. Project administration will be the responsibility of Dr G. Simpson and Mr J. Fargher of SAGRIC International. These personnel, together with contract research consultants engaged to provide specialist advise on specific aspects of the project, comprise the Australian research team.

The Malaysian research team will operate 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 have been nominated by UPM as joint research leaders in Malaysia. They will be supported at UPM by two senior research economists, Dr Fatimah Mohd. Anshad (Cost and Quality Analysis) and Dr Roslan Abd. Ghaffar (Systems Analysis), three research assistants, Mr Muzafar, Mr Azman, and Miss Hafrizah, and two graduate assistants funded by IDRC, Mr Salleh Yahya and Mr Siow Keat Foo. MARDI collaborators will be Dr Othman, agronomist, and two economists, Mr Shaaban and Mr Syed. Mr Loo Kau Fa, Chief Engineer, has been nominated as the prime contact in LPN.

During the period 1 January to 30 June 1985, the management structures were developed and all other arrangements for project activities were finalised for a start on 1 July as scheduled. Dr Ryland conducted a seminar broadly outlining the project to local participants at UPM on 3 May 1985.

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 Assistant
Mr Azman Bin Hassan, Research Assistant
Miss Hafrizah, Research Assistant
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 Shaaban, Economist
Mr 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

Project 8312

Program Development and Coordination

Commissioned organisation — CSIRO Division of Entomology

Introduction

The formulation and implementation of the ACIAR Grain Storage Research Program has been achieved by contracting Project 8312 with the CSIRO Division of Entomology. The project 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. Project 8312 has an initial duration of three years.

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.

The objectives of Project 8312 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 workshops as appropriate in cooperation with local organisations and publish proceedings of these workshops.
6. To produce, as required, publications relevant to grain storage in developing countries.

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, formerly Scientific Liaison Officer in the Division of Entomology, was appointed Editor of the *ACIAR Grain Storage Newsletter* on 13 March 1983. He has spent approximately five weeks per year on project activities, editing and producing the biannual newsletter and other project publications. On his resignation from the Division on 28 February 1985, he was retained by the Division as a communications consultant to continue his association with the project. He has also been contracted directly by ACIAR to assist in the organisation and production of the proceedings of the ACIAR/NAPHIRE/AFHB Seminar on Pesticides and Humid Tropical Grain Storage Systems. As well as attending all internal workshops of program personnel, during 1984 Mr Highley visited the Philippines (15–18 August), Malaysia (18–25 August), and Thailand (25–28 August) to gather material for the newsletter and to promote the research information network in Southeast Asia. As part of this trip, he participated in the ASEAN Crops Post-Harvest Programme 1984 Grains Post-Harvest Workshop, which was held in Kuala Lumpur from 21–24 August, and presented a paper on 'Moving towards pesticide free storage of grain in Australia', which he co-authored with Dr D.E. Evans of CSIRO. He also attended the ACIAR/NAPHIRE/AFHB pesticides seminar which was held in Manila from 27–30 May 1985.

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. She replaced Mrs L. White who left the Division in January 1985.

Mr D. Rofe was appointed as Projects Officer on 4 September 1984 to provide administrative assistance to all ACIAR projects in the Division of Entomology, including those in the Grain Storage Research Program. He spends half his working time on ACIAR-related activities, including:

- 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;
- assistance with the preparation and coordination of progress reports.

The Research Program Coordinator made the following overseas visits to facilitate conduct of activities in the program in Southeast Asia.

Malaysia and Philippines — 17 August to 1 September 1984

Philippines, Thailand, and Malaysia — 14–20 October 1984

Malaysia, Singapore, and Philippines — 7–12 January 1985
Philippines — 25 March–1 April 1985
Singapore and Indonesia — 21–30 April 1985
Philippines — 25 May–1 June 1985

In addition, periodic visits have been made to the contracting organisations in Australia.

Internal Workshops

Workshops attended by project personnel are held twice a year, hosted in turn by each of the project groups in Australia. The general objectives of these workshops are:

1. To familiarise Australian participants in the ACIAR Grain Storage 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 be relevant to the program.
6. To inspect relevant research activity within the host organisation.

Following a decision at the second workshop to expand the meeting at which annual reports are discussed to provide for attendance by all professional staff, the third workshop was held at the Queensland Department of Primary Industries (Project 8309) on 31 July and 1 August 1984. The 27 participants were welcomed by Mr G.S. Purss, the Director of the Division of Plant Industry. After presentation of progress reports by the various project leaders, and discussion on a further 21 topics nominated by project personnel for inclusion in the agenda, the participants inspected work in progress, both in Project 8309 and elsewhere in the Entomology Branch.

The fourth workshop, scheduled for the CSIRO Wheat Research Unit in Sydney (Project 8344), was held over from the first half of 1985 until 25 July 1985 as the earliest date at which all project leaders could attend.

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 postharvest 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 network is the *ACIAR Grain Storage Newsletter* published twice a year. The newsletter contains 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.

The newsletter also contains articles on topics likely to be of general interest to a wide cross section of its readers in various countries. So far, these more general accounts have dealt with the rice industry in Australia, the ASEAN Crops Post-Harvest Programme, NAPHIRE, the ASEAN Food Handling Bureau, MARDI, CSIRO, thermal disinfestation of stored grain, and pesticide residues. Coverage of the last of these topics is seen as a major project. Mr Jack Snelson, who recently retired from the position of Pesticides Coordinator in the Australian Department of Primary Industry, has produced a comprehensive, 60 000-word account covering all aspects of the regulation of pesticide residues in stored grain. This is being published in three parts, arranged around the Seminar on Pesticides and Humid Tropical Grain Storage Systems held in Manila in May 1985. The first, on the significance and safety of pesticide residues, appeared in the second issue of the newsletter in December 1984. The second and third parts, dealing with maximum residue limits and with efforts to achieve

Brisbane Workshop participants (L to R): Dr Bruce Champ, ACIAR; Mr Kerry Fitzgerald, Queensland Department of Primary Industries; (back) Mr Bob Erskine-Smith, Queensland Department of Primary Industries; Mr Gordon Purss, Queensland Department of Primary Industries; Mr Ed Highley, ACIAR; (back) Mr Jan van Graver, CSIRO Division of Entomology; Mr Russell Parker, Queensland Department of Primary Industries; Dr Robert Driscoll, University of New South Wales; Dr Jim Desmarchelier, CSIRO Division of Entomology; Mr Mark Bason, CSIRO Wheat Research Unit; Mr Geoff Pym, Ricegrowers' Co-operative Mills Ltd; Mr Lindsay Bramall, Ricegrowers' Co-operative Mills Ltd; Ms Julie Keating, Queensland Department of Primary Industries; Mr James Derby, Ricegrowers' Co-operative Mills Ltd; (back) Dr Peter Gras, CSIRO Wheat Research Unit; Dr Tuan Nguyen, CSIRO Division of Chemical and Wood Technology, Agricultural Engineering Group; Dr Ian Batey, CSIRO Wheat Research Unit; Mr Steven Wilson, CSIRO Division of Chemical and Wood Technology, Agricultural Engineering Group; Mr Robert Corner, Ricegrowers' Co-operative Mills Ltd; Mr Peter Annis, CSIRO Division of Entomology; (back) Professor Jim McWilliam, ACIAR; Mrs Rosalind Goodwin, CSIRO Division of Entomology; (back) Mr John Wiseman, CSIRO Division of Entomology; Dr Graham Thorpe, CSIRO Division of Chemical and Wood Technology, Agricultural Engineering Group; Ms Gayle Marshall, Queensland Department of Primary Industries; Mr Tom Adamczak, University of New South Wales; Dr Merv Bengston, Queensland Department of Primary Industries; Dr Peter Samson, Queensland Department of Primary Industries.

international harmonisation of regulations covering pesticide residues, will be published in newsletters 3 and 4.

Some 650 copies of each issue of the *ACIAR Grain Storage Newsletter* are now distributed via an ever-growing mailing list.

Databases and Information Retrieval Services

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

There was a substantial increase in demand for the library and information services during the year. Following extensive coverage of these services in the newsletter, 27 specialist searches were performed, almost half of them requested by members of the various country research teams. There was also an increase in demand for copies of earlier searches, particularly from overseas workers. The topics of all searches made are listed in the newsletter. The following searches were carried out during the year.

- Drying of paddy
- Velocity distribution in packed beds of porous media
- Destruction of insects, mites, and microorganisms by microwaves
- Modelling of insecticide resistance
- Graetz problem in fluid mechanics of porous media
- Postharvest diseases of garlic
- Heat produced by respiration of damp bulk grain
- Ambient air drying of grain in high-humidity tropical conditions
- Snails as hosts for human and animal diseases
- Resistance of *Rhyzopertha dominica* to insecticides
- Statistical programs for CP/M microcomputer operating system

LPN Director-General, Mr Shaharuddin Hj. Haron (left) visited Australia in April 1985 for discussions concerning implementation of Projects 8308 and 8344 in Malaysia. He is seen here with Mr G. Pym of Ricegrowers' Co-operative at Leeton, New South Wales.

- Storage of bagged grains and legumes
- Insecticidal treatment and fumigation of bagged grains and legumes
- Uneven application of insecticides to stored grains
- Rice husks as fuel
- Irradiation of citrus fruits
- Residues of ethylene dibromide in citrus fruits
- Scale insects
- Scanning optical microscopes
- Ecology of stored products insects

There was also a substantial increase in the number of requests for publications, to well over 300. Most of the requests from overseas were for material produced by ACIAR and CSIRO.

An important element of the program's library resources is its possession of the only copy of the Stored Products Reference Index managed by the United Kingdom Ministry of Agriculture, Fisheries and Food. An exciting development during the year has been the progress made towards computerisation of the Index. Trials have been performed on a subset of the database using the STATUS retrieval language running on MAFF Prime computers. The research information network is liaising with the MAFF library to ensure that program participants gain the earliest possible access to the machine-readable form of the database.

Collaborative Activities

Participation in GASGA

ACIAR is the nominated Australian participant in the Group for Assistance on Systems relating to Grain After-harvest (GASGA). The Annual Executive Meeting, scheduled for England in 1985, commenced on 1 July.

Attendance at International Conferences and Workshops

A CSIRO/Australian Grain Institute Seminar and Workshop on Aeration System Design was held in Melbourne on 10–11 July 1984 and was attended by all personnel from Project 8310 as well as Mr T. Adamczak (Project 8308A), Mr J. Darby and Mr G. Pym (Project 8308A), Mr Loo Kau Fa (Project 8308), Dr Ismail Shamsuddin (LPN), and the Program Coordinator.

The ASEAN Crops Post-Harvest Programme 1984 Grains Post-Harvest Workshop, held from 21–24 August in Kuala Lumpur, Malaysia, was attended by a large contingent of ACIAR personnel who had arranged their scheduled project travel to coincide with the workshop. Those attending were Mr Ahmad Robin Wahab (Project 8307), Mr Chuwit Sukprakarn (Project 8307), Mrs G. Sabio (Project 8307), Mr J. van S. Graver (Projects 8307A,B), Mr Loo Kau Fa (Project 8308), Dr Ratana Putranon (Project 8308), Mr Justin Tumambing (Project 8308), Dr R. Driscoll (Project 8308A), Mr L. Bramall (Project 8308B), Mr G. Pym (Project 8308B), Mr A. Rahim Muda (Project 8309), Mr Ong Seng Hock (Project 8311), Mrs P. Sayaboc (Project 8309), Dr M. Bengston (Project 8309), Dr P.R. Samson (Project 8309), Dr P. Gras (Project 8314), Dr G. Ryland (Project 8344), Dr J. Johnston (Project 8344), Mr E. Highley (Project 8312), and the Program Coordinator. Mr Highley presented a paper on 'Moving towards pesticide free storage of grain in Australia', which he co-authored with Dr D.E. Evans of CSIRO.

Dr Somchart Soponronnarit (Project 8308) attended a Seminar on Technology for Rural Development held at Khonkaen University in Thailand on 16–17 February 1985 and presented a paper entitled 'A feasibility study of in-store paddy drying', by S. Soponronnarit, C. Karnjanaboon, and R. Chirarattananon.

Dr G.R. Thorpe (Project 8310) was sponsored by the Commonwealth Science Council to attend the International Conference on Research and Development of Renewable Energy Technologies in Africa, which was held in Reduit, Mauritius, from 25 March–1 April 1985. He chaired a technical session on Energy Utilisation Technology: Crop Drying Commodities and presented a paper on 'Experiments on an open-cycle solar regenerated desiccant bed grain cooling system'. He also visited FAO, Rome, for discussions on a proposed FAO publication on 'Modified environments in agricultural buildings for developing countries'. An Industrial Dryers Workshop was organised by the National Energy Research Development and Demonstration Council in Sydney on 13 June 1985. Mr T. Adamczak (Project 8308A), Mr L. Bramall (Project 8308B), Dr R.H. Driscoll (Project 8308A), and Dr G.R. Thorpe (Project 8310) attended. Mr Bramall presented a paper on 'Drying paddy rice in New South Wales' and Dr Thorpe on 'Grain drying research'.

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 15th Meeting of the Group in Bangkok from 16–18 October 1984, and the 16th Meeting in Manila from 26–27 March 1985. The latter meeting was followed by a field trip to Cotabato and the National Food Authority integrated grains complex at Tacurong in central Mindanao.

Other Aspects of Collaboration

ACIAR was represented by the Program Coordinator as an observer at the 2nd Meeting of the Programme Steering Committee of the ASEAN Crops Post-Harvest Programme in Manila on 10–11 January 1985. He also participated in the Donor-ASEAN Consultation Meeting of the Programme which was held in Singapore from 25–27 April 1985.

Dr R.H. Driscoll (Project 8308A) visited Indonesia, Malaysia, Thailand, and Singapore in July 1984 and delivered a lecture on rice-drying technology at the Universitat Sumatera Utara, in Medan, Indonesia.

Mr T.F. Ghaly (Project 8310) visited Egypt in February–March 1985 under the UNDP Transfer of Know-how Through Expatriate Nationals Project. Whilst in Egypt, Mr Ghaly made a study of factors affecting the loss of rice quality during storage. The Egyptian Government plans to implement some of his key findings.

Mr J.W. Sutherland (Project 8310) was a leader of a course on postharvest technology run at the University of Brawijaya, Indonesia during March 1985. This work was sponsored by the International Development Program of Australian Universities and Colleges.

A delegation from Malaysia visited Australia in July 1984 to attend a Project Formulation Meeting concerned with a feasibility study of bulk handling of paddy and rice in Malaysia. The delegates were Dr Ismail Shamsudin, Director-General, National Paddy and Rice Authority of Malaysia (LPN), Mr Zainuddin Dato Awang Ngah, Deputy Secretary-General, Ministry of Public Enterprises, Mr Ahmad Ilham Abdul Samad, State Director of LPN for Kedah-Perlis, and Mr Loo Kau Fa, Director of Engineering, LPN. They first attended a CSIRO/Australian Grain Institute Seminar and Workshop on Aeration System Design, which was held in Melbourne on 10–11 July 1984. En route to the Project Formulation Meeting, which was held at the Ricegrowers' Co-operative in Leeton on Friday 13 July, the party inspected the Grain Elevators

Board of Victoria's Dunolly wheat sub-terminal with its pilot fluidised-bed heat disinfestation plant, and the Rice Marketing Board's computerised in-store rice drying complex at Deniliquin. After the meeting, the party inspected rice storage and processing facilities in the Leeton–Griffith area on 14 July, and the N.S.W. Grain Handling Authority's (GHA) export terminal at Sydney on 17 July.

Following the appointment of Encik Shaharuddin Hj. Haron as the new Director-General of LPN in December 1984, he visited Australia from 14–21 April 1985 for discussions concerning the implementation of Projects 8308 and 8344 in Malaysia. He participated in a Project 8308 Team Leaders' Meeting held initially at the University of New South Wales and then at the Ricegrowers' Co-operative in Leeton. He also inspected the GHA terminal in Sydney, the Yanco Rice Research Station, and various storage and processing facilities of the Ricegrowers' Co-operative and the Rice Marketing Board, including the rice mill at Deniliquin.

The ACIAR Liaison Officer in the Philippines, Miss Leonardo Nallana, visited the University of New South Wales and the Ricegrowers' Co-operative at Leeton in October 1984 during a familiarisation visit to Australia. She held general discussions with Project 8308A personnel and inspected the facilities at the Ricegrowers' Co-operative.

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 Seminars

The first seminar with which the program is associated, on 'Pesticides and Humid Tropical Grain Storage Systems', was held in Manila from 27–30 May 1985.

A second seminar, on 'Preservation of Grain Quality by Aeration and In-store Drying', is planned for Kuala Lumpur from 9–11 October 1985. It will be conducted jointly with GASGA, the Malaysian Agricultural Research and Development Institute, Lembaga Padi dan Beras Negara, and the ASEAN Food Handling Bureau. The seminar is designed to present the current state of knowledge under broad headings of objectives, basic principles, and design systems, followed by a discussion of individual case studies. Particular emphasis will be given to simulation of the processes involved and the extension of the models so developed into practical application.

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
Mrs J. Olditch, Secretary
Mr D. Rofe, Divisional Project Officer

International Seminar on Pesticide Use

ACIAR, in collaboration with the National Post-Harvest Institute for Research and Extension (NAPHIRE) of the Philippines and the ASEAN Food Handling Bureau (AFHB), organised an international seminar on the topic 'Pesticides and Humid Tropical Grain Storage Systems', held in Manila from 27–30 May 1985.

The seminar sought to define the relevance and state of knowledge of pesticide technology in the humid tropics and to develop recommendations on the directions in which the technology might best be guided. The attendance of almost 200, drawn from most countries in the region and from many other parts of the world, reflected the high degree of interest in these matters.

Mr F. Duban, the Acting Executive Director of NAPHIRE, gave the address of welcome and Professor J.R. McWilliam presented an overview of the seminar. In his keynote address Minister Jesus Tanchanco, Administrator of the National Food Authority and Presidential Adviser on Food, expressed alarm at the postharvest losses in the world's food supplies and urged participants to evolve effective pest management programs with emphasis on economy and safety. He referred to the collaborative activities between ACIAR and NAPHIRE in developing integrated programs which incorporate physical, biological, and chemical control measures.

In choosing authors for the 29 papers which were presented, the seminar organisers enlisted from within and outside the region leading specialists on particular topics. Many papers were given by scientists associated with the pesticides and other projects of the ACIAR Grain Storage Research Program.

Major issues to emerge at the seminar were har-

Seminar Program: Pesticides and Humid Tropical Grain Storage Systems

Address of Welcome — Mr F. Duban
Seminar Overview — Professor J.R. McWilliam
Introduction of Participants — Dr B.R. Champ
Introduction of Guest Speaker — Dir. V. Racho
Keynote Address — Minister J.T. Tanchanco

Pest Problems and Current Use of Pesticides
Chairman — E.D. Magallona; Rapporteur — M.G. Ramos
Pest problems and the use of pesticides in grain storage in Malaysia — A. Rahim Muda
Pest problems and the use of pesticides in grain storage in the Philippines — F.M. Caliboso, P.D. Sayaboc, and M.R. Amoranto
Pest problems and the use of pesticides in grain storage in Thailand — Chuwit Sukprakarn
Pest problems and the use of pesticides in grain storage in Indonesia — M. Sidik, H. Halid, and R.I. Pranata
Problems relating to pest control and the use of pesticides in grain storage: the current situation in ASEAN and future requirements — R.L. Semple

Some Constraints to Use of Pesticides
Chairman — R. Labadan; Rapporteur — R.L. Semple
Management of pest control in grain storage systems — D. Halliday and D.J.B. Calverley
Safety considerations in insecticide usage in grain storage — J.T. Snelson
Regulatory requirements for pesticide use — J.T. Snelson
Industry perspectives in pest control in the humid tropics — J.C. Gonzalez, Jr.
Developing country perspectives and use of pesticides — E.D. Magallona

Background Studies on Residual Pesticides
Chairman — B. Morallo-Rejesus; Rapporteur — J.T. Snelson
Background studies on the metabolism of residual pesticides in stored grain — D.G. Rowlands (presented by C.E. Dyte)
Behaviour of pesticide residues on stored grain — J.M. Desmarchelier
Biological efficacy of residual pesticides in stored grain at high humidities and moisture contents — P.R. Samson

Background Studies on Fumigants
Chairman — M. Bengston; Rapporteur — C.E. Dyte
Sorption and desorption of fumigants on grains: mathematical descriptions — H.J. Banks
Movement of fumigants in bulk grain — T.V. Nguyen
Action and inaction of fumigants — N.R. Price
The biological efficacy of fumigants: time/dose response phenomena — R.G. Winks (presented by C.J. Waterford)

Framework for Use of Pesticides
Chairman — D.J.B. Calverley; Rapporteur — J. van S. Graver
Principles of integrated use of chemicals in grain storage in the humid tropics — M. Bengston
Occurrence of resistance to pesticides in grain storage pests — B.R. Champ
Modelling of strategies to overcome resistance — H.N. Comins
Quality control and methods of application of pesticides to stored grain — J.M. Desmarchelier

Treatment Techniques
Chairman — V.F. Wright; Rapporteur — D.J.B. Calverley
Grain protectants — M. Bengston
Application of fumigants for the protection of grain and related products — H.J. Banks
Fabric spraying for pest control in grain storage — D.J. Webley
Use of pesticides in bag storage of grain — D.J. Webley
Use of carbon dioxide and sealed storage to control insects in bagged grain and similar commodities — P.C. Annis and J. van S. Graver

Integration of Chemicals into Storage Systems
Chairman — L.J. Fredericks; Rapporteur — M. Bengston
Use of pesticides in systems for central storage of grain — D.J. Webley
Use of pesticides for insect control in farm storage — V.F. Wright
An assessment of the benefits and costs of pest control methods in humid tropical grain storage systems — G.J. Ryland

Closing Session
Chairman — B.R. Champ; Rapporteur — E. Highley
Reports of Session Chairmen
Summary of Recommendations
Acknowledgements — M. Ramos
Closing Remarks — L.J. Fredericks

monisation of the regulations covering pesticide use in the various countries of the region, and the need to develop strategies to combat the alarming development of resistance to fumigants in the major pest species. As regards the former, the UNDP/UNIDO-sponsored Regional Network for Production, Marketing, and Control of Pesticides in Asia and the Far East has already done much. Seminar participants strongly supported its activities.

As regards countering fumigant resistance, the seminar recommended that a working party, drawn from all interested groups, be set up to examine the feasibility of developing a code of practice for fumigation in the region. The Working Party on Suggested Recommendations for Good Fumigation Practice in the ASEAN Region subsequently established has since held its first meeting.

The papers from the Manila seminar are being published in the ACIAR Proceedings Series.

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Program Coordinator, Dr B.R. Champ, introduced participants at the ACIAR/NAPHIRE/AFHB Pesticides Seminar in Manila.

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