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Integrated management of insect pests of stored grain in the Philippines

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Integrated management of insect pests of stored grain in the Philippines

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Foreword

The Australian Centre for International Agricultural Research (ACIAR) has had in place a comprehensive impact assessment program for many years. The Bureau of Agricultural Research of the Philippines' Department of Agriculture (DA-BAR) has undertaken some impact assessment studies in the past and is interested in expanding this activity.

ACIAR and DA-BAR have been partners in collaborative research and development activities since ACIAR's inception. The two organisations feel that there are mutual gains to be made from expanding this collaboration to the impact assessment activities each undertakes. In addition, the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) has recently substantially expanded is impact assessment program.

All three organisations have agreed to develop collaborative impact assessment study (IAS) activities and share resources and experiences to make these studies more effective. In 2007–08, three studies were commissioned. This report is on the second of these, which was developed primarily between DA-BAR and ACIAR.

Between 1983 and 1994, ACIAR and partner organisations supported four projects that developed effective methods for treating stored grains for control of pests. These projects covered several countries in South-East Asia, including the Philippines. The combined research effort between the Bureau of Postharvest Research and Extension (BPRE) and two research groups in Australia, the Queensland Department of Primary Industries (QDPI) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), developed effective alternative control options for major pests of stored grains.

This assessment focused on the impact in the Philippines and, through surveys of members of the grain sector, found that there has been significant adoption of the outcomes. This has been primarily by the larger storage and handling sectors of the rice and other grain industries.

The study found that the return on this significant investment by all parties was substantial, with a net present value of research gains to the Philippines of PHP65,544m or A$1,696m. This provides a benefit:cost ratio of approximately 174:1 and an internal rate of return of 46.6%.

ACIAR and DA-BAR are pleased with their partnership through this collaborative study, which has facilitated more detailed on-the-ground surveys and information collection than is usually possible. We congratulate the study group from both countries on working so well together.

Peter Core
Chief Executive Officer
ACIAR

Nicomedes P. Eleazar
Director
DA-BAR

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
BAS	Bureau of Agricultural Statistics (the Philippines)
BPRE	Bureau of Postharvest Research and Extension (the Philippines)
DA	Department of Agriculture (the Philippines)
DA–BAR	Bureau of Agricultural Research of the Department of Agriculture (the Philippines)
IPM	integrated pest management
IRR	internal rate of return
NFA	National Food Authority (the Philippines)
NPV	net present value
OP	organophosphate (pesticide)
PCARRD	Philippine Council for Agriculture, Forestry and Natural Resources Research and Development
PhilRice	Philippine Rice Research Institute
PHP	Philippine pesos
ppm	parts per million
QDPI	Queensland Department of Primary Industries
R&D	research and development
SP	synthetic pyrethroid (pesticide)

Acknowledgments

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The following private establishments were consulted on their pest management practices and we deeply appreciate the information they provided: Vitarich Corporation, San Miguel Foods Inc., Foremost Farms, CJ Philippines, Universal Robina Corporation, Purina Philippines, SL Agritech and Bayer Crops Science, Inc.

Executive summary

From 1983 to 1994, the Australian Centre for International Agricultural Research (ACIAR) supported a series of four research projects on the use of pesticides in protecting stored grains in the tropical areas of Australia, the Philippines, Malaysia, Thailand and China. In the Philippines, the research team came from the Bureau of Postharvest Research and Extension (BPRE) and the Queensland Department of Primary Industries (QDPI).

Resistance to malathion, an organophosphate pesticide, was becoming widespread. Pest management technologies were developed based on integrated pest management (IPM) principles of using chemicals in combination and in rotation at lowest effective dose rates when indicated by pest population monitoring. Applying minimum levels of pesticide for control likely delivers improved human and environmental health outcomes through both reduced exposure in grain storage facilities and reduced pesticide residues on grains.

In the Philippines, the following combinations of pesticides were developed for admixture with grain in bulk storage and for protective spraying combined with fumigation of grain stored in bags:

- pirimiphos-methyl + deltamethrin + piperonyl butoxide
- pirimiphos-methyl + permethrin + piperonyl butoxide
- fenitrothion + fenvalerate + piperonyl butoxide
- pirimiphos-methyl + permethrin
- deltamethrin.

The present study estimated the ex-post rate of return earned from ACIAR's investment in the four research projects in the Philippines on the management of grain pests. This required estimating flows of costs and benefits from 1983, when the projects began, out to 2030, as suggested in ACIAR's impact assessment guidelines.

The present value (5% discount rate) of the total investment in the four projects from 1983 to 2005 was A$9.6m (2007 dollars) or 373 million Philippine pesos (PHP). ACIAR's share of this investment was 72% and the shares to QDPI and BPRE were 11% and 16%. We estimate that BPRE and PhilRice will continue investing in research and extension at the rate of about PHP306,000 each year to 2030 to maintain the efficacy of these technologies.

The efficacy of the technologies was proven for stored rice, maize and mung bean, although the financial analysis conducted here was restricted to rice.

While these technologies increased the cost of pest protection from PHP0.07/kg to PHP0.60/kg, they reduced wastage rates from 9.5% to 4.8% per year. Under this scenario we estimated that the total benefits from the new technologies were PHP622 for each 1,000 kg of paddy (unhusked) rice, with the amounts going to farmers, processors and consumers being PHP72, PHP26 and PHP524, respectively. Consumers receive a larger share of benefits because the demand for rice is less elastic than the supply.

In the Philippines, the main users or adopters of the technologies were the National Food Authority (NFA) and large traders and millers. The technologies are less useful to many households and small traders who hold grain for only short periods. The ACIAR/BPRE technologies are applicable to about 30% of the rice stored by NFA. By 2008, the ACIAR/BPRE technologies were being applied to all of this 30% potential market. The other groups that store grain for long periods and need pest management technologies are the larger traders and millers. Only about half of all rice stored in the commercial sector is a target for the ACIAR/BPRE technologies and, by 2008, about half this potential market had adopted them. In 2008, we estimated that, of the 14.8m tonnes of rice for food in the Philippines, these technologies could potentially be applied to 6.4m tonnes and were actually being applied to 3.9m tonnes (61%). This is a much higher level of adoption than anticipated in earlier studies. In our analysis, adoption by both NFA and the commercial sector began in 1991 and increased linearly to the 2008 levels.

From the adoption of the ACIAR/BPRE grain pest management technologies, the present value of the stream of benefits (change in total economic surplus) to 2030 amounted to PHP65,924 m (A$1,706m). The present value of investment in the research is PHP380m (A$9.8m). This investment was made by ACIAR, BPRE, the Philippine Rice Research Institute and other partners. Hence, the net present value (NPV) of the investment was PHP65,544m (A$1,696m). The benefit:cost ratio was 174:1. The internal rate of return (IRR) of the stream of benefits realised from the technology adoption was 46.6%. The NPV for ACIAR, which financed 72% of the development of the technologies, was A$1,226m (Table 1).

These results suggest that the investment in research into stored grain pest management by ACIAR and its partners has been a profitable one. If adoption has been overstated by classing as adopters some who merely use more potent chemicals rather than IPM principles, then it is likely that at least some of the estimated welfare benefits should more properly be attributed to the agencies that developed the new pesticides rather than to those, in this case ACIAR and BPRE, that funded the development of the new IPM technologies. If, for example, the actual adoption in the commercial sector by the groups to which the technologies are applicable was 25% rather than 50%, the benefit:cost ratio falls to 115:1 and the IRR falls to 40.1%.

Adoption of the ACIAR/BPRE technologies that prevent storage losses from pest damage has also a potential to improve the quality of the diet of Filipinos, especially poorer people. Members of the poorest quintile of the population spend roughly a third of their income on rice. When rice prices drop by 1%, the quantity consumed increases by approximately 0.25%. While consumption of other foods that are complements or substitutes for rice in the diet also changes, overall there is likely to be a large nutritional gain among the poor if rice prices fall following adoption of improved technologies to manage grain pests. Market inefficiencies that do not allow the productivity gains from the new technologies to be reflected in lower rice prices harm the nutritional status of the poor.

Several lessons can be learned from the ACIAR-supported research on pesticide management. The role of the agency conducting the research, in this case BPRE, is deemed not well defined in terms of technology dissemination. Since the devolution of field agricultural extension officers from the Department of Agriculture to the local government sector in the early 1990s, technology extension has been constrained. This function used to be with the department's Bureau of the Agricultural Extension, now the Agricultural Training Institute. National government programs need to be coordinated with the local government units, as the latter may have different priorities.

Table 1. Summary results of impact assessment of research on integrated management of insect pests of stored grain

	Australia	Philippines
Benefit:cost ratio	174:1	174:1
Internal rate of return	46.6%	46.6%
Net present value		
Total	A$1,696m	PHP65,544m
Return to ACIAR	A$1,226m	
ACIAR's cost share	72.3%	

1 Background and objectives of the impact assessment study

The Australian Centre for International Agricultural Research (ACIAR) has had a strong culture of evaluating the impact of its research investments to demonstrate their value to taxpayers in Australia and stakeholders in partner countries, and to guide the allocation of research resources in the future to potentially higher pay-off ends.

Peak agricultural research institutions in the Philippines, including the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) and the Department of Agriculture–Bureau of Agricultural Research (DA–BAR) have been interested in applying ACIAR's experience to further develop their own capacity in impact assessment. In 2007, ACIAR, PCARRD and DA–BAR decided to jointly fund impact assessments of three areas of research and development (R&D) supported by ACIAR and Philippine and other partner institutions. The partners agreed to conduct impact assessments in the following three areas:

- the control of endoparasites in goats
- the development of two-stage drying processes for grains, including rice
- pest management in grain storage in the face of developing problems of resistance of storage pests to pesticides.

A number of criteria guided the choice of research areas to be assessed. The research had to have been largely completed, so that the industry had had time to adopt the technologies. In this first round of impact assessments, there was a deliberate attempt to select research areas where at least the science was thought to have been successful, even if the level of adoption was uncertain. An attempt was made to assess different types of technologies in different industries at different points in the marketing chain. The interests, priorities and skills of the three partners influenced the choice. In each case, the program of research assessed consisted of a number of sequential research projects funded by ACIAR, and sometimes projects funded by other agencies such as the International Fund for Agricultural Development, PCARRD and DA-BAR that were inextricably linked to the ACIAR projects.

ACIAR commissioned Dr John Mullen from the New South Wales Department of Primary Industries, Australia, to coordinate the assessments with Philippine collaborators. PCARRD and DA–BAR commissioned economists and experts from the University of the Philippines Los Baños, the Bureau of Agricultural Statistics (BAS) and the Philippine Rice Research Institute (PhilRice) to work with Dr Mullen. These organisations also provided in-kind support to the impact assessment process.

Here we report an assessment of the impact of research funded by ACIAR and the National Postharvest Institute of Research and Extension, now the Bureau of Postharvest Research and Extension (BPRE) within the Department of Agriculture (DA), into the management of pests of stored grain in the Philippines.

In hot, humid climates such as experienced in the Philippines, grain insect pests, followed by fungi, rodents and birds, have been found to be the major cause of losses of stored grain. Several studies have recorded the magnitude of losses due to insect infestation. In 1976, losses due to insect infestation in maize stored for 8 months in government warehouses without the appropriate pest control measures were estimated to be 34% of its weight (Caliboso 1977). This loss was reduced to 11% in 1984 (Caliboso et al. 1985) and 9% in 1986. The reduction in losses was attributed to use of appropriate pest-control techniques (admixture of chemical protectants with stored grain) and improved storage structures and design. The same study found that the loss in milled rice could reach 148,000 tonnes/year valued at US$49.6m. This is based on the average mean loss of 21% due to insects for a period of 10 months.

While the advent of synthetic pesticides promised cheap, effective control of grain pests, it soon became evident that ongoing R&D was required to maintain the efficacy of pesticides because insects inevitably develop resistance to them.

Australia was a leader in the development of technologies for reducing losses due to pests in stored grain. However, the existing Australian technologies were most applicable to grain storage under conditions of high temperatures and low moisture. Hence, there was concern about implementing pest control under conditions of both high temperature and moisture, as experienced in northern Australia in the maize and peanut industries, for example. Clearly, similar conditions apply in many countries in Asia. This gave the impetus for ACIAR to support, as part of its wider program in grain storage research, a series of research projects on the use of pesticides for stored grain pest management. The projects ran from 1983 to 1994, and involved research groups in Australia, the Philippines, Malaysia, Thailand and China.

In the Philippines, the research projects were undertaken by the National Postharvest Institute of Research and Extension, now BPRE. The Australian partners were the Entomology Branch of the Queensland Department of Primary Industries (QDPI) and the Division of Entomology of the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

The objective of the study reported here was to estimate the ex-post rate of return earned from ACIAR's investment in the Philippines on research into the management of grain pests undertaken in four projects described in Section 3. This required an assessment of the potential efficiency gains within the grain processing and storage sector from the technologies developed as part of the ACIAR projects. An assessment was also made of the rate and extent of adoption of the technologies by grain processors. Estimates of changes in welfare were related to the R&D investment made to generate them, to indicate if the work has been a good use of ACIAR's limited research resources. We employed the approach to impact assessment detailed in the guidelines recently completed by ACIAR (Davis et al. 2008). Figure 1 summarises our approach in undertaking the assessment.

Major steps in the impact assessment included:

- describing the background to the ACIAR projects, the research processes undertaken and the links with other projects and agencies conducting research in this area
- describing and analysing the impact or adoption pathway by identifying project results and causal links and mapping inputs to project benefits
- relating inputs, outputs and outcomes from the project within a benefit–cost framework.

Key parameters used in the impact assessment were based on BAS data, research results, the judgments of research and extension personnel, and the findings of a survey conducted in March 2008 as part of the impact assessment.

A number of factors confound the analysis. First, as noted above, ACIAR has not been the only agency supporting research into the management of grain pests. In particular, since the ACIAR projects concluded in 1996, BPRE and PhilRice have continued to invest in research to maintain and improve the efficacy of the integrated pest management (IPM) technologies developed during the ACIAR projects. We have evaluated these four 'ACIAR' projects and the continuing Philippine research as a package. It is difficult to attribute between the various agencies that made investments, the welfare gains from the body of research and extension undertaken. Our general approach has been to avoid making attributions. Rather, we have assessed the returns to total investment by all agencies and assumed that the research resources provided by each agency were equally efficient and earned the same average rate of return over the whole investment. By assuming that

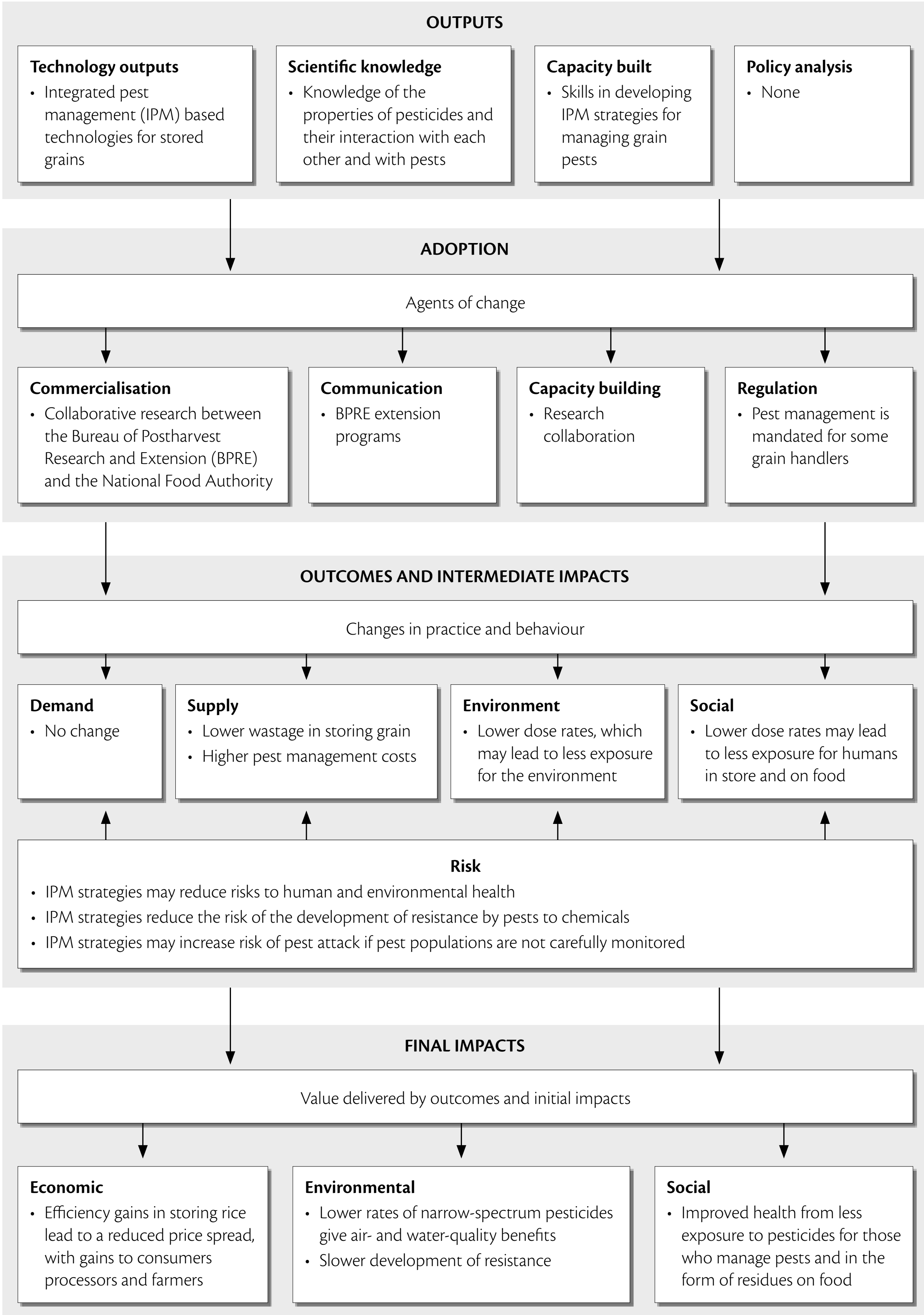

Figure 1. Summary of approach to impact assessment

ACIAR shared in the benefits from the R&D in the same way as it shared in investment costs, an estimate was made of the net present value of the ACIAR investment (and for other partners). This approach required investments by the other agencies in the Philippines to be identified.

Second, the ACIAR projects were not confined to the Philippines, creating further attribution issues. In addition, by confining attention to estimating the returns to investments in the Philippines, the total benefits from the research program are understated to the extent that the technologies have spilled over to partner countries and further afield.

2 Grain storage and pest management in the Philippines

This section briefly describes the grain storage practices in the Philippines used by farmer-producers, private traders/millers, and the National Food Authority (NFA), the country's central grain-marketing agency.

2.1 Farmers

At the farm level, producers store their grains for three purposes: for consumption until the next harvest, as seed for planting in the next season and for selling when prices become favourable. Recent studies (BAS 2007; Mataia 2007) show that, of the total supply of paddy (unhusked) rice, on average 88% is available for food, and 12% for feeds, seeds and wastage. Of the 88% available for food, about three-quarters is considered marketable while the remaining quarter is allotted for home consumption. Farmers seldom practise chemical pest-control methods due to the small volume of grains stocked and fast turnover of stocks.

2.2 Private traders/millers

Most of the marketable surplus of farmers ends up in commercial warehouses of private traders/millers. An estimated 68% of the country's food grain storage facilities is accounted for by private commercial warehouses (AYC 1989).

Commercial millers and traders store their grains mostly in 50 kg jute or polypropylene bags. In commercial warehouses, sacks are stacked on the floor or pallets to about 2 m high. During the peak harvest season, stocks are piled up to the warehouse walls and around supporting pillars. Non-observance of proper handling and pest control methods may result in considerable losses. The practice of building flat stores adjoining the mill house is one cause of heavy infestation of pests in stored grain. The mill equipment provides perfect hiding places for insect pests. Regular pest-control measures depend to a large extent on the length of storage. If there is quick turnover of stock, regular cleaning, including structural spraying, is practised. In cases where traders and millers practise fumigation and residual spraying, this is applied mostly to milled rice in bags before distribution to retailers (PCARRD 2001).

2.3 Government level storage

NFA is the government body engaged in storing grains. It operates a 90-day buffer stock based on estimates of general consumption during lean months and weather-related production shortfalls. Buffer stock is stored long term to ensure stable supply and prices. NFA undertakes stock build-up through domestic procurement of paddy and importation of rice in times of low crop production. It procures about 5% of total paddy production.

NFA uses two systems for storing grain in its warehouses: the bag system, which is the prevalent mode of storage, and the bulk system where bulk facilities (silos) are available. At present, silos are installed in the major maize-producing areas such as those in Isabela, South Cotabato, Bukidnon and Sultan Kudarat.

Bag storage can be either conventional bag storage or the 'sealed enclosure fumigation storage technique' (SEFUST). Most of the NFA-owned and leased warehouses apply the conventional bag storage system because it has lower capital costs, it allows different commodities to be stored in the same facility, it permits heat dissipation and minimises the management skills required. This system, however, imposes high operating costs and results in higher losses due to pest infestation.

NFA implements pest control measures in warehouses of bagged grain on the basis of monthly inspections of stock. The most common method of detecting insect presence is visual inspection (87%), followed by physical analyses. Pest control includes protective and residual spraying, fogging, fumigation and the observance of warehouse hygiene and sanitation. Rodents are controlled through baiting with the use of poison, trapping and screening of gaps in the warehouse fabric (PCARRD 2001).

3 ACIAR-supported pesticides research projects

ACIAR has supported four projects on managing pests of stored grain in the Philippines (Table 2).

3.1 Project PHT/1983/009

Before the series of research projects in the Philippines, farmers and processors were using chemicals as grain protectants against pests. It was observed, however, that over time some pests developed resistance to specific chemicals, particularly the organophosphate pesticide malathion. This observation prompted the monitoring of resistance in different Coleoptera (beetles and weevils) dominating the pest complex in grain storages in the Philippines and the screening of new chemicals that would be applied through the series of four projects, which began with an exploratory project, PHT/1983/009. A nationwide survey showed that resistance of major coleopteran pests to malathion was widespread. All 60 populations of the rust-red flour beetle (*Tribolium castaneum*) tested were resistant to malathion. Of these, 48 exhibited a malathion-specific type of resistance, while 12 showed some degree of resistance to pirimiphos-methyl, another organophosphate. Based on knockdown, the degree of resistance to malathion was estimated at >500× at the $KD_{99.9}$ level.[1] For the lesser grain borer (*Rhyzopertha dominica)*, eight populations had a malathion-specific type of resistance (5–15× at $KD_{99.9}$); one showed cross-resistance to the organophosphate pirimiphos-methyl and two were still susceptible to malathion.

All 38 populations of the maize weevil (*Sitophilus zeamais*) were still susceptible to malathion. It was thus concluded that, where mixed populations of different stored grain pests were present, malathion could no longer be used because adequate control would not be achieved. A degree of cross-resistance to pirimiphos-methyl was detected but the compound may have remained sufficiently potent to permit its use.

Laboratory screening showed that synthetic pyrethroids (e.g. deltamethrin) were effective against *R. dominica* but not against *S. zeamais,* while organophosphates (e.g. chlorpyrifos-methyl) were more potent against *S. zeamais* than *R. dominica.* When organophosphates were combined with pyrethroids such as deltamethrin, they were effective against all stored product pests and were more economical to use than each individual pesticide alone.

Trials of admixture of chemical protectants with maize were conducted on a commercial scale in NFA's bulk-storage facility at General Santos City, South Cotabato. Field trials were conducted in simulation with the operating system of NFA. Treated maize was shipped and stored in bags in Cebu City for 8 months. For paddy, treatment trials on grain admixture were conducted at NFA's storage in Isabela for a 12-month storage period. The results of PHT/1983/009 indicated that grain protectant combinations were more biologically and economically effective than single treatments of either an organophosphate or a synthetic pyrethroid (Table 3).

1 The concentration that is effective against 99.9% of a test population.

Table 2. Australian Centre for International Agricultural Research projects on the use of pesticides in grain storage in the Philippines

Project no.	Project title	Duration	Collaborating countries	Commodity focus
PHT/1983/009	Integrated use of pesticides in grain storage in the humid tropical countries	1983	Australia, Malaysia, the Philippines	Rice, maize
PHT/1983/011	Kinetics of decay of candidate pesticides for integrated pest control programs	1984–1987	Australia, Malaysia, the Philippines	Rice, maize
PHT/1986/009	Integrated use of pesticides in grain storage in the humid tropics	1987–1990	Australia, China, Malaysia, the Philippines, Thailand	Rice, maize, legumes
PHT/1990/009	Increasing efficiency of integrated pest control in grain storage and minimising pesticide residues by the use of mixtures of grain protectants	1991–1994	Australia, Malaysia, the Philippines	Maize, mung bean

Table 3. Estimated losses of rice and maize stored in the Philippines under different pest management methods, based on experiments of the Bureau of Postharvest Research and Extension

Pest management method	Loss (%)
Paddy	
Traditional (12 months' storage)	12.2
ACIAR[a] project PHT/1983/009 (admixture)	4.3–7.4
Traditional (12 months' storage)	4.4
ACIAR project PHT/1986/009 (improved traditional[b], 12 months' storage)	1.5–3.0
Milled rice	
Untreated (7 months' storage)	4.4
Traditional controlled (7 months' storage)	2.4
ACIAR project PHT/1986/009 (improved traditional, 7 months' storage)	0.6–1.2
Maize	
Traditional (9 months' storage)	9.0
ACIAR project PHT/1983/009	3.4–5.7
Traditional (9 months' storage)	6.5
ACIAR project PHT/1986/009	1.3–3.0
Traditional (4.5 months' storage)	7.0
ACIAR project PHT/1990/009	0.11–0.19

[a] Australian Centre for International Agricultural Research

[b] Bag spraying plus fumigation

3.2 Project PHT/1983/011

Since the studies under PHT/1983/009 focused mainly on the application of chemicals, very little information was provided on the behaviour of pesticides when exposed to the high ambient humidities and grain moisture contents that prevail in the humid tropics. Hence, project PHT/1983/011 was undertaken to look into the kinetics of decay of the pesticides used, in order to determine the rates of application needed for specific commodities and storage intervals. Samples from PHT/1983/009 were analysed and the results served as input to PHT/1983/011. Field trials were undertaken to compare the data obtained from commercial warehouses with those from laboratory models. Due to the difficulty in developing a comprehensive model, however, project activity was confined to pesticide-residue monitoring.

3.3 Project PHT/1986/009

The data generated by PHT/1983/011 were used in the experiments undertaken under PHT/1986/009, which extended the scope of work to treatment of bulk stored grains in commercial storages, bag stacks and the fabric of storage buildings. Research collaborators from Queensland, Australia, conducted basic research focused on the evaluation of the performance of grain protectants, including the insect-growth regulator methoprene, at the high grain moisture and/or relative humidity levels that prevail in tropical countries. The insect-growth regulators were then a new class of pesticides characterised by much lower mammalian toxicities. For treatment of grains such as paddy and milled rice in bags, the efficacy of residual spray combined with fumigation to protect grains from insect infestation was evaluated. Moreover, the efficacy of synergised combinations of insecticides was evaluated and the commodity range was extended to mung beans.

For maize, grain was treated in General Santos City (where there are silos) and stored in Cebu City for 9 months, while for paddy, treatment trials on grain admixture were again conducted at NFA Isabela for a duration of 12 months. Grain admixture treatments were more effective and beneficial than traditional NFA control strategies and yielded reductions in losses due to insect pests ranging from 60% to 80% both for maize and paddy (Table 3).

The grain protectant treatments developed in PHT/1983/009 were evaluated as residual insecticides and integrated as necessary with fumigation of bag stacks in Cabanatuan City, Luzon, for paddy, and in Santiago, Isabela, for milled rice stored for 12 months and 7 months, respectively. Bag spraying combined with fumigation was also more effective than the traditional control method in both trials. Compared with standard NFA controls, losses were reduced by 52–68% for paddy and 50–77% for milled rice (Table 3).

3.4 Project PHT/1990/009

There was significant progress in developing effective treatments of pests in grain storage through the first three projects. While the use of synergised combinations of insecticides (mixtures) increased their efficacy, the potential toxicological impact of pesticide residues on health and the environment became a major public concern. An anticipated increasing reliance on pesticide use, especially in developing countries, paved the way for PHT/1990/009, which aimed primarily to evaluate the use of insecticide mixtures deemed to have greater potency than their individual components, thereby allowing reduced application rates and, in turn, reduced residue levels (Champ 1994). These component studies provided new information in terms of losses in comparison to traditional grain pest management (Table 3).

To make research relevant, laboratory work and field trials focused on the major pest species of maize (*S. zeamais*, *T. castaneum* and *R. dominica)* and mung bean (*Callosobruchus maculatus*). The insecticides used at reduced rates with maximum potency were mixtures of organophosphates such as pirimiphos-methyl and fenitrothion, and pyrethroids such as deltamethrin and permethrin. The mixtures of protectants that were evaluated and tested were pirimiphos-methyl and deltamethrin, fenitrothion and fenvalerate, and pirimiphos-methyl and permethrin. The pyrethroids used were synergised with piperonyl butoxide at a rate of 10 mg/kg. The study showed that there is strong augmentation among these grain protectants. The best treatment would be the use of lower dosages of deltamethrin or fenvalerate (with or without piperonyl butoxide) with an organophosphate.

Under PHT/1990/009, pesticide residue levels were studied through extensive laboratory work involving tests on insect cultures, and bioassays on treated surfaces and grains. These investigated the efficacy of synergists such as piperonyl butoxide at reduced levels that could also reduce insecticide residue levels. The field trials included the verification of minimum effective doses of pesticides applied to maize and mung bean to obtain 100% protection.

Based on field trials, complete mortality of storage pests (*R. dominica*, *S. zeamais*, and *T. castaneum)* was achieved for at least 3 months using the above mixtures.[2] The results of the three ACIAR projects identified the reduced application rates of the grain protectants that still maintained the potency of the protectant combinations and lowered residues after storage (Table 4). Further reducing the application rates of these mixtures is not feasible because pest control is compromised.

2 For mung bean, the treatments gave complete control of *C. maculatus* adults for at least 3 months.

3.5 Total investment in the ACIAR-supported projects

The data on investment in the various research projects (Table 5) come from a variety of sources. ACIAR provided data on its expenditure. A proportion of total expenditure by ACIAR for each project has been attributed to research in the Philippines and this estimate has been used here. The ACIAR source does not provide an estimate of the in-kind and cash contributions from Australian and Philippine collaborators, but estimates were taken from Chudleigh (1991) for the first three projects. For the most recent project, we have assumed that the contributions from QDPI and BPRE have continued at the same rate as

Table 4. Maximum residue limits (MRL), dosage rates and residue levels of different grain protectants in maize after 4.5 months' storage

ACIAR project number	Grain protectant	MRL (mg/kg)	Dosage (mg/kg)	Residue after storage (mg/kg)
PHT/1983/009	Deltamethrin	2.0	1.0	0.14
PHT/1986/009			0.4	0.06
PHT/1990/009			0.1	0.02
PHT/1983/009	Fenitrothion	10.0	12.0	0.32
PHT/1986/009			10.0	0.11
PHT/1990/009			6.0	0.19
PHT/1983/009	Fenvalerate	5.0	1.0	0.11
PHT/1990/009			0.5	0.01
PHT/1983/009	Permethrin	2.0	1.0	0.08
PHT/1990/009			0.5	0.01
PHT/1983/009	Pirimiphos-methyl	10.0	6.0	0.50
PHT/1986/009			8.0	1.59
PHT/1990/009			4.0	0.38
PHT/1990/009			4.0	0.33

Table 5. Investment in research and development (R&D) in stored grain pest management technologies in the Philippines by the Australian Centre for International Agricultural Research (ACIAR), the Bureau of Postharvest Research and Extension (BPRE), the Philippine Rice Research Institute (PhilRice) and the Queensland Department of Primary Industries (QDPI)

	ACIAR	BPRE/ PhilRice	QDPI	Present value of R&D investments (5% discount rate)				
				ACIAR	BPRE/ PhilRice	QDPI	Total	
	A$ nom	PHP nom.	A$ nom	A$ real	A$ real	A$ real	A$ real	PHP real
1983	21,743	884,146	15255	70,124	73,796	49,197	193,118	7,462,019
1984	267,240	1,178,861	30509	820,835	93,709	93,709	1,008,254	38,958,660
1985	502,271	1,178,861	30509	1,469,274	89,247	89,247	1,647,767	63,669,295
1986	323,973	1,178,861	30509	902,577	84,997	84,997	1,072,571	41,443,873
1987	206,047	1,178,861	30509	546,704	80,950	80,950	708,603	27,380,236
1988	362,788	1,178,861	45764	916,747	77,095	115,642	1,109,484	42,870,157
1989	240,659	1,178,861	45764	579,175	73,424	110,135	762,734	29,471,848
1990	202,416	1,178,861	45764	463,941	69,927	104,891	638,759	24,681,487
1991	163,912	1,178,861	45764	357,800	66,597	99,896	524,293	20,258,553
1992	154,363	1,178,861	45764	320,910	63,426	95,139	479,475	18,526,806
1993	109,380	1,477,615	45764	216,565	75,714	90,609	382,888	14,794,707
1994	139,461	1,461,536	45764	262,974	71,324	86,294	420,593	16,251,584
1995	16,083	2,265,030		28,882	105,272		134,154	5,183,670
1996	12,911	2,057,132		22,082	91,056		113,139	4,371,651
1997		1,237,168			52,154		52,154	2,015,216
1998		1,040,525			41,776		41,776	1,614,196
1999		1,058,621			40,478		40,478	1,564,066
2000		1,020,908			37,177		37,177	1,436,520
2001		946,638			32,831		32,831	1,268,585
2002		3,696,545			122,098		122,098	4,717,832
2003		2,862,715			90,054		90,054	3,479,648
2004		1,000,601			29,977		29,977	1,158,321
2005		541,750			15,458		15,458	597,279
Present value (at 5% compound)				6,978,591	1,578,537	1,100,707	9,657,835	373,176,209
Share of total cost (%)				72	16	11		

in 1991. Chudleigh's contributions from partners were expressed in 1990 Australian dollars. Here, all expenditure was first converted to 2007 Australian dollars and totalled across the three agencies. This total was then converted to a series of investments from 1983 to 1996 in Philippine pesos and Australian dollars.

Since the completion of the ACIAR projects, BPRE and PhilRice have continued to invest in R&D with private chemical companies to maintain and improve the efficacy of integrated management of pests in stored grain. BPRE and PhilRice provided details on the operating expenditure they incurred since 1995 and this has been doubled to incorporate an in-kind contribution from the organisations to support these activities. Brief details of this work are presented in Table 6.

Real investment in research was compounded forward to 2007 at a rate of 5% (analogous to discounting a stream of future investments or benefits). The value in 2007 of the stream of investments in grain pesticide research in the Philippines by ACIAR and its partners totalled A$9.6m or PHP373m (Table 5). Of this total, ACIAR contributed almost A$7m or 72%.

Table 6. Research conducted to maintain the pesticide technologies developed by Australian Centre for International Agricultural Research (ACIAR) projects

Research conducted	Commodity	Agency	Year
Efficacy of cyfluthrin against stored product pests	Rice, maize, mung bean	Bureau of Postharvest Research and Extension (BPRE), Bayer	1993–1994
Testing of efficacy of ACIAR/BPRE technologies for stored product pests	Rice, maize, mung bean	BPRE	1995–2003
Chemical control of psocids in storage	Rice, maize	BPRE	2002–03
Baseline response of selected stored product pests to phosphine	Maize	BPRE	2002–03
Pirimiphos-methyl + λ-cyahalothrin against pests on stored commodities + mites	Maize	BPRE, Syngenta, Cargill	2005–06
Application rates in bag spraying and fumigation	Rice	Philippine Rice Research Institute	Ongoing

4 The outputs from the ACIAR, BPRE and PhilRice projects

4.1 New technologies, new knowledge and capacity built

The findings of the four ACIAR projects are reported in some detail in Yanson et al. (2002). They found that several mixtures of pesticides were both more potent and left fewer residues than previous pest management technologies. Hence, grain losses were reduced, and there were lower human and environmental health risks. Admixtures with grain in bulk-handling systems were more successful than treating grain stored in bags.

At least from a scientific viewpoint, Chudleigh (1991) implied that the set of ACIAR projects was successful in both Australia and the Philippines. In both countries, pest management technologies were developed that could be used where malathion resistance was developing and which resulted in residues within acceptable limits.

These technologies were successful in hot, humid conditions under which pesticides break down more quickly. The technologies ranged from admixtures to grain to strategies for bag and fabric protection. In the Philippines, it was found to be more effective to apply protectants to rice after drying. Much of the work was done by BPRE in cooperation with the Technology Research Division of NFA. The technologies were expected to be used in NFA, commercial and on-farm storage systems.

Knowledge-based IPM technologies were developed initially in response to a spiraling increase in pesticide use and its impact on farm productivity and profitability. Stern et al. (1959), entomologists at the University of California, were the first to assemble the various concepts that make up what is now referred to as IPM. They called for the integration of biological and chemical control strategies based on:

- greater knowledge of the ecosystem
- science-based monitoring and prediction of pest populations to identify economic thresholds
- the augmentation of natural enemies
- the use of selective insecticides.

All of these have become important components of IPM programs. The antithesis of IPM is applying broad-spectrum pesticides on a fixed schedule, irrespective of the size of pest populations.

Arising from the ACIAR/BPRE research were technology packages/options based on IPM in storage of cereals such as maize, paddy and milled rice, and legumes:

- *Grain admixture utilising recommended organophosphate (OP) insecticide or synthetic pyrethroid (SP), or a combination of both*

  The technology is applied to newly harvested grain with a moisture content of no more than 14%. Diluted insecticide is sprayed at a rate of 1 L/tonne on the grain moving on a conveyor. After insecticide application, the grain is placed in 50 kg capacity bags that are stored in warehouses. With this technology, pest infestation can be prevented for up to 8–9 months for maize and 12 months for paddy. The strength (dose) of diluted insecticide may vary according to the desired number of months that the grains will be stored.

Depending on the dominant pest monitored in a storage warehouse, insecticides can be applied singly, using either an OP or an SP. When pests dominating a warehouse include *Sitophilus* species and *T. castaneum*, the choice of pesticide can be from any of the OPs recommended. If *R. dominica* dominates the storage area, then the choice of pesticide should be from any of the recommended SPs. Where a complex of pest species is present, a mixture or combination of both OP and SP at reduced doses can be utilised. Synergisation with piperonyl butoxide increases the effectiveness of the SP.

The technology applies well to hybrid seed growers as they normally store their seeds in their own storage areas, which are particularly susceptible to insect infestation.

The technology is also well suited to feed mills, which normally have a conveyor system on which insecticide can be admixed with the grain. However, if grain to be stored is already infested, fumigation to kill the insects present is recommended before admixture of insecticide.

The following is a list of pesticide and pesticide combinations/mixtures recommended for grain admixture:

- organophosphates
  - pirimiphos-methyl
  - fenitrothion
- synthetic pyrethroids
  - deltamethrin
  - permethrin
  - fenvalerate
- pesticide combination
  - pirimiphos-methyl + deltamethrin
  - pirimiphos-methyl + permethrin
  - fenitrothion + fenvalerate.

■ *Bag spraying and fumigation*

Bag stacks are fumigated to control existing infestations inside the stacks. Fumigation must be in accordance with industry standards: the establishment of a gastight enclosure, the use of the recommended dose of fumigant and, most importantly, an exposure period to the fumigant of not less than 7 days.

After fumigation, recommended insecticides may be applied to the grain stack, either once or every 3 months using the recommended concentrations and rates of application.

A protection period of 12 months for paddy and 7 months for milled rice can be achieved using the recommended insecticides.

The insecticides that can be used by the industry for effective control of infestation through bag spraying and fumigation are:

- organophosphates
  - pirimiphos-methyl
- synthetic pyrethroids
  - deltamethrin
  - permethrin
- combination
  - pirimiphos-methyl + permethrin
  - pirimiphos-methyl + deltamethrin.

Users choose between these insecticides depending on the pest problems they face, as described earlier. The options are summarised in Table 7.

The challenge in making this impact assessment of the ACIAR and BPRE research is to identify and measure benefits from these knowledge-based technologies over and above the benefits from the 'calendar' use of new chemicals whose efficacy may quickly depreciate as resistance emerges and which may be associated with higher levels of pesticide residues in food chains.

4.2 Adoption pathways and additional investments required

The four pathways to adoption in integrated use of pesticides developed under the ACIAR projects are summarised in Table 8. These pathways are interrelated.

Table 7. Recommended stored grain protection chemicals and commercial cost of treatment[a]

Application	Chemical	Rate of application	Percentage active ingredient	Dosage	Cost of treatment
Admixture	Pirimiphos-methyl + permethrin	1 litre of diluted insecticide per tonne of grain	25 EC/10 EC	4 ppm/0.5 ppm	PHP0.60/kg
	Pirimiphos-methyl + deltamethrin	ditto	25 EC/2.5 SC	4 ppm/0.1 ppm	PHP0.60/kg
	Fenitrothion + fenvalerate	ditto	50 EC	6 ppm/0.5 ppm	PHP0.62/kg
	Deltamethrin	ditto	2.5 SC	1 ppm	PHP0.64/kg
	Pirimiphos-methyl	ditto	25 EC	10 ppm	PHP0.66/kg
	Permethrin	ditto	10 EC	1 ppm	PHP0.57/kg
Surface spray / bag spraying	Pirimiphos-methyl	1 L/20 m^2	25 EC	1% (QS) 4% (SS)	PHP292/20m^2 (QS) PHP691/20m^2 (SS)
	Permethrin	ditto	10 EC	0.2% (QS) 0.8% (SS)	PHP220/20m^2 (QS) PHP413/ 20m^2 (SS)
	Deltamethrin (SP)	ditto	2.5 SC	0.12% (SS) 0.03% (QS)	PHP211/20m^2 (QS) PHP377/20m^2 (SS)
Fumigation	Aluminium phosphide	1–2 tablets per tonne	Phosphine	1–2 tablets per tonne	PHP850/fumigation[b]

[a] Cost includes profit/margin of commercial pest control

[b] Minimum commercial rate

Note: EC = emulsifiable concentrate; SC = solid concentrate; ppm = parts per million; 20 m^2 = 80 bags of 50 kg capacity; QS = quarterly spraying; SS = single spray.

Commercialisation

The ACIAR/BPRE technologies were adapted in partnership with the Technology Research Division of NFA through pilot testing in NFA's central headquarters warehouse in Quezon City. They were widely disseminated to all NFA regional and provincial warehouses through their warehouse managers. Likewise, the technologies were pilot tested in trader and farmer cooperatives as a further means of dissemination.

Communication

One way of communicating the technologies was through the development of IPM and integrated commodity management extension modules. These were designed for the various stakeholders in the domestic rice and maize industries. The other communication materials were articles written for scientific journals, and extension material in the form of flyers and newsletters. The target groups were researchers in NFA and BPRE, and policymakers at the DA, as well at the grain processing and storage sector personnel.

Table 8. Adoption pathways for integrated use of pesticides in stored pest grain management in the Philippines

Item	Initial user	Transfer process	End user
Commercialisation			
Partnership with commercial organisations	National Food Authority (NFA) Technology Research Directorate	Pilot testing	NFA warehouses (regional, provincial)
Partnership with farmers	Trader cooperatives Farmer cooperatives	Pilot testing Technology demonstrations	Trader cooperatives Farmer cooperatives
Communication			
Integrated pest management and integrated commodity management protocols developed	Rice and maize industry stakeholders	Provision of manuals	Rice and maize industry stakeholders
Journal articles, workshop proceedings, flyers, news items, bulletins	Researchers, policymakers	Learning, building stock of knowledge, potential networking	Input into further research and development, commercialisation
Capacity building			
Action research and provision of research equipment	Bureau of Postharvest Research and Extension (BPRE) and NFA researchers	Participatory research of initial users	Researchers
Training programs, attendance at conferences	BPRE and NFA researchers	Enhanced capacity	Researchers, warehouse managers
Regulation			
Administrative Order No. 29 (2004)	Department of Agriculture policymakers	Policy change on pesticide use; hybrid rice seed technology	Hybrid seed growers

Capacity building

To enable technology adoption, participatory research with potential adopters was conducted by NFA and BPRE researchers to develop a better understanding and appreciation of the technologies. The provision of the equipment required to conduct research to adapt the technologies further enhanced capacity building. Research skills were also enhanced through postgraduate studies (Masters degrees for two researchers) and attendance at scientific conferences and meetings.

Regulation

Recognising that hybrid seeds, specifically M1, are very susceptible to pest damage that reduces their viability, DA issued Administrative Order No. 29, series 2004, which made it compulsory for the hybrid seed growers to use the technologies in seed storage.

5 Outcomes from ACIAR and BPRE research

The outcomes from the ACIAR/BPRE research efforts resulted in pest control strategies that reduced the cost of grain storage because lower wastage rates more than offset pesticide costs. These strategies were adopted by a proportion of the grains industry, including commercial firms and NFA, that stored grain for periods of longer than 3 months. The technologies were applicable to maize and other grains but we have focused our evaluation on the storage of rice.

5.1 Potential cost savings in the grain storage sector

The welfare gains from the ACIAR/BPRE research have already been subject to analysis in studies by Chudleigh (1991) and Yanson et al. (2002).

Previous evaluations

Chudleigh (1991) argued that the benefits of the new pest management technologies flowed from reduced losses in storage leading to a smaller margin between farm and retail prices or, in other words, reduced marketing costs. He argued that the change in economic surplus could be approximated as this reduction in marketing costs per tonne of grain applied to the amount of grain treated.[3]

In Australia, the main beneficiaries of the ACIAR technologies were the peanut industry and the northern rice and maize industries. The benefits to the peanut industry were estimated to be A$35,380 annually from 1988 to 1994. The benefits to the rice and maize industries were estimated to be, respectively, A$63,000 and A$89,600 annually from 1995 to 2002.

Chudleigh estimated the benefits from the new protectant technologies for rice and maize in the Philippines. The benefits were largely estimated in the form of savings in weight loss from insect damage avoided. Chudleigh estimated that the NFA might store about 300,000 tonnes of paddy and milled rice at risk of insect attack, and that the amount in the commercial sector might be about 500,000 tonnes. Assuming that the technologies were applied to all this rice (at a 75% success rate) he further assessed that the loss from insect attack might be reduced from 6% in the case of NFA to 3% and from 4% to 2% in the commercial sector. The new technologies added A$1/tonne to the cost of storage. The benefits from the use of these technologies in the maize industry, calculated using a similar approach to rice, were about 25% of those in the rice industry and mainly accrue through the NFA system.

Chudleigh estimated that the benefit:cost ratio for the set of three projects was in the range 1.5:1–6:1 (with the internal rate of return (IRR) in the range 16–43%) with more than two-thirds of the benefits going to the Philippines (net present value (NPV) A$10.3m). The remaining benefits went largely to Malaysia (NPV A$3.0m) with a small share to Australia (NPV A$0.4m). Estimates of benefits and costs were expressed in 1990–91 Australian dollars.

3 The economic impact of grain storage technologies is more fully explained in Section 6.

The review of the projects by Yanson et al. (2002) was not entirely consistent with the Chudleigh review, in part because Chudleigh conducted his analysis around 1991 before the fourth project was completed and while adoption and resistance patterns were still developing.

Although Chudleigh expected the problems of pest resistance to insecticides would continue to develop, and circumscribed the impact of the research in recognition of this, he did not identify, as Yanson et al. did, an existing level of resistance to pirimiphos-methyl. Nor could Chudleigh discuss how, in response to this resistance, mixtures of organophosphates and pyrethroids were developed that were more potent but created fewer residue problems because they could be administered at lower dose rates. Yanson et al. noted that the most cost-effective treatment for paddy was a mixture of chlorpyrifos-methyl, permethrin, and piperonyl butoxide and for maize, a mixture of fenitrothion, fenvalerate and piperonyl butoxide.

Yanson et al. seemed far more conservative in their assessment of adoption than was Chudleigh. They were concerned that low adoption would persist within NFA until it moved to greater use of bulk handling and storage technologies. They implied that the benefits from the grain protectant technologies are small in bag storage systems.

Considering on-farm storage of rice, it was noted that a constraint to adoption was that farmers in general are unable to purchase the recommended chemical mixtures, often because the chemicals are from different firms. Some interest in the technologies was noted among mung-bean growers in the municipality of Urdaneta, Pangasinan province in Region I, although access to the mixed chemicals remained a constraint. There was also continuing interest among maize growers in Isabela province in Region II and in Mindanao.

Yanson et al. did not attempt to estimate a rate of return on the investment in research by ACIAR and its partners.

In the absence of the ACIAR/BPRE technologies, grain storage firms would no doubt have begun using the new chemicals. It is unlikely, however, that they would have been able to identify the combinations of chemicals that gave control of the spectrum of pests at use rates that not only delayed the emergence of resistance but also reduced pesticide residues in food chains.

Estimated cost savings

We used partial budgeting techniques to estimate the change in the cost of transforming paddy into milled rice within the rice processing sector resulting from the use of technologies for protecting grain from pests developed by the ACIAR/BPRE research. See Table 9 for the results of the analysis.

As already noted, the ACIAR/BPRE grain protection research can be viewed as reducing storage costs within the rice processing sector or, in other words, a narrowing of the price spread between farm and wholesale rice prices. These changes in costs arise from reduced grain losses and reduced costs of treating insect-damaged grain. These reductions offset the likely higher costs of the new pest control strategies.

Price spread budgets for the alternative grain technologies have been prepared. They accommodate cost changes in the form of waste reduction and lower grain cleaning costs offset by changes in pest management costs. The difference in costs between two technologies relative to the price of the bundle of inputs used in processing rice from paddy to milled form has been treated as an estimate of the relative change in the cost of processing inputs, $E(CMI)$, used in the model outlined in Section 6 to estimate welfare changes. The price of processing inputs was estimated as the difference in revenue from purchasing 1,000 kg of paddy and the revenue from selling the equivalent (adjusted for wastage) quantity of milled rice expressed per kg of milled rice under the traditional ('without research') scenario.

The parameters used in these budgets were based on research by the ACIAR partners, the expert opinions of scientists and economists interviewed in the course of this impact assessment, and the findings from a small survey of large rice traders and millers conducted in 2008 as part of this impact assessment.

We first estimated the costs of the pest control strategies. The costs associated with the three technology packages and the grain losses were:

- pirimiphos-methyl + deltamethrin + piperonyl butoxide[4] (PHP0.60/kg)

[4] ACIAR project PHT/190/009 recommended variable inclusion of piperonyl butoxide in this combination (Sayaboc et al. 1998, p. 155).

Table 9. Comparative budgets (in Philippine pesos) of taking 1,000 kg of 14% moisture content paddy to wholesale level using Australian Centre for International Agricultural Research (ACIAR) / Bureau of Postharvest Research and Extension (BPRE) and traditional technologies

	Technologies	
	ACIAR/BPRE	**Traditional**
Cost of paddy at farm gate	14,360	14,360
Transport costs farm to warehouse	50	50
Milling costs	181	172
Storage cost	56	53
Transport costs warehouse to wholesale	248	235
Pesticide cost	371	41
A. Total costs	15,265	14,911
B. Total revenue	18,490	17,577
Net revenue (B – A)	3,224	2,666
Incremental profit per kg paddy	0.95	
Price spread		5.47

Parameters used:		
Paddy farm price	14.36/kg	
Milling cost	0.19/kg	
Storage cost	0.09/kg	
Transport costs	0.05/kg	farm gate to warehouse
	0.40/kg	warehouse to wholesale centre
Pesticide cost		
Traditional	0.07/kg	
ACIAR	0.60/kg	
Milling recovery	65%	
Moisture content of paddy at farm	14%	
Wholesale rice price	29.88/kg	
Pest losses		
Traditional	9.5%	
ACIAR	4.8%	

- pirimiphos-methyl+ permethrin + piperonyl butoxide (PHP0.60/kg)
- fenitrothion + fenvalerate + piperonyl butoxide (PHP0.62/kg).

In the budgets in Table 9 we use the average cost of PHP0.60/kg across these three packages. We have assumed that those who do not adopt the ACIAR/BPRE packages use chemicals singly on a 'calendar' basis without monitoring pest populations. We have assumed that they use pirimiphos-methyl at a cost of PHP0.07/kg.

Estimates of losses to pests under each technology, which are a key parameter in our analysis, are given in Table 10. It is unusual that experimental losses are larger than losses experienced in the field. Taking a conservative approach, we have used the BPRE losses in our analysis.

Table 10. Estimated losses from pests under the Australian Centre for International Agricultural Research (ACIAR) / Bureau of Postharvest Research and Extension (BPRE) and traditional technologies

Source of data	Loss (%)	
	ACIAR/BPRE	Traditional
Survey	2.0	9.0
BPRE	4.8	9.5

Under the traditional technology, starting with 1,000 kg of paddy, 588 kg of milled rice were available at wholesale level, reflecting, in part, an assumption that 9.5% is lost to grain pests. The cost of processing and protecting grain under this technology is PHP14,911/1,000 kg. The price spread between farm and wholesale after adjusting the farm price by the yield of 58.8% to a wholesale equivalent price is PHP5.47/kg (in 2008).

The total cost of processing rice using the ACIAR/BPRE technologies was estimated to be PHP15,265/1,000 kg, a little more than the traditional method of grain protection. There was, however, an increase in revenue from lower wastage (4.8%) associated with the ACIAR/BPRE technologies. The estimated net benefit from the adoption of the ACIAR/BPRE technologies is PHP559/1,000 kg of paddy or PHP0.95/kg in wholesale equivalent units. This gain in profit expressed relative to the price of processing inputs, which is represented by the price spread for the technologies, translates into a relative change in the cost of processing inputs of 17%, a quite large supply shift.

5.2 Evidence on adoption

In this section, we first estimate the potential or target volume of rice to which the ACIAR/BRPE technologies might apply and then report our estimate of the rate and extent of adoption of the technologies.

Only a portion of rice production in the Philippines is held in storage for long enough to warrant protecting from grain pests and hence only this portion is the target for adoption of the grain protection technologies described here (see Table 13). In 2008, domestic paddy production was 16,815,548 tonnes (t) of which 88% (14,797,682 t) was available for food and 12% for feeds, seeds and wastage. Seventy-three per cent of the 88% available for food is considered marketable, while the remaining 27% is kept for home consumption. An estimated 68% (10,062,424 t) of the grain available for food was stored by the commercial sector and 5% (739,884 t) by NFA. In addition, NFA imported 3,955,260 t of rice (in paddy equivalent terms) in 2008. Thirty per cent of all the rice held by NFA is a potential target for the ACIAR/BPRE technologies, considering that there are other technologies or control strategies adopted by NFA such as the Volcani cube and SEFUST sealed enclosures.

Of the rice stored by the commercial sector, much is held for too short a period to warrant insecticide protection from pests. The large traders/commercial millers who handle 50% of all rice stored, some 5,031,212 t, are likely to use pesticide technologies.

Using these same parameters, a series for the potential quantity of rice in paddy equivalent terms that is likely to have been a potential target for the ACIAR/BPRE technologies was developed back to 1983. Actual NFA imports were available to only 2001. We assumed that, before then, the NFA imported about 1.2 million t each year.

It is very difficult to define what constitutes adoption of knowledge-based technologies that have a number of components. In the case of IPM technologies, a key component would appear to be that pesticide applications are made at minimal rates and at intervals based on monitored populations of pests and their predators rather than at 'calendar' intervals. In the case of the technologies being assessed here, a key characteristic would appear to be that chemicals are used in combination, that these combinations are rotated to minimise the development of resistance and that pest populations are monitored to indicate when protection is required.

Adopters of the technologies would therefore be those who:

- fumigate at the start of storage and spray insecticide (protective spraying) either once or every 3 months (using the recommended insecticides and dose)
- spray insecticide layer by layer as the bag stack is built, then fumigate after stacking
- admix the grain with insecticide, using the recommended application rate and insecticide concentration
- monitor the kind of pest present in the storage and apply the effective insecticide as evaluated and recommended, e.g. an organophosphate against weevils and a synthetic pyrethroid against the lesser grain borers.

Example of non-adopters would be those who use the evaluated insecticides for fogging and structural spraying on a calendar basis, without inspection and monitoring for insect infestation.

A limited survey of one warehouse operated by NFA and eight traders/processors and seven seed growers/producers in Luzon, Visayas and Mindanao was conducted as part of this impact assessment to provide some insights into how pests of stored grain are managed in the Philippines and the extent to which the ACIAR/BPRE technologies have been adopted. Large traders and processors located in the major rice-producing provinces were sampled.

The most commonly used insecticides are listed in Table 11. The organophosphates and deltamethrin were used by 37.5% and 25% of those surveyed. Similarly, fumigants such as phosphine were used by 37.5% of respondents. Except for malathion, fipronil and larvin, the pesticides used by the respondents were components of recommended admixture technologies. Malathion was used by only one respondent, although at least one or two big flour companies still used this protectant until 2007. As would be expected, those who store grain eventually become aware of chemicals superior to malathion and start using them, although use of superior chemicals does not, by itself, indicate that a processor has adopted the ACIAR/BRPE technologies.

Table 11. Chemicals used in stored grain pest management in the Philippines

Chemical group	Number reporting	%
Organophosphate	6	37.5
Deltamethrin	4	25.0
Permethrin	2	12.5
Fipronil	2	12.5
Fumigant	6	37.5
Larvin	2	12.5
Malathion	1	6.25

As defined in this report, adopters of ACIAR/BPRE technologies are those who used single, combinations or sequences of insecticides either as an admixture or to bagged grain after monitoring of pest populations. Based on this definition, the respondents were categorised as adopters or non-adopters (Table 12).

In our judgment, because of its own research program and its close links with BPRE, we have classed NFA as an adopter of the ACIAR/BPRE IPM technology. NFA is mandated to keep grain safe from pests in long-term storage. The amount so stored was about 5.7% of total paddy rice production in 2008.

Based on the survey of the eight representative feed mills/plants undertaken in 2008, we estimate that about half the rice (2,515,606 t) held by the large firms was protected using the ACIAR/BPRE technologies. This is a much higher rate of adoption than that anticipated by Chudleigh (1991). Households do not treat their small stocks of milled and paddy rice. Seed growers, who handle a relatively small volume, treat all their stock of seeds as mandated by DA administrative order.

We therefore estimate that, in 2008, the ACIAR/BPRE technologies were being applied to about 60% of all rice to which they could potentially be applied, amounting to about 23% of all rice available for food (Table 13). We have assumed that adoption of the technologies commenced in 1991 and have linearly extrapolated final adoption rates of 30% for NFA and 50% for traders over the 1991–2008 period. The average rates of adoption and the quantities involved are given in Table 13.

Table 12. Adoption of Australian Centre for International Agricultural Research / Bureau of Postharvest Research and Extension stored grain protection technologies

Respondent group	Adopter	Non-adopter	Total	Rate of adoption (%)
Seed growers	6	1	7	86
Traders	4	4	8	50
National Food Authority	1	0	1	100
All	11	5	16	69

5.3 Human and environmental health consequences

There are likely to have been significant human and environmental health benefits from the set of research projects evaluated here. In particular, an important objective of PHT/1990/009 was to evaluate the use of insecticide mixtures with greater potency than their individual components, thereby allowing reduced application rates and, in turn, reduced residue levels in food, feed and the environment (Champ 1994). Reductions in dosage rates lead to lower residue levels and these were noted in Table 4.

No attempt has been made to value these human and environmental health benefits. To make judgments about human health and related consequences, we would need to know how exposure to chemicals has changed as a result of these projects, how exposure translates into human disease incidence and the costs associated with the different health problems.

Table 13. Potential and actual quantities (tonnes) of paddy rice treated by Australian Centre for International Agricultural Research (ACIAR) / Bureau of Postharvest Research and Extension (BPRE) protection technologies, 1983–2008

	Potential adoption of ACIAR/BPRE technologies			Quantity adopted			Average adoption rate (%)
	NFA[a] target	Private target	Total	NFA	Private	Total	
1983	453,436	2,182,637	2,636,073				
1984	460,484	2,342,401	2,802,885				
1985	473,377	2,634,636	3,108,012				
1986	479,200	2,766,640	3,245,840	–	–	–	–
1987	469,869	2,555,124	3,024,993	–	–	–	–
1988	475,559	2,684,099	3,159,658	–	–	–	–
1989	481,999	2,830,065	3,312,063	–	–	–	–
1990	487,625	2,957,592	3,445,217	–	–	–	–
1991	484,830	2,894,240	3,379,070	26,935	80,396	107,331	3.18
1992	482,714	2,846,290	3,329,004	53,635	158,127	211,762	6.36
1993	481,674	2,822,715	3,304,389	80,279	235,226	315,505	9.55
1994	496,245	3,152,986	3,649,231	110,277	350,332	460,608	12.62
1995	496,279	3,153,762	3,650,042	137,855	438,023	575,878	15.78
1996	506,086	3,376,044	3,882,130	168,695	562,674	731,369	18.84
1997	505,893	3,371,674	3,877,567	196,736	655,603	852,339	21.98
1998	470,067	2,559,603	3,029,670	208,918	568,801	777,719	25.67
1999	512,726	3,526,558	4,039,285	256,363	881,640	1,138,003	28.17
2000	478,090	3,706,912	4,185,002	265,606	1,029,698	1,295,303	30.95
2001	548,263	3,876,097	4,424,361	335,050	1,184,363	1,519,413	34.34
2002	811,150	3,970,579	4,781,730	540,767	1,323,526	1,864,293	38.99
2003	534,237	4,039,165	4,573,403	385,838	1,458,587	1,844,425	40.33
2004	693,386	4,337,438	5,030,823	539,300	1,686,781	2,226,081	44.25
2005	620,762	4,369,219	4,989,981	517,301	1,820,508	2,337,809	46.85
2006	1,066,029	4,585,750	5,651,780	947,582	2,038,111	2,985,693	52.83
2007	1,127,773	4,859,066	5,986,839	1,065,119	2,294,559	3,359,678	56.12
2008	1,408,543	5,031,212	6,439,755	1,408,543	2,515,606	3,924,149	60.94

[a] National Food Authority

6 Impact assessment

6.1 Welfare analysis of project benefits

The benefits from new technology packages that give better control of pests in stored grain were estimated using standard welfare (economic surplus) analysis, as described in detail in, for example, Alston et al. (1995). New pest management technology can be thought of as reducing costs in the grain handling and processing sector. The impact of new processing technology can be represented graphically in only a heuristic manner. The market for processing inputs is shown in Figure 2. Equilibrium is initially at price W_{20} and quantity X_{20}. If new pest management technology results in a cost saving of *vz* pesos for all units of production, the supply curve shifts from S_{20} to S_{21}, the price of processing inputs fall to W_{22} and the quantity increases to X_{22}. The suppliers of these inputs enjoy a gain in economic surplus of area *wxzy*.

The impact of new technology on the producers and consumers of rice is illustrated in Figure 3, which is drawn under the assumptions that paddy and processing inputs must be used in fixed proportions (there is, in other words, no input substitution), that the processing sector is competitive and that inputs are perfectly elastic in supply. These assumptions are relaxed in the empirical work below. Under these assumptions, a reduction in processing costs results in the price spread between paddy and milled rice shrinking by the amount of the cost reduction. This is represented as a parallel upward shift in the demand curve for paddy rice to D_{X11}. The production and price of paddy rice increase to X_{11} and W_{12}, and the price of milled rice falls to P_1.

The consumers of milled rice benefit to the extent of area *jihg*. Paddy producers benefit by the area *abdc*. All benefits are shared by producers of paddy and consumers of milled rice. If processing inputs are less than perfectly elastic in supply, some of the benefits of this technology can now be captured by the suppliers of processing inputs.

Input substitution in rice processing makes the demand for paddy more elastic and therefore increases the benefits to rice farmers from an increase in farm-level productivity. However, in the case of new rice processing technology, substitution that makes the demand for paddy more elastic also reduces the increase in demand arising from an increase in processing efficiency. The substitution effect works in the opposite direction to the scale effect, instead of complementing it as is the case for new farm technology. With large substitution possibilities, rice producers could lose from greater processing efficiency (i.e. demand for paddy could fall) but because the opportunities for substituting processing inputs for rice are likely to be limited (and less than the elasticity of demand for milled rice), the demand for paddy is likely to increase with the increased use of processing inputs, although to a lesser extent than with fixed factor proportions.

Empirical welfare analysis of the impact of new technologies in processing has often been evaluated using a 'Muth' model in which a farm input and a non-farm input are used to produce a processed product for sale in a wholesale or retail market (Muth 1964; Mullen et al. 1988, 1989). This model is described in detail in Alston et al. (1995, pp. 253–264).

The solution in terms of relative changes in the prices and quantities of processed rice (P, Q) and the inputs, farm rice (X_1, W_1) and processing inputs (X_2, W_2) for a reduction in the cost of pest management (a shift in the supply of processing inputs) is described in the following set of equations from Alston et al. (1995, p. 261) (note that for simplicity of presentation here, other supply and demand shifters have been set to zero):

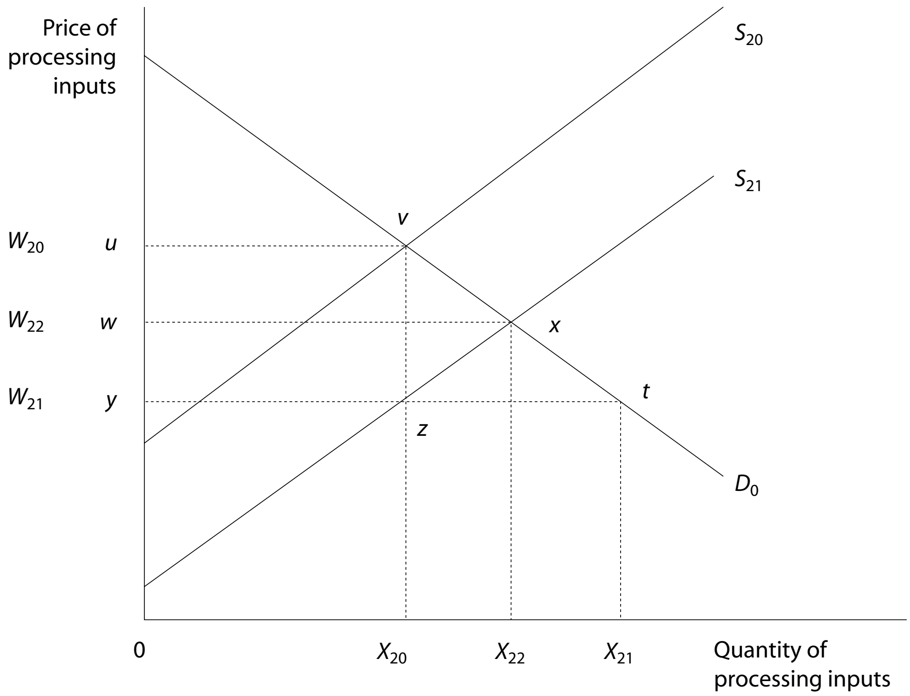

Figure 2. New processing technology and the market for processing inputs

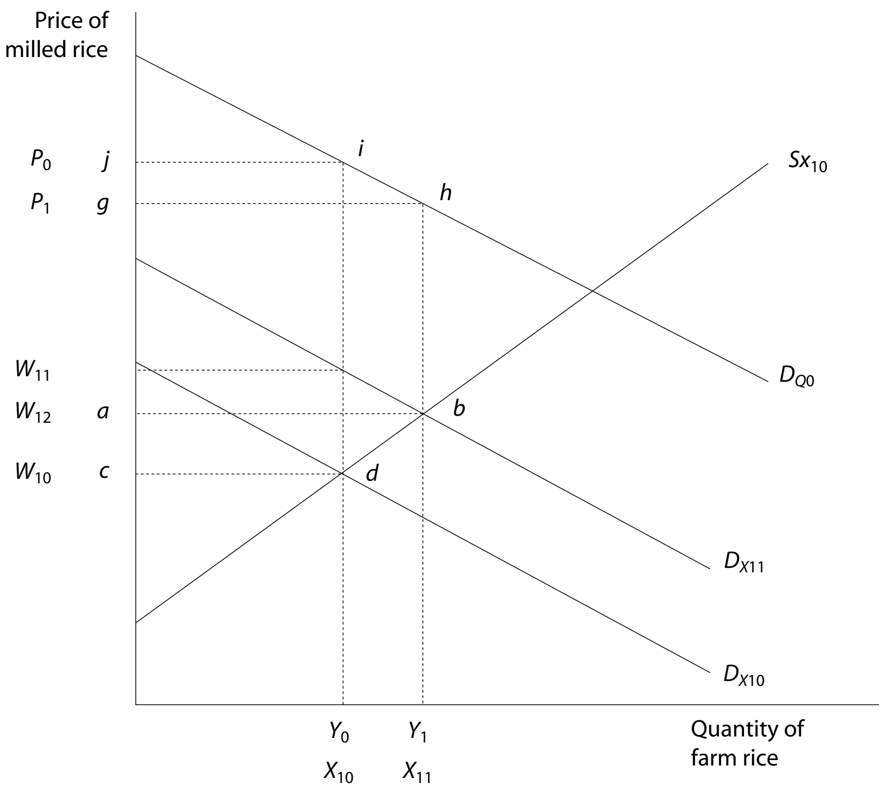

Figure 3. New processing technology in a multistage model

$$EQ = s_2\varepsilon_2\eta(\sigma + \varepsilon_1)\beta_2/D \quad (1)$$

$$EP = -s_2\varepsilon_2(\sigma + \varepsilon_1)\beta_2/D \quad (2)$$

$$EX_1 = -s_2(\sigma - \eta)\varepsilon_1\varepsilon_2\beta_2/D \quad (3)$$

$$EX_2 = \{\eta\sigma + (s_1\sigma + s_2\eta)\varepsilon_1\}\varepsilon_2\beta_2/D \quad (4)$$

$$EW_1 = -s_2\varepsilon_2(\sigma - \eta)\beta_2/D \quad (5)$$

$$EW_2 = -(s_2\sigma + s_1\eta + \varepsilon_1)\varepsilon_2\beta_2/D, \text{ where} \quad (6)$$

$$D = \sigma(\eta + s_1\varepsilon_1 + s_2\varepsilon_2) + \eta\,(s_2\varepsilon_1 + s_1\varepsilon_2) + \varepsilon_1\varepsilon_2 \quad (7)$$

and

β_2 is the downward shift in the supply of processing inputs relative to the price of the bundle of inputs used in processing rice; s_1 and s_2 are the shares of expenditure on farm rice (W_1X_1) and processing inputs (W_2X_2) relative to total revenue (PQ); ε_1 and ε_2 are the elasticities of supply of farm rice and processing inputs; η is the absolute value of the elasticity of demand for processed rice; and σ is the elasticity of substitution between farm rice and processing inputs. Note that efficiency gains in processing encourage firms to use more processing inputs and less farm inputs and if $\sigma > \eta$ then farmers can lose from the technology.

The gains to input suppliers and consumers (including processors and traders) are given by (Alston et al. 1995, p. 256):

$$\Delta PS_i = W_iX_i\,(EW_i + \beta_i)(1 + 0.5EX_i) \quad (8)$$

$$\Delta CS = -P_0Q_0\,EP(1 + 0.5EQ) \quad (9)$$

where i can be farmers or the rice storage and wholesaling sector.

Total industry gains are the sum of the changes in economic welfare to farmers, the wholesale sector and consumers.

6.2 Parameter values used in modelling welfare changes

An estimate of the shift in the supply of processing inputs

Above, we estimated the change in the cost of processing rice as a result of new pest management technology. Because budget analyses already reflect the impact of the technology on the input mix and on input prices, the change in processing costs has to be adjusted to arrive at a 'pure' estimate of the supply shift in a manner suggested by Mullen et al. (1988):

$$\beta_2 = E(CMI)/\{1 - (1 - s_2)\sigma\} \quad (10)$$

where $E(CMI)$ is the relative change in the cost of processing inputs estimated from the budgeting studies.

Demand and supply parameters

The demand and supply elasticity values used here, which are based on limited econometric estimates, including those of Estrada and Bantilan (1991), and the judgment of industry experts, are:

elasticity of demand, η	–0.29
elasticity of supply of paddy, ε_1	0.33
elasticity of supply of processing inputs, ε_2	5.0
elasticity on substitution between inputs, σ	0.2

At the prices given in the budget in Table 9, farm and processing input shares were 0.82 and 0.18, respectively, and the supply shift was 21%.

Equilibrium price and quantity

Equations (8) and (9) indicate that welfare effects are significantly influenced by the choice of product price and quantity. Welfare analysis of the type applied here is generally conducted using prices and quantities judged to be those existing when the industry is in equilibrium. Of course the industry is never in equilibrium, so analysts must make a judgment. When conducting an ex-ante evaluation of technology, a common approach has been to use recent industry history as a basis for selecting equilibrium prices and quantities. The prices and estimates of welfare changes are regarded as being real (rather than nominal) and projected forward over the period of the analysis, disregarding other exogenous impacts on the industry that will likely qualify the actual benefits accruing.

In an ex-post analysis such as that presented here, the difficulties and consequences of the choice of price and quantity are clearer. One could choose the price and quantity pertaining when the technology was first adopted or those at the time the analysis was conducted. Alternatively, and perhaps ideally, one could attempt to estimate the welfare effects in each year since the technology was first adopted. This would, however, likely require an econometric approach to isolate the impacts of exogenous influences other than the new technology on the rice industry, with one consequence being a much more expensive welfare analysis.

An important reason for basing an analysis on 2008 is that the difference in production costs between the two technologies can be more accurately estimated. If 1983 were chosen, an attempt would need to be made to replicate practices and prices pertaining then. Hence, our analysis is based on a budget prepared for conditions in 2008. To maintain comparability with the other two Philippine impact assessments conducted simultaneously, welfare gains were expressed in 2007 terms.

An important consideration in this analysis has been the steady increase in paddy production from 7.3 million t in 1983 to 16.8 million t in 2008. Estimates of welfare gains based on production in 2008 would seriously overstate gains up to 2008. We have therefore estimated the welfare gains for 1,000 kg in 2008 and applied this to actual production since 1983, adjusted to the amount of rice for which the technologies are applicable using the assumptions in Table 13 to get an indication of the potential welfare gains from the new technologies. These potential gains are further qualified by the estimated rate and extent of adoption.

As for our treatment of costs, we used the price spread of PHP5.47/kg in 2008 over all years.

Another dimension to the choice of equilibrium price is that, in the approach used here, *k*, the supply shift, is estimated as the change in unit production costs as a proportion of the price of processing inputs, on the assumption that price in equilibrium is equal to the long-run average cost of production. If the adoption of the technology has had a price impact, then *k* may be overestimated, and perhaps the technology itself may have been modified. Simultaneously, there are likely to have been other positive and negative influences on price and the technology, including a potential reduction in the demand for storage services as a result of better pest control and possible dynamic effects across seasons. We have not attempted to assess these more complex potential impacts here.

6.3 Financial analysis of baseline scenario

Using the ACIAR stored grain pest control technologies, the total welfare gains to the Philippines for every 1,000 t of paddy processed and stored using the ACIAR stored pest grain technologies amounts to about PHP621. Of this, PHP72 goes to rice growers, PHP25 to processors and PHP524 to consumers (Table 14). More than 84% of the value of the change in total welfare accrued to consumers, while 12% went to farmers or suppliers of paddy and only 4% went to processors and traders.

Table 14 also presents the estimates of potential welfare changes in 2008, were the technologies applied to the potential volume of rice requiring protection given in Table 13. Were the ACIAR/BRPE grain pest management technologies applied to all the rice requiring protection in 2008, the change in total economic surplus would amount to PHP4,002m or A$103.5m. Farmers would realise PHP466m (A$12.1m) of this benefit, processors PHP164m (A$4.2m) and consumers PHP3,372m (A$87.3m).

To estimate the actual welfare gains, these annual potential benefits were projected forward to 2030 and adjusted by the estimated rates of adoption of the technologies. Our survey results indicate that the adoption of the technologies reached about 60% in 2008 and, with ongoing investment in research and extension activities, we expect it to remain at that level until 2030. Given the perennial problem of pests developing resistance to control measures, the efficacy of the technologies can be maintained only by ongoing investment in research by institutions such as BPRE and PhilRice. In our baseline scenario, we have assumed that BPRE and PhilRice will continue to invest in pest management research at the rate of nearly A$8,000 (PHP306,000) per year, the rate of investment in 2005, until 2030.

In 2030, the future stream of benefits and the ongoing investment by BPRE and PhilRice are converted to perpetuities by dividing by the interest rate. The stream of future benefits was discounted at a rate of 5% to a present value in 2007 as recommended in the ACIAR impact assessment guidelines (Davis et al. 2008).

Table 14. Welfare gains, in Philippine pesos (PHP) and Australian dollars (A$), for 1,000 kg paddy and the 2008 quantity of rice potentially suitable for treatment with the Australian Centre for International Agricultural Research / Bureau of Postharvest Research and Extension technologies

	Gains per 1,000 kg		Gains for quantity potentially protectible in 2008		Shares
	PHP	A$	PHP	A$	(%)
Producers	72	1.9	466m	12,063,265	0.12
Wholesalers	26	0.7	164m	4,247,119	0.04
Consumers	524	13.6	3,372m	87,278,565	0.84
Total	622	16.1	4,002m	103,588,949	

The present value of benefits to the Philippines amounts to PHP65,924m (A$1,706m). The present value of investment in the research is PHP380m (A$9.8m). This investment was made by ACIAR, BPRE, PhilRice and other partners. Hence, the NPV of the investment is PHP65,544m (A$1,696m). The benefit:cost ratio is 174:1. The IRR of the stream of benefits realised from adoption of the technologies is 46.6%. The NPV for Australia, which financed 72% of the development of the technologies, is A$1,225m (Table 15).

Table 15. Welfare impacts of Australian Centre for International Agricultural Research (ACIAR) / Bureau of Postharvest Research and Extension technologies

	Australia	Philippines
Benefit:cost ratio	174	174
Internal rate of return	46.6%	46.6%
Net present value		
Total	$1,696m	PHP65,544m
ACIAR return	$1,225m	
ACIAR cost share	72.3%	

While there seems to be strong evidence that the science and technology development supported by these four projects has been highly successful, there is some doubt as to whether the benefits from these projects have exceeded costs by so large a margin. We noted above that the level of adoption used here far exceeded expectations of previous analysts such as Chudleigh (1991). It is often easy to overestimate the level of adoption of information-based technologies that have several components, such as the IPM technologies developed here. Users may claim to be adopters of IPM that critically involves monitoring of pest populations as a basis for treatment decisions using pesticides in combination and rotation to avoid the development of resistance, while they are merely continuing their use of the chemicals, albeit newly available compounds, on a calendar basis. If adoption has been overstated by classing as adopters some who merely use more potent chemicals rather than IPM principles, then it is likely that at least some of the estimated welfare benefits should more properly be attributed to the agencies that developed the new pesticides rather than to those, in this case ACIAR and BPRE, that funded the development of the new IPM technologies. If, for example, the actual adoption in the commercial sector by those to whom the technologies are applicable was 25% rather than 50%, the benefit:cost ratio falls to 115:1 and the IRR to 40.1%

7 Summary

From 1983 to 1994, ACIAR supported a series of four research projects on the use of pesticides to protect grain stored in the tropical areas of Australia, the Philippines, Malaysia, Thailand and China. The projects were intended to reduce losses in stored grains due to insect pest infestation in these countries, which are characterised by both high temperatures and humidities and where resistance to pesticides such as malathion was emerging.

The technologies developed were based on IPM principles, including the use of combinations of pesticides in rotation and the monitoring of pest populations as a basis for grain protection decisions. In addition, the technologies focused on identifying minimum levels of pesticide needed for control, hence delivering improved human and environmental health outcomes through both reduced exposure in grain storage facilities and reduced pesticide residues on grains.

In the Philippines, the research was conducted in collaboration between the QDPI and BPRE, which two agencies provided largely in-kind support, with the bulk of the financial support coming from ACIAR.

The present value (5% discount rate) of the total investment in the four projects from 1983 to 2005 was A$9.6m (2007 dollars) or PHP373m. ACIAR's share of this investment was 72% and those of QDPI and BPRE 11% and 16%.

On the technical side, the ACIAR/BPRE pesticide research collaboration was successful in introducing IPM-based grain protection strategies based on knowledge of the life cycle of pests and their interaction with chemicals, and on monitoring pest populations. New chemicals were also introduced as grain protectants against pests in the humid tropics such as the Philippines where development of resistance to the then widely used malathion had been detected. The new chemical admixture and mixture technologies (deltamethrin, fenitrothion, fenvalerate, permethrin, pirimiphos-methyl) can be used singly or in combination for protection of stored grain. For bagged storage, they may also be used in conjunction with an initial fumigation to treat any existing infestation. The efficacy of the technologies was proven for stored rice, maize and mung bean, although the financial analysis conducted here was restricted to rice.

Arising from the ACIAR/BPRE research, the main pesticide packages promoted by BPRE for pesticide admixture in bulk storage, and fumigation and protective spraying of grain stored in bags, were:

for grain admixture –

- pirimiphos-methyl + deltamethrin
- pirimiphos-methyl + permethrin
- fenitrothion + fenvalerate
- pirimiphos-methyl

for bag spraying with fumigation –

- pirimiphos-methyl + permethrin
- deltamethrin.

The average cost of these technologies was PHP0.60/kg, somewhat higher than traditional technologies based on pirimiphos-methyl, which cost about PHP0.07/kg.

In the Philippines, much rice is traded and stored by small traders and households. Turnover is rapid and hence there is little demand for expensive pest management technologies. Hence, the targeted users or adopters of the technologies are organisations that handle large volume of grains.

NFA is responsible for maintaining a buffer stock of rice to meet domestic shortfalls in production. The agency's procurement of unmilled rice or paddy is small, estimated at 5% of annual production, but it also imports significant quantities of milled rice which are often the equivalent to 15% of paddy production available for food.

The ACIAR/BPRE technologies are applicable to about 30% of the rice stored by NFA. By 2008, the ACIAR/BPRE technologies were being applied to all of this 30% potential market.

The other groups that store grain for long periods and need pest management technologies are the larger traders and millers. The private sector (as distinct from NFA and households) handles and stores about 68% of the rice available for food, and the large traders and millers account for half of this. Only about half of all rice stored in the commercial sector is a target for the ACIAR/BPRE technologies and, by 2008, about half this potential market had adopted the technologies. In 2008, we estimated that of the 14.8 million tonnes of rice for food in the Philippines, these technologies could potentially be applied to 6.4 million tonnes and were actually applied to 3.9 million tonnes (61%). This is a much higher level of adoption than anticipated by Chudleigh (1991). In our analysis, adoption by both NFA and the commercial sector began in 1991 and increased linearly thereafter to the 2008 levels.

The present study estimated the ex-post rate of return earned from ACIAR's investment in the Philippines on research into the management of grain pests associated with the four projects. The returns associated with the technologies are driven by the cost savings from better pest management and the extent of adoption of the technologies.

The new pest management technologies are more expensive than the traditional technologies by about PHP0.53/kg but the wastage rate from grain pests is reduced from 9.5% to 4.8%. Hence, we have estimated a net return of PHP0.95/kg. The welfare analysis reported here is based on an equilibrium displacement model of the rice processing sector. More efficient pest management strategies are modelled as a shift in the supply of processing inputs. The price of processing inputs, the price spread between farm and wholesale prices, was PHP5.47/kg in 2008 and hence the relative change in the supply of processing inputs was 21%.

Under this scenario we estimated that the total benefits from the new technologies were PHP621 for each 1,000 kg of paddy rice and that the proportions going to farmers, processors and consumers were PHP72, PHP26 and PHP524, respectively. Consumers receive a larger share of benefits because the demand for rice is less elastic than is the supply.

The benefits from the research program were estimated out to 2030 as ACIAR requires (Davis et al. 2008). The nature of pest management technologies is such that, unless there is ongoing maintenance research, the development of resistance by pests to pesticides means that the technologies become obsolete, even in the case of IPM approaches. Maintenance research needs to be conducted, either by the government or the private sector, or in a partnership of the two. BPRE experience has found that collaboration in maintenance research with stakeholders from the private sector such as chemical companies and seed companies has been promising both in terms of funding and usage of the technologies. We estimated that ongoing investment by BPRE and PhilRice at the rate of about PHP306,000 per year, their rate of investment in 2005, was required to maintain this flow of benefits.

From the adoption of the ACIAR/BPRE grain pest management technologies, the present value of the stream of benefits (change in total economic surplus) to 2030 amounted to PHP65,924m (A$1,706m). The present value of investment in the research is PHP380m (A$9.8m). This investment was made by ACIAR, BPRE, PhilRice and other partners. Hence, the NPV of the investment was PHP65,544m (A$1,696m). The benefit:cost ratio was 174:1. The IRR of the string of benefits realised from technology adoption was 46.6%. The NPV for Australia, which financed 72% of the development of the technologies, was A$1,225m (Table 15).

These results suggest that the investment in research into stored grain pest management by ACIAR and its partners has been a profitable one. If adoption has been overstated by classing as adopters some who merely use more potent chemicals rather than IPM principles, then it is likely that at least some of the estimated welfare benefits should more properly be attributed to the agencies that developed the new pesticides rather than to those, in this case ACIAR and BPRE, that funded the development of the new IPM technologies. If, for example, the actual adoption in the commercial sector by those to whom the technologies are applicable was 25% rather than 50%, the benefit cost ratio falls to 115:1 and the IRR falls to 40.1%.

Adoption of ACIAR/BPRE technologies that prevent storage losses from pest damage has also a potential to improve the quality of the diet of the Filipinos, especially among the poor. People in the poorest quintile of the population spend roughly a third of their income on rice. When rice prices drop by 1%, quantity consumed increases by approximately 0.25% (Mutuc 2003). While consumption of other foods that are complements or substitutes for rice in the diet also changes, overall there is likely to be a large nutritional gain among the poor if rice prices fall following adoption of improved technologies to manage grain pests. Market inefficiencies that do not allow the productivity gains from the new technologies to be reflected in lower rice prices harm the nutritional status of the poor.

Several lessons can be learned from the ACIAR-supported research on pesticide management. The role of the agency conducting the research, in this case BPRE, is not well defined in terms of technology dissemination. Since the devolution of field agricultural extension officers from the DA to the local government sector in the early 1990s, technology extension has been constrained. This function used to be with the DA's Bureau of the Agricultural Extension, now the Agricultural Training Institute. National government programs need to be coordinated with the local government units, as the latter may have different priorities.

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