ADOPTION OF ACIAR PROJECT OUTPUTS

STUDIES OF PROJECTS COMPLETED IN

2006–07

Australian Government
Australian Centre for
International Agricultural Research

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Editors: David Pearce and Debbie Templeton

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Research that works for developing countries and Australia

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The Australian Centre for International Agricultural Research (ACIAR) operates as part of Australia's international development cooperation program, with a mission to achieve more productive and sustainable agricultural systems for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing-country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

ACIAR Adoption Studies

ACIAR seeks to ensure that the outputs of its funded research are adopted by farmers, policymakers, quarantine officers and other intended beneficiaries. As part of its efforts to monitor the outputs and outcomes of its projects, ACIAR commissions project leaders and participants to revisit projects 3–4 years after completion, and report back to ACIAR on the medium-term outcomes of the work. This series reports the results of these studies.

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Foreword

The Australian Centre for International Agricultural Research (ACIAR) contributes to Australia's aid program by investing in agricultural research projects that are designed to reduce poverty and promote sustainable development.

One of the challenges facing ACIAR and its partner scientists is to ensure that projects leave a legacy that continues to benefit partner countries and communities, and Australia, well after the project itself is completed.

It is not good enough for projects to be delivering benefits only while donor funds are provided. Successful projects impart knowledge and skills and leave in place technology that is sustainable in the long term under local conditions.

Formal, independent project impact assessments have always been an important part of ACIAR's accountability process and means of improving project selection and management. The adoption studies that form the body of this report are another important way of evaluating finished projects. They are primarily undertaken to provide ACIAR, and our collaborators, with a greater understanding of the contextual environment in which we operate. They are usually undertaken by the Australian project leader 3 to 4 years after the completion of a large project and provide ACIAR with qualitative, and where possible quantitative, information on the difference the project has made at the scientific and community levels in the partner countries and Australia. All large projects are potential candidates for adoption studies. Exclusion only occurs if the research is continuing through a follow-on project, the project has already been evaluated under the more in-depth impact assessments, or the project leader (or suitable substitute) is unable to undertake the adoption study.

This is the 8th year these adoption studies have been completed. We now have an adoption study portfolio containing 76 sets of projects from which we are able to learn important lessons that can be fed back into our project development, design and implementation process.

I particularly want to thank the Australian project participants who revisited partner countries to gather and collate data, and write the adoption statements that form the basis of this publication.

I also want to thank the many project participants in our partner countries who hosted visits, helped with data gathering and provided useful insights on the ongoing impact and effectiveness of these projects. My sincere thanks to each of you for your support.

Nick Austin
Chief Executive Officer
ACIAR

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Overview

David Pearce and Debbie Templeton

Introduction

This report summarises the adoption results for 11 Australian Centre for International Agricultural Research (ACIAR) projects. Eight of them were completed in 2006–07, the other three finishing up to 3 years earlier.[1] The countries and research areas covered in these 11 projects are diverse. The projects presented here cover:

- eight partner countries (the Philippines, two projects; Bangladesh, one project; China, two projects; Vietnam, one project; Papua New Guinea (PNG), four projects; Indonesia, two projects; Sri Lanka, two projects; South Africa, one project)
- nine broad farm-level commodities (chickpea, peanut, mango, melons, banana, cocoa, coconut, lucerne and eucalypts)
- two fisheries projects (prawns, and lake and reservoir fisheries)
- one biological control project covering a number of crops.

The outputs from these projects show a very broad pattern of results. Most of the projects developed new technologies designed for use by farmers, managers or breeders, with one project focusing at the small-scale processing level.

Many of the projects also developed new scientific knowledge that will help future research and management decisions. This knowledge ranged from fundamental understanding of contamination risks in the food chain (in the cases of peanut, mango and banana), to hybridity mechanisms in trees, to yield prediction methods for fisheries.

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1 These three adoption studies are included here because they are an adjunct to an earlier adoption study or because they could not be completed in time for the earlier publications.

Six of the projects also developed knowledge for policy and policymakers, ranging from fisheries management findings to policy results applying to areas as diverse as weed management, food contamination and understanding of food supply chains.

All of the projects involved extensive capacity building within partner countries and institutions, ranging from formal university-based training to a variety of on-the-job training approaches. Many projects also established basic research infrastructure that continues to be used in many cases.

The 11 adoption studies indicate a generally high level of adoption of the project results, with most projects reporting a high or medium level of adoption, although in some cases there was no adoption of individual project outputs. In each case, the adoption results provide some useful ongoing lessons and observations.

What was discovered — project outputs

ACIAR's adoption studies classify outputs into three broad categories:

- **new technologies or practical approaches** to dealing with particular problems or issues, designed to ultimately be applied at the farm or processing level and, in some cases, at the breeder level
- **new scientific knowledge or basic understanding** (pure or basic science) of the phenomena or social institutions that affect agriculture, designed as input into further research processes, ultimately to help in the future development of practical approaches at the farm or processing level
- **knowledge, models and frameworks for policymakers** or broad-level decision-making, not necessarily at the farm level but in the overall environment in which farmers (and processors) must operate.

Not surprisingly, given the diversity of ACIAR-funded research, there is considerable overlap between these categories, and many projects contribute to more than one of them. Table 1 summarises the outputs for the 11 projects covered in this report.

New technologies were the major outputs for most of the projects. These were targeted at both the farm and postharvest levels, as well as more broadly at managers and breeders.

New technologies at the farm level included:

- integrated crop management packages for chickpeas
- new peanut varieties
- techniques for predicting yield and optimal stocking rates for fisheries
- new *Eucalyptus* genetic stock
- recommendations for nitrogen application for mango
- development of embryo culture and propagation techniques for coconut
- postharvest treatments for melons
- new lucerne varieties.

New technologies for breeders included a range of culture and clonal techniques for coconut, as well as screening techniques for acidity, salinity and cold for lucerne. In addition, new genetic stock for eucalypts was introduced into South Africa.

One project (cocoa) developed technologies for small-scale fermentation that could be applied at the smallholder level or more broadly for specialist processors.

One interesting special case was the release of a biological control agent for the invasive weed *Chromolaena odorata*. In principle, this is applicable at the farm level (as it improves productivity for a range of crops), but does not require explicit adoption by farmers.

New scientific knowledge was an important output from 10 of the projects. The subject matter of this was highly variable, ranging from better understanding of pests and contaminants in production and in the subsequent food chain (in the cases of botrytis grey mould in chickpea in Bangladesh, aflatoxin in peanut in Indonesia and fungal infections in mango and banana in Sri Lanka and the Philippines), to advances in breeding (in the case of identifying biochemical markers of natural plant defences in melons in China, understanding genetic techniques for hybridisation in eucalypts in South Africa, the identification of cocoa breeding lines in PNG and the production of new in-vitro propagation techniques for coconut in PNG), to models for predicting yield in fisheries (in the cases of prawns in PNG and lake and reservoir fisheries in Sri Lanka), to increased understanding of the effectiveness of biological control agents in tropical regions.

Around half the projects also developed **knowledge or models relevant to policymakers**. Again, this knowledge was very diverse and included management policy tools for fisheries (in the cases of prawns in PNG and lake and reservoir fisheries in Sri Lanka), weed policy information (relevant to PNG and Australia), programs on aflatoxin awareness (particularly in Indonesia), increased understanding of supply chains for melons (China), manuals for cocoa inspectors (in PNG) and strategies for the collection and conservation of coconut.

Table 1. Summary of project outputs

Project	New technologies or practical approaches	Scientific knowledge	Knowledge or models for policy and policymakers
1. Integrated management of botrytis grey mould of chickpea in Bangladesh and Australia	Integrated crop management package for chickpea	Better understanding of nature of host-plant resistance to the botrytis grey mould pathogen Identification of moderately tolerant cultivars	
2. Biological control of *Chromolaena odorata* in Papua New Guinea	Identification and release of a biological control agent (a gall fly)	Increased understanding of the effectiveness of different agents in tropical regions—applicable outside Papua New Guinea	Additional information for weed policy development in Papua New Guinea and Australia

continued …

Table 1. (continued)

Project	New technologies or practical approaches	Scientific knowledge	Knowledge or models for policy and policymakers
3. Reducing aflatoxin in peanuts in Indonesia and Australia	Development of a new peanut variety with tolerance to aflatoxin contamination Biocontrol technology Establishment of a low-cost enzyme-linked immunosorbent assay (ELISA) detection system	Understanding of the level of aflatoxin in the Indonesian peanut food chain Demonstration of a high level of fungal contamination at farm level Decision-support tool for aflatoxin risk assessment	Aflatoxin awareness program
4. Management strategies for enhanced fisheries production in Sri Lanka and Australia	Techniques for predicting yield and optimal stocking rates, along with management information for communal fishing societies	Models to predict the yield from fisheries, based on a number of observable characteristics, and the feasibility of introducing a subsidiary fishery for naturally recruited indigenous species	Predictive yield models with implications for optimal fishing craft numbers Guidelines for the selection of non-perennial reservoirs for culture-based fisheries
5. Biology and status of the prawn stocks and the trawl fishery in the Gulf of Papua		Technical information on the fishery, including maximum biological yield and dynamics of the fishery	Recommendations on management measures for the prawn fishery, leading to a new management plan
6. High-performance eucalypts and interspecific hybrids for marginal lands in south and eastern South Africa and south-eastern Australia	New genetic stock (for use by breeders initially)	Knowledge of the reproductive biology of particular eucalypts Knowledge of the genetic mechanisms associated with hybridity in forest trees	
7. Management of postharvest diseases of tropical and subtropical fruit using their natural resistance mechanisms in Sri Lanka, the Philippines and Australia	Practical recommendation to avoid excessive nitrogen application during crop production	Wide range of specific scientific knowledge related to greater understanding of host defence mechanisms against fungal infections in mangoes and bananas	

continued …

Table 1. (continued)

Project	New technologies or practical approaches	Scientific knowledge	Knowledge or models for policy and policymakers
8. Coconut tissue culture for clonal propagation and safe germplasm exchange in Indonesia, Vietnam, Papua New Guinea and the Philippines	Development of an efficient embryo culture technique Development of a clonal-propagation technique Genetic-fidelity test for coconut Approach to propagating high-value mutant varieties	Refined tools for the tissue culture of coconut	Development of coherent strategies for the collection and conservation of coconut germplasm from remote national and international sources
9. Postharvest handling and disease control in melons in China and Australia	Improvements in a range of postharvest management techniques for melons	Identification of biochemical markers of natural plant defence, including antifungal compounds, in melons	Range of findings to promote improvement in understanding and management of the melon supply chain
10. Lucerne adapted to adverse environments in China and Australia	Release of new lucerne varieties Screening techniques for tolerance to soil acidity, salinity and cold		
11. Cocoa fermentation and drying and genotype quality assessment in Papua New Guinea	Small-scale fermentation technologies Small-scale (solar or combination solar/kiln) drying technologies	Identification of cocoa breeding lines	Draft manual for cocoa inspectors

Capacity development

Most of the projects presented here had explicit objectives to improve the capacity for research and development (R&D) in partner countries, and all of the projects had substantial capacity-building outcomes. Table 2 summarises the capacity developed and used in the projects covered in this report.

Capacity development included training in basic experimental and research skills, both through formal training and less formal on-the-job training. Many of the projects involved training to obtain higher academic qualifications.

A number of the projects included the enhancement of research infrastructure, varying from basic laboratory equipment provided as part of the project, to the establishment of research systems such as geographical information system (GIS) tools and models, as well as enzyme-linked immunosorbent assay (ELISA) diagnostic systems and software for analysing plant genetics.

In most cases, the research capacity and research infrastructure continue to be used. In two cases, researchers who were originally junior during the course of the project now hold senior positions within the relevant organisations. In other cases, trained staff have moved to take positions in commercial organisations. In some cases, due to a lack of funds or changed priorities within the country concerned, the capacity developed is no longer used.

Table 2. Research capacity built by the projects

Project	Partner-country/ies research capacity built	Research infrastructure	Capacity utilised
1. Integrated management of botrytis grey mould of chickpea in Bangladesh and Australia	Capacity development of both researchers and farmers through a series of workshops and training sessions		Limited use due to reduced priority in Bangladesh
2. Biological control of *Chromolaena odorata* in Papua New Guinea	Considerable capacity development within both regional agencies and farm communities	Physical infrastructure developed in the course of the project	Human and physical capacity continues to be used
3. Reducing aflatoxin in peanuts in Indonesia and Australia	Training for Indonesian scientists in agronomic management, crop modelling and aflatoxin analysis with enzyme-linked immunosorbent assay (ELISA) systems	ELISA systems	Ongoing use of expertise developed in the course of the project
4. Management strategies for enhanced fisheries production in Sri Lanka and Australia	Extensive training of researchers to higher degree and PhD level Training of extension officers and fisheries inspectors Training of farmers (many formerly rice farmers)	Models and geographical information systems developed	Capacity continues to be used in relevant government agencies, fishing communities and the scientific community in general Teaching on culture-based fisheries has become a component of a number of university courses
5. Biology and status of the prawn stocks and trawl fishery in the Gulf of Papua	Formal and informal on-the-job training for National Fisheries Authority staff and Gulf province staff	Improved capacity of licensing and data control	Trained staff remain employed and active in their respective organisations

continued …

Table 2. (continued)

Project	Partner-country/ies research capacity built	Research infrastructure	Capacity utilised
6. High-performance eucalypts and interspecific hybrids for marginal lands in south and eastern South Africa and south-eastern Australia	Project training (including training manual) and postgraduate study, particularly in genetic data analysis and breeding strategy development and implementation	Software for analysis of genetic hybrids Bench-top propagation facilities	Trained staff continue in their roles
7. Management of postharvest diseases of tropical and subtropical fruit using their natural resistance mechanisms in Sri Lanka, the Philippines and Australia	Capacity building major component of project Included postgraduate training (PhD) and specific training in Australia for some partner-country project staff	Range of research equipment purchased under the project	Most postgraduate students now in positions where they continue to extend the knowledge from the project
8. Coconut tissue culture for clonal propagation and safe germplasm exchange in Indonesia, Vietnam, Papua New Guinea and the Philippines	Researchers in each of the partner countries received core training in laboratory techniques associated with clonal propagation and the production of plantlets	Basic laboratory infrastructure (autoclave, laminar airflow hoods etc.) was provided to a number of partner agencies	Both human and physical capacity continues to be utilised In some cases, trained staff have left the original institution to use their skills in commercial enterprises
9. Postharvest handling and disease control in melons in China and Australia	Improved Department of Agriculture capacity to deliver extension services Training of over 30 postgraduate students	Basic laboratory infrastructure purchased; pilot demonstration cool room built in Gansu province	Department of Agriculture capacity continues to be utilised Trained researchers continue to be active with expanded research in partner institutions
10. Lucerne adapted to adverse environments in China and Australia	Capacity building was a major objective and outcome of the project leading to improved scientific and technical capacity for lucerne breeding in China and Australia		Capacity continues to be utilised in China with expansion of forage breeding programs in the institutions involved
11. Cocoa fermentation and drying and genotype quality assessment in Papua New Guinea	Staff of Papua New Guinea Cocoa and Coconut Institute (CCI) trained in cocoa quality evaluation techniques and laboratory skills	A range of project-funded equipment supplied	Capacity remains within CCI but is not being used due to a lack of funds Project-funded equipment is not being used

Uptake of the R&D outputs—progress along adoption pathways

Table 3 summarises the adoption outcomes for the projects covered in this report.

Most of the projects covered here had a number of different objectives and outputs. Summarising the often complex adoption outcomes for a range of projects is inevitably a difficult task and involves an element of judgment. For the summary presented in Table 3, as in previous adoption reports, a four-level classification scheme is used.

In this classification scheme, the lowest level of adoption is *O*, or no uptake of the results by either initial or final users of the outputs of the project. As Table 3 indicates, three projects had no adoption of *some* of the project outputs (although in each of these cases, there was low or high adoption of other project outputs).

The next level of adoption is *N*, the circumstance where there has been some uptake by initial users but no uptake by final users of the research. Six projects had some outputs falling into this category (again, in each of these cases, other components had higher adoption).

The next level of adoption is *Nf*, the circumstance where there has been uptake by initial users and some uptake by final users. Six projects had outputs falling into this category.

The highest level of adoption, *NF* (use by initial and final users), was achieved to some degree in at least some of the project components in eight of the projects reported here.

Table 3. Current levels of adoption of key project outputs

Project	New technology/ practical approach	Scientific knowledge	Knowledge, models for policy
1. Integrated management of botrytis grey mould of chickpea in Bangladesh and Australia	*O* — integrated commodity management package not used, due to farmers abandoning chickpea	*N* — limited uptake in Australia and Bangladesh	
2. Biological control of *Chromolaena odorata* in Papua New Guinea	*NF* — successful release of control agent	*Nf* — use of information in a range of agencies	
3. Reducing aflatoxin in peanuts in Indonesia and Australia	*Nf* — new variety *NF* — ELISA systems	*Nf* — quantification in food chain *O* — knowledge of infection at farm level *O* — decision-support tool	

continued …

Table 3. (continued)

Project	New technology/ practical approach	Scientific knowledge	Knowledge, models for policy
4. Management strategies for enhanced fisheries production in Sri Lanka and Australia	*NF* — formation of effective communal fishing societies	*NF* — models widely accepted and used in scientific literature	*NF* — managerial measures now used in most perennial reservoirs *NF* — change in policy and legislation to allow culture-based fisheries in non-perennial reservoirs *NF* — change in gear regulations for fisheries in large reservoirs to permit the introduction of a subsidiary fishery for naturally recruited, indigenous species
5. Biology and status of the prawn stocks and trawl fishery in the Gulf of Papua		*Nf* — use of knowledge varies across institutions	*NF* — new management plan gazetted in 2008 *O* — total allowable catch mechanism not currently being used
6. High-performance eucalypts and interspecific hybrids for marginal lands in south and eastern South Africa and south-eastern Australia	*N* — new genetic material *N* — hybrid material	*NF* — new knowledge and techniques	
7. Management of postharvest diseases of tropical and subtropical fruit using their natural resistance mechanisms in Sri Lanka, the Philippines and Australia	*NF* — recommendation now part of Horticulture Australia's 'Better mangoes' program	*N* to *Nf* — variable depending on specific components Many aspects being taken forward by project participants	

continued …

Table 3. (continued)

Project	New technology/ practical approach	Scientific knowledge	Knowledge, models for policy
8. Coconut tissue culture for clonal propagation and safe germplasm exchange in Indonesia, Vietnam, Papua New Guinea and the Philippines	*Nf* — development of efficient embryo culture technique *N* — development of clonal-propagation technique *Nf* — genetic-fidelity test for coconut *Nf to NF* — approach to propagate high-value mutant varieties (*NF* particularly in the Philippines)	*Nf* — use of information in a range of agencies	*Nf to NF* — information and new techniques adopted and used by researchers in each institution for intended and unintended outputs *Nf to NF* — findings of the project incorporated into long-term production practices by the international coconut community
9. Postharvest handling and disease control in melons in China and Australia	*N to NF* depending on particular postharvest technique	*N*—technology delayed in adoption by final users until registered for use	*NF* — high level of improved understanding of supply-chain issues
10. Lucerne adapted to adverse environments in China and Australia	*N* — project varieties released and currently in seed multiplication phase		
11. Cocoa fermentation and drying and genotype quality assessment in Papua New Guinea	*O* — technologies developed have not been adopted for a variety of reasons		*O* — technologies have not been approved or incorporated into manual for cocoa inspectors

Note:

Level of uptake is summarised as high, medium, low or none using the following key:

NF Demonstrated and considerable use of results by the initial and final users.

Nf Demonstrated and considerable use of results by the initial users but only minimal uptake by the final users.

N Some use of results by the initial users but no uptake by the final users.

O No uptake by either initial or final users.

Factors contributing to adoption of project outputs

There is always a wide variety of factors underlying particular adoption outcomes. In a broad sense, a number of common factors emerge related to knowledge, incentives and barriers. They can be summarised as follows:

- Knowledge
  - Do the final users *know* about the project outputs?
  - Is there *continuity of staff* in organisations associated with adoption (leading to the ongoing transfer of knowledge)?
  - Are the outputs too *complex* to absorb relative to the capacity of the users (do users have a sufficient knowledge base to support adoption)?
- Incentives
  - Do users have sufficient *incentives* to adopt the outputs?
  - Does adoption of the outputs increase *risk or uncertainty* for the users (thus reducing incentives to adopt)?
  - Is adoption either *compulsory* or indirectly *prohibited* (an extreme form of incentive or barrier)?
- Barriers
  - Do potential users face *capital or infrastructure constraints*, limiting their ability to fund the adoption of the outputs?
  - Do potential users of the outputs face *cultural or social* constraints to adoption?

Table 4 summarises some of the major factors affecting adoption for the projects reported here.

For the studies reported here, relatively high levels of adoption appear to have been driven by either strong economic incentives or a mix of regulatory and legislative changes that allowed economic incentives to emerge.

Relatively low levels of adoption resulted mostly from either changed incentives during the course of the project—leading to limited incentives to adopt project outcomes—or lack of legislative and general government support for ongoing adoption of the project results.

Table 4. Factors influencing adoption and impact—summary of key findings

Factor		Key findings
Knowledge	*Do potential users know about the outputs?*	In the botrytis grey mould (BGM) project in Bangladesh, there was a clear indication of good knowledge of project outcomes. In the cocoa project in Papua New Guinea (PNG), considerable lack of information from the perspective of potential users inhibited adoption. In the prawn fishery in PNG, some new fishing operators were not aware of the features of the new management plan. In the postharvest diseases of the tropical fruit project, the lack of ACIAR support for an end-of-project workshop limited ability to disseminate project findings. In the aflatoxin project in Indonesia, awareness of the issue is limited, affecting adoption of outputs. In the case of fisheries management in Sri Lanka, considerable dissemination of project outputs enhanced adoption. In the case of postharvest handing of melons in China, there was high awareness of project outcomes due to the close relationships between the Chinese researchers and the end users and through the end-of-project workshops.
	Is there continuity of staff in organisations associated with adoption?	This did not appear as a major issue in the projects covered in this report.
	Are outputs complex in comparison with the capability of the users?	This did not appear as a major issue in the projects covered in this report.
Incentives	*Are there sufficient incentives to adopt the outputs?*	In the BGM project in Bangladesh, farmers abandoned chickpea cultivation for a variety of reasons, thus reducing incentives to adopt project outputs. In the case of the coconut tissue-culture project, the adoption of techniques for propagating high-value mutant varieties was very high because of economic incentives (high sale price) associated with these varieties. In the case of the prawn fishery in PNG, poor economic conditions have limited adoption of some of the proposed changes in the management plan. In the case of fisheries in Sri Lanka, legislative changes as a result of the project created economic incentives to adopt other project outcomes. In the case of postharvest handing of melons in China, strong economic incentives (better returns for farmers) drove adoption of several aspects of the projects.

continued …

Table 4. (continued)

Factor		Key findings
	Does adoption increase risk or uncertainty?	This did not appear as a major issue in the projects covered in this report.
	Is adoption compulsory or effectively prohibited?	Adoption in the case of cocoa fermenting and drying technologies in PNG has been prevented through lack of regulatory recognition of the technologies. In the case of the prawn fishery in PNG, limited enforcement has reduced effective adoption of some of the recommendations in the management plan. In the case of aflatoxin in Indonesia, regulatory standards and enforcement have reduced adoption of some project outputs.
Barriers	*Do potential users face capital or infrastructure constraints?*	In the case of solar dryers for cocoa in PNG, the capital cost of polycarbonate sheeting (compared with the cost of constructing a wood-fired kiln) may be inhibiting adoption. In the coconut tissue-culture project, ongoing funding within partner institutions has been a barrier to further adoption of the outcomes of the project. In the case of postharvest handing of melons in China, the high cost of cool-chain infrastructure has been a barrier to uptake for many individual farmers.
	Are there cultural or social barriers to adoption?	Review of the fisheries project in Sri Lanka indicated that there had been little focus on gender components of the project. While this was not an explicit barrier to adoption, further examination of this issue may enhance future adoption.

Lessons

The results that emerge from the adoption studies reported here provide a number of lessons for ACIAR-funded projects.

Incentives for adoption

In the botrytis grey mould (BGM) study in Bangladesh, farmers abandoned growing chickpeas for a variety of reasons, effectively eliminating incentive to adopt any of the research outputs—despite the clear demonstration in the adoption study that farmers were well aware of the findings (particularly the integrated-commodity-management package). This particular issue has arisen in the past for ACIAR-funded projects where economic incentives to produce a particular product changed during the course of the research project.

In constrast, the project on postharvest handling and disease control for melons in China indicated very strong financial incentives for farmers to adopt research findings — particularly in terms of supply-chain management and requirements.

The need for better understanding of economics before research

The BGM adoption study noted the importance of a prior value-chain study to identify potential constraints to adoption. To some extent, better understanding of economic trends may have assisted at the design stage of the project.

The need for more generally specified project objectives and methods

The BGM study noted that, in hindsight, a more generally specified study would have benefited the overall research. In particular, problems arose in the focus on chickpea, in that, for the years of the study, rainfall was relatively low and so BGM was not as great a constraint. While this could not, of course, have been anticipated, a more general system-based research plan could have dealt with this problem. Combined with the points about this study noted above, this may have enhanced overall research outcomes.

Regulation affecting adoption

The fishing project in Sri Lanka illustrated the power of regulatory change in helping achieve adoption. One of the outcomes of this project was a change in legislation in Sri Lanka to allow the use of non-perennial reservoirs for fishing (this legislative change itself resulting from the scientific findings of the project). This significantly changed incentives for communities to undertake this form of fishing, leading to the development of economically productive activities.

This is in contrast to the cocoa fermentation and drying project in PNG, for which lack of policy recognition has effectively prevented adoption. In this case, the project fermentation and drying technology has not been approved by the Cocoa Board, meaning that there is no legal avenue to adopt the technology.

Regulatory systems in the food chain

Related to this general regulatory point, the aflatoxin project in peanuts highlighted some key differences between the food regulatory systems in Australia and Indonesia. While the Australian system is considered to provide a mix of 'carrots and sticks' to deal with contamination (resulting in all peanuts sold being safe), in Indonesia considerably less effective regulation meant that not all peanuts sold to consumers are safe. Further, the Indonesian system provided little incentive to manage contamination throughout the food chain. Contamination is regulated, but the regulations are not enforced.

Cost effectiveness of biological control

The chromolaena biological control project in PNG demonstrates again the effectiveness of biological control agents—particularly where these have been identified or used in earlier projects or in other similar countries. The release of biological control agents has a number of benefits for adoption as, once established, the agents essentially look after themselves. This cuts through many of the institutional issues that often arise in developing countries.

Communication

The coconut-tissue culture project found that communication between Australia and the four partner countries (PNG, Indonesia, Vietnam and the Philippines) was considerably enhanced through the use of a web-based communication platform (in this case, the product Google-Groups) that was used to post and comment on research protocols and so on.

Surprising power of niche-market opportunities

In the coconut-tissue culture project, the research outputs to do with the better propagation of high-value coconut mutant varieties proved to be very popular because of the economic incentives involved. In some of the partner countries, the mutant varieties (particularly those with a soft endosperm or aromatic water) provided niche-market opportunities, leading to very high adoption of the technology.

Ongoing engagement: the line between research and implementation

The adoption results from the prawn fishery project in PNG suggest that some form of continued engagement beyond the life of the project may have enhanced adoption. While the key outputs of the project were embedded in a management plan (that was gazetted), most of the elements of the management plan have not actually been implemented. This case raises a frequent issue for ACIAR-funded projects, namely the deliniation between research responsibilities and ongoing implementation of research outcomes.

Time frames for adoption

The eucalypt project in South Africa illustrated the very long time frames associated with adoption for particular tree-based crops. While the project successfuly led to an increase in genetic stock for South Africa, adoption by final users is some way off because of the long time frames involved in the breeding and evaluation processes.

Integrated management of botrytis grey mould of chickpea in Bangladesh and Australia (CIM/2001/039)

M. Yusuf Ali

Project number	CIM/2001/039
Project name	Integrated management of botrytis grey mould of chickpea in Bangladesh and Australia
Collaborating institutions	Australia: Centre for Legumes in Mediterranean Agriculture (CLIMA), The University of Western Australia; Western Australian Department of Agriculture; Department of Natural Resources and Environment, Victoria; University of Melbourne; NSW Agriculture, Tamworth, New South Wales Bangladesh: Bangladesh Agricultural Research Institute (BARI) in collaboration with the Department of Agricultural Extension (DAE); International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); Chris Johansen, an international consultant based in Bangladesh
Project leaders	Australia: Professor Kadambot Siddique Bangladesh: Dr Md. Abu Bakr
Duration of project	1 July 2002 – 23 November 2006
Funding	Total: A$1,527,100 (ACIAR contribution: A$898,780)
Countries	Bangladesh, Australia
Commodity	Chickpea
Related projects	LWR/2005/001

Motivation for the project and what it aimed to achieve

Chickpea was once a major pulse crop of Bangladesh, supplying valuable nutrition to humans and animals. However, its area rapidly declined from the 1980s with the expansion of irrigation, and chickpea was replaced mainly by irrigated boro[1] rice. One of the major reasons for the decline in chickpea cultivation was its unstable and uncertain yield due mainly to the notorious foliar disease, botrytis grey mould (BGM), and damage caused by the pod-boring insect *Helicoverpa armigera*. In rainy, overcast and foggy winters, BGM can cause complete crop loss. The uncertainty in production due to BGM was one of the major causes of disappearance of chickpea across the country. However, chickpea remains a preferred and staple foodstuff in Bangladesh and imports have had to dramatically increase to meet the demand of the growing population. Chickpea is widely used in the Muslim fasting month (the Ramadan) for breakfast with chapatti bread, in preparation of different food items for festivals and as roasted chickpea for street selling. Moreover, as a leguminous crop, its cultivation helps to improve soil fertility such that the subsequent crop requires less fertiliser.

BGM is not only a South Asian disease but is also the second-most important foliar disease of chickpea in Australia. There had been various component studies on the nature of the disease and options for its management conducted in South Asia, largely coordinated through ICRISAT programs, and Australia. However, there had been few attempts to combine this information into an integrated disease management (IDM) package suitable for application in farmers' fields. Further, there had been no attempts so far to combine IDM with an overall integrated crop management (ICM) package for chickpea. Thus, the project was undertaken to manage BGM at the farm level through an ICM package in the traditional chickpea-growing areas of Bangladesh. Previous screening studies had identified a negligible degree of host-plant resistance to BGM but it was nevertheless considered worthwhile to screen new germplasm lines and breeding progeny for resistance to BGM. Bangladesh provided an ideal location for field screening, due to the endemic nature of the disease and pre-existing mist spray facilities at the BARI research station at Ishurdi to enhance humidity in the crop canopy. Field screening for BGM was difficult in Australia due to interactions with *Ascochyta* blight, a disease not present in Bangladesh. Thus, a major objective of the project was to better assess the degree of genetic resistance to BGM in chickpea and thence the viability of developing resistant, or at least less susceptible, varieties. Another major objective of the project was to train Bangladeshi scientists in recently evolved on-farm research and development techniques, and in foliar disease resistance screening and breeding.

The overall aim of the project was to achieve stable and economically viable yields of chickpea through a farmer participatory research and development approach, primarily in Bangladesh but with spillover implications for elsewhere in South Asia and in Australia. The project arose from discussions during 1999–2000 among researchers previously collaborating in chickpea research, particularly studies of foliar disease management, in South Asia and Australia. These included Professor Kadambot Siddique (CLIMA, University of Western Australia), Dr Chris Johansen (agricultural consultant, Dhaka, Bangladesh), Dr Md. Abu Bakr (pulse pathologist, BARI, Bangladesh), Md. Ali Afzal (legume breeder, BARI) and Dr S. Pande (pathologist, ICRISAT).

1 An irrigated, high-yielding, cold-tolerant rice cultivated during the winter months in India and Bangladesh.

Outputs—what the project produced

To tackle the BGM problem of chickpea in Bangladesh and elsewhere, there were two streams of effort. First, about 500 germplasm samples from across the globe were collected and evaluated in two locations of Bangladesh, in Australia, at ICRISAT and in Nepal, for selection of resistant/tolerant lines. Second, based on available technology, an ICM package was formulated and its performance evaluated in farmers' fields across the traditional chickpea-growing districts of Bangladesh for four seasons (2002–03, 2003–04, 2004–05 and 2005–06).

On-station field screening was done for 4 years in Bangladesh to identify chickpea lines with useful levels of resistance to BGM. Nearly 500 genotypes were screened in 2002–03, 208 in 2003–04, 200 in 2004–05 and 281 in 2005–06. From the second season onwards, entries comprised promising selections from the previous season plus new entries. Screening was conducted at two locations: at Jessore under natural levels of BGM infestation, and at Ishurdi where mist spraying was used to enhance the disease. Further, at Ishurdi, *Botrytis cinerea* spore inoculum was sprayed onto the field screening nurseries in the latter two seasons to further enhance the disease development. There were clear differences in reaction to

Australian and Bangladeshi scientists inspect a trial of integrated disease and crop management of botrytis grey mould in chickpea in a farmer's field at Faridpur, Bangladesh. (Photo: BARI, Gazipur)

BGM, as measured on a 1–9 scale, at each location in all seasons. Apart from the first season, there was a reasonable negative correlation between disease score and seed yield. Some lines with moderate levels of resistance were identified, with a consistent reaction across sites and seasons (e.g. the Australian variety Genesis 836, screened as ICCV96836).

It was possible to identify eight lines with relatively higher levels of resistance in both growth-room and field assessments: 97015-1008, 99038-1015, 97164-1001, 97037-1465, 94-012×98V4006, 97-139A×34-99V4001, 98176-1044 and 99039-1026. However, there has been no visible success in the development of BGM-resistant chickpea cultivars in Australia or Bangladesh, or at ICRISAT, although many genotypes have been identified as moderately tolerant. However, scientific methods developed through this research could, in the future, help to develop chickpea cultivars resistant to BGM and *Ascochyta* blight.

Isolates of *B. cinerea* have been collected in Bangladesh, India, Nepal and Australia since 2003 and subjected to PCR-based microsatellite DNA analysis. A high degree of adaptive potential of the fungus was found for Bangladesh isolates. This suggests that multiple resistance genes and mechanisms will be required if durable resistance is to be achieved.

A seed infection and germination test found suitable in Australia for assessing chickpea seed for infection with *Ascochyta rabiei* has also been found applicable for *B. cinerea*.

Mr Fakhrul Islam Alamgir (seated third from left), State Minister for Agriculture in the Government of Bangladesh, opened a review workshop on the ACIAR-funded chickpea botrytis grey mould management project that was held at the Bangladesh Agricultural Research Institute (BARI), Gazipur, in February 2004. Dr M. Nurul Alam, Chairman of BARI, is seated second from left, and Dr M. Matiur Rahman, BARI Director for Research, is standing third from left. Australian project leader Professor Kadambot Siddique is standing third from right. (Photo: BARI, Gazipur)

Project staff discussing botrytis grey mould management methods with chickpea farmers. (Photo: BARI, Gazipur)

On-farm tests demonstrated that use of BGM-free seed improved yields only under moderate levels of BGM infection, but not with severe infection. Although fungicidal seed treatment did not minimise BGM damage, seed treatment with Vitavax-200® reduced the incidence of collar rot (caused by *Sclerotium rolfsii*), a constraint to chickpea of increasing importance in South Asia. On-farm variety evaluations have been conducted since 2003–04 to determine farmers' preferences for varietal characteristics in this BGM-prone environment, so that these traits may be incorporated into the development of any future BGM-resistant varieties. The released variety BARI Chola 5 was generally preferred, because of its high yield potential and ability to recover from BGM damage.

From the 2002–03 season, ICM packages incorporating best-bet technologies for BGM management, along with other optimal agronomic packages, were assembled and tested in farmer-managed operational-scale plots (666 m^2) and compared with adjacent plots where prevailing farmers' practice was followed. For BGM management, the recommended ICM practice was use of a chickpea variety less susceptible to BGM, reduced seed rate, delayed sowing, thinning to prevent excessive vegetative growth and need-based foliar application of fungicide. Other important components of the ICM package are application of superphosphate, seed treatment with Vitavax-200® and integrated management of pod borer. From almost 500 demonstrations conducted during four seasons, it was observed that, on average, ICM package fields yielded more than 1 tonne/hectare of grain over the years, which was 20–60% more than yields from farmers' traditional plots.

In Australia, best-bet management components for BGM have been integrated into, and are completely compatible with, *Ascochyta* blight management procedures. During the excessively wet chickpea season in eastern Australia in 2010, BGM became a major constraint and procedures for its management evaluated under this project became relevant.

Before each chickpea-growing season, familiarisation, project planning, and review and training sessions were held for DAE and BARI staff involved in the project. Following these sessions, training was provided to all farmers participating in on-farm trials, evaluations and demonstrations, usually during the first half of November. In February 2004, in-the-field training was provided to participating farmers and DAE personnel in identification and management of BGM and pod borer. In March–April 2004 and 2005, training was provided to farmers in appropriate methodology for preserving chickpea seed. Additionally, several motivational tours were arranged for the farmers and DAE field staff at the podding stage of the crop.

Project staff visit a farmer's field in Shalikha, Magura, Bangladesh, to observe the results of a trial of the chickpea botrytis grey mould management package. Australian project leader Professor Kadambot Siddique is second from right, and Dr Md. Abu Bakr, project coordinator in Bangladesh, is to his right. (Photo: BARI, Gazipur)

The project resulted in many seminars/workshops, conference papers, scientific articles in international journals and extension pamphlets in Bengali. There were regular media reports on the project in both Bangladesh and Australia.

Adoption—how the project outputs are being used

Field surveys conducted in February 2011 confirmed that farmers and field workers in the original project area of Rajbari, Faridpur, Magura, Jessore and Jhenidah districts of Bangladesh know about the technology packages for minimising the effect of BGM disease and controlling pod borer, along with other technology options that can be applied for profitable chickpea cultivation. However, other factors override chickpea cultivation in the abovementioned traditional chickpea-growing areas. From 2006–07 onwards, for various reasons, the majority of the farmers almost abandoned chickpea cultivation. Our well-attended eight focus group discussions and farmer interviews revealed that farmers abandoned chickpea cultivation because of unstable yield, severe pod borer attack, relatively low economic return, social problems (stealing) due to small area and, in some places, because of the priority to ensure food security by growing boro rice. In some places, the low price for chickpea compared with other crops, due to the low import price of chickpea, has discouraged the farmers from continuing chickpea cultivation. However, a spillover effect of this project's finding was clearly observed in the High Barind Tract (HBT) area of north-western Bangladesh. Farmers are following the BGM management packages, which they learned through the On-Farm Research Division of BARI, DAE and PROVA (a Rajshahi-based non-government organisation). Currently, HBT farmers have the highest area (about 3,500 ha) under chickpea cultivation, whereas the rest of the country has less than 500 ha. As the HBT is a rainfed, drought-affected area, crop options are limited, and chickpea is a relatively profitable crop. In many areas, farmers would still remain interested in growing chickpea if a BGM-resistant, high-yielding variety were available together with a cheap and effective control method for pod borer, and if chickpea returned a higher market price than currently.

However, to attain the future reintroduction of chickpea, continuous resistance breeding is needed through gene pyramiding for the development of effective BGM-tolerant cultivars. It appears, however, that BARI is not continuing this endeavour, perhaps because of absence of experienced chickpea breeders and downgrading of priorities for chickpea research. In Australia, the BGM tolerance, or lesser susceptibility, identified under this project is being used in ongoing breeding programs, at least to avoid super-susceptibility of advanced selections and, it is hoped, to maximise incorporation of the genetic resistance that is available.

Since initiation of the project, the priority of BGM as a constraint to chickpea cultivation in Bangladesh has changed. From 2002–03, winters have been relatively dry, creating less favourable conditions for BGM infestation. Over this period, pod borer has assumed the role of the major biotic constraint to chickpea production.

Impact—the difference the project has made or is expected to make

The project proved successful in being able to transfer the process of managing BGM at field level. However, at farmer level the impact is not apparent, because farmers have largely abandoned chickpea cultivation due to changing biotic and socioeconomic circumstances. For example, BGM has assumed lesser priority as a biotic constraint; alternative crops are preferred for reasons of food security or greater profit; imports of chickpea have depressed farmgate prices etc. This project would have benefited if a value-chain analysis of the chickpea subsector in Bangladesh had been made before, or early in, the project. This could have identified actual and potential bottlenecks in the value chain that would need to be freed up if improved BGM management were to feed through to impact (in terms of improved livelihoods for those involved in the entire chickpea value chain). Although the project primarily focused on agronomic constraints, it should also have undertaken advocacy roles in addressing socioeconomic and policy aspects that prevent implementation of any improved agronomy. As an example, although there was an attempt to establish 'seed villages' by the project, this aspect should have received greater emphasis so as to ensure the commercial and sustainable supply of high-quality chickpea seed.

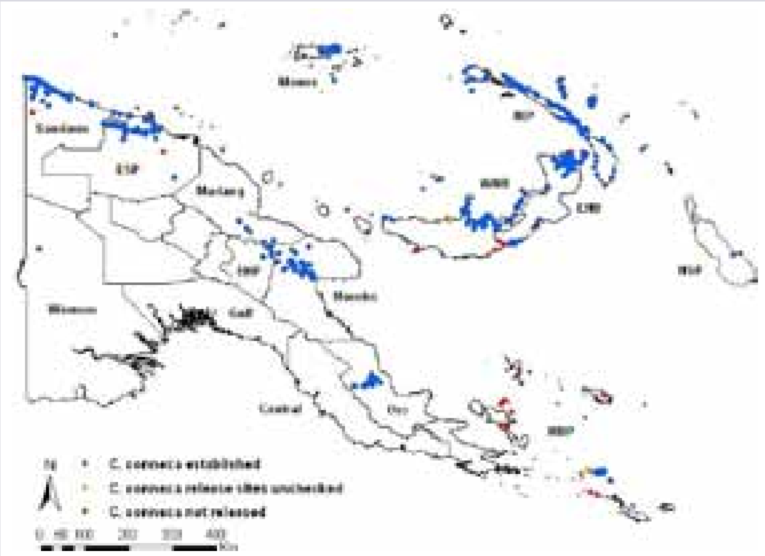
Dr Md. Yusuf Ali (centre, facing), assigned consultant for the chickpea botrytis grey mould (BGM) management project adoption study, meets with a group of farmers in their yard at Rajbari, Bangladesh, to determine the levels of their adoption of BGM management packages. (Photo: BARI, Gazipur)

Under the project, BARI and Australian scientists have been able to develop improved screening methods for BGM, and gain a better understanding of the nature of host-plant resistance to the BGM pathogen. They have identified a few moderately tolerant chickpea cultivars collected from across the globe that could pave the way for development of BGM-resistant/tolerant chickpea lines. Additionally, a few lines have been identified that are both BGM and *Ascochyta* blight (a major disease in Australia) tolerant. Australian scientists are much closer to developing chickpea cultivars that incorporate currently available levels of tolerance to BGM. Development of a markedly BGM-resistant chickpea cultivar would seem a prerequisite for revival of chickpea cultivation in Bangladesh and in other places where BGM is a problem.

Biological control of *Chromolaena odorata* in Papua New Guinea (CP/1996/091)

Michael Day

Project number	CP/1996/091
Project name	Biological control of *Chromolaena odorata* in Indonesia and Papua New Guinea
Collaborating institutions	Australia: Department of Natural Resources and Water, Queensland Indonesia: Universitas Nusa Cendana; SEAMEO Regional Centre for Tropical Biology; Gadjah Mada University; Indonesian Oil Palm Research Institute; Centre de Cooperation Internationale en Recherche Agronomique pour le Développement Papua New Guinea: National Agricultural Research Institute (NARI), formerly the Department of Agriculture and Livestock; Oil Palm Research Association Philippines: Philippine Coconut Authority (Note 11/3/2002—Variation 3—Review of Review recommended an increase in budget and an extension of 3 years in PNG only—the project was no longer active in Indonesia or the Philippines.)
Project leaders	Dr Michael Day, Department of Employment, Economic Development and Innovation, Queensland
Duration of project	1 July 1997 – 31 March 2007
Funding	Total: A$1,397,611 (ACIAR contribution: A$1,055,012)
Countries	Papua New Guinea (Indonesia, Philippines)
Commodities	Crops
Related projects	AS2/1991/010, LPS/2003/028



The distribution of chromolaena in Papua New Guinea, showing where the gall fly *Cecidochares connexa* has been released, where it has established and where it is not yet present.

Motivation for the project and what it aimed to achieve

Chromolaena odorata (chromolaena) (family Asteraceae), originally from the Caribbean and northern South America, is one of the world's worst weeds, affecting many tropical countries in Africa and Asia. It is a fast-growing woody shrub, reaching about 3 m tall. It can invade farming lands, lowering farm productivity, and outcompete natural vegetation, reducing biodiversity. In Papua New Guinea (PNG), it invades subsistence farms, smothering crops such as taro, cassava and pawpaw, as well as infesting plantations where it can interfere with the harvesting of coconuts or establishment of oil palm and cocoa. In grazing areas, it can outcompete preferred species, reducing productivity.

The plant flowers prolifically and produces thousands of barbed seeds that can be spread by wind, machinery, animals or on people's clothing and possessions. Chromolaena can be controlled by herbicides or manually but this is usually expensive and time-consuming and its rapid regrowth means that control efforts needs to be repeated frequently.

Biological control (biocontrol) of chromolaena has been suggested since the 1960s, when investigations undertaken by the Commonwealth Institute of Biological Control from 1966–72 identified 225 natural enemies of the weed. Several of these were considered promising for biocontrol and were released in West Africa in the 1970s.

An ACIAR-funded project on the biocontrol of *C. odorata* started in Indonesia and the Philippines in 1991. The rationale of the project was that controlling chromolaena in neighbouring countries to Australia not only helps farmers and increases food security in those countries but also reduces the risk of the weed reaching Australia. In 1991, when the project commenced, chromolaena was not found in Australia. However, it was later discovered in North Queensland in 1994 and became the target of a national eradication project.

Two biocontrol agents, the moth *Pareuchaetes pseudoinsulata* and the gall fly *Cecidochares connexa*, were introduced into Indonesia in 1993 and 1995, respectively, and both established. Following the introduction of these agents into Indonesia, the project was extended in 1998 to include PNG. In PNG, chromolaena was also considered a major weed of subsistence farms and plantations, where it smothered food crops and interfered with harvesting, reducing productivity and income. The impacts of chromolaena in PNG were likely to increase as the weed was spreading rapidly due to logging.

The PNG project aimed to reduce the impact of chromolaena on landholders, by introducing biocontrol agents that were deemed host specific and effective elsewhere. By controlling chromolaena in PNG, it was hoped that time spent on weeding would fall, while food production and income would rise.

The main agency involved in PNG was the National Agricultural Research Institute (NARI), formerly the Department of Agriculture and Livestock. Staff in NARI had been involved in an Australian Agency for International Development (AusAID)-funded project on the biocontrol of water hyacinth in PNG, which was managed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and ended in 1998. Other organisations involved were the PNG Oil Palm Research Association (PNGOPRA), the National Agriculture Quarantine Inspection Authority (NAQIA) and the PNG Department of Conservation (DEC). The last two organisations were involved because they are the organisations that issued the import permits for the biocontrol agents.

Outputs—what the project produced

The main outcome of the project was the control or significant reduction of chromolaena in most provinces of PNG. Areas that were once monostands of chromolaena have been converted back into subsistence farms, and plantations in which chromolaena was the main understorey species are now clear of the weed. This outcome was the result of the primary outputs of the project: (a) knowledge of the extent of the chromolaena problem and its impact of the livelihoods of smallholders, (b) an understanding of effective biocontrol agents and (c) significant capacity built in biocontrol of weeds.

Chromolaena was confirmed at over 700 sites in 13 lowland provinces. Through the results of public awareness campaigns and interviews, chromolaena was found to seriously affect landowners in terms of lost productivity and income and a significant increase in the time spent weeding food gardens. Chromolaena can quickly invade food gardens and its rapid growth can smother a range of crops including taro, cassava, banana and pawpaw. In plantations, chromolaena impeded the harvesting of fallen coconuts, while in grazing lands it outcompeted preferred grasses, significantly reducing stocking rates. Where chromolaena infestations were particularly severe, subsistence farmers had to slash and remove chromolaena almost daily to keep gardens clear of the weed. The increase in time spent weeding had numerous flow-on effects. Some food gardens became smaller because it was not possible to maintain larger food gardens, thus reducing productivity and income by up to 50% and having a significant effect on food security. In addition, there was considerably less time available for other activities such as repairs to houses, or there was a requirement for children to assist with farming, thus removing them from school.

The gall fly *Cecidochares connexa*, an agent for biological control of chromolaena. (Photo: C. Wilson)

Three insects, the moth *P. pseudoinsulata*, the gall fly *C. connexa* and the leaf-mining fly *Calycomyza eupatorivora*, were introduced as biocontrol agents during the project. *Pareuchaetes pseudoinsulata* was released widely but established only in Morobe and Eastern Highlands provinces, where it defoliates chromolaena seasonally. Rearing the moth was labour intensive, and large numbers were required to ensure establishment. Researchers in other countries also reported difficulties in rearing and achieving establishment. As a result, the rearing program was shortened and *P. pseudoinsulata* is not recommended for release in other countries.

The leaf-mining fly *C. eupatorivora* was imported numerous times from South Africa but did not establish. It was thought that PNG was too hot for the insect and it is not recommended for other tropical countries, such as East Timor.

The gall fly *C. connexa* was released at over 350 sites in all provinces where chromolaena occurs and established at nearly 300 sites. It later spread to over 350 additional sites, some of which were 100 km away. At the completion of the project, there were still about 25 sites that needed to be checked for establishment and about 50 sites where the gall fly was never released. Given the high establishment rate (98%) and the high rate of dispersal, it is quite likely that the gall fly is present in many of these areas by now. However, some of the more remote islands in Milne Bay would still require field releases.

Field monitoring of the gall fly found that, as the number of galls increased, branches can die, thereby reducing biomass and flower and seed production. At high gall levels (>50 galls/plant), whole plants can die, thus allowing the re-establishment of food gardens or natural vegetation. Numerous 'before gall fly' and 'after gall fly' photos were taken and have been used in various presentations. Such information is particularly useful for other countries where chromolaena is a problem. Control was reported in nearly 200 sites covering eight provinces, with partial control at many more sites.

Socioeconomic surveys conducted on nearly 200 landowners found that 83% of respondents thought there was much less chromolaena now than before the gall fly was released. About 70% of respondents stated that they were benefiting from the control of chromolaena, with 50% of respondents stating that weeding times were reduced by 50% and that control costs had fallen by 45%. Over 62% thought that crop yield and income increased following the control of chromolaena.

Throughout the project, databases were established to record information on where chromolaena was present, where the gall fly was released and had established, and to where it had naturally spread. Information was also collected on the effect of the gall fly on chromolaena at selected sites and the impact of the project on landholders. The information was useful for reporting and presentations, as well as assisting in planning future releases and other activities within the project.

At the commencement of the project, only one staff member in NARI was experienced in weed biocontrol. However, during the course of the project, numerous staff gained significant experience in the discipline. The project leader left the organisation midway through the term of the project and commenced work for

Kunibert Tibil, District Administrator, Kavieng, New Ireland, holding dead stems of chromolaena with galls. (Photo: W. Orapa) the Fiji-based Secretariat of the Pacific Community where, through his experience in weed biocontrol, he was able to enhance biocontrol throughout the Pacific. The junior scientist took over as the in-country project leader and quickly gained skills in all aspects of weed biocontrol and the importance of good data collection and processing. Labourers employed by the project to assist with releases, field monitoring and collection of agents are now being employed by other projects.

As biocontrol agents were released throughout the country, there was a need for project staff to liaise with provincial officers who had much local knowledge but often had little experience in weed biocontrol. However, towards the end of the project, through working with project staff, these provincial officers were skilled enough to be able to release biocontrol agents they received, then monitor results. This was a huge saving for the project in terms of time and funds. Serendipitously, these provincial officers are also being used in the current project on the biocontrol of mikania, another invasive weed.

Reporting the success of the gall fly on chromolaena was particularly relevant to researchers in other countries where chromolaena was also a problem. The project produced numerous publications, mainly presented at international workshops on the management and biocontrol of chromolaena: one paper was presented in Bangalore, India (1996), two in Durban (2000), two in Cairns (2003), one in Taiwan (2006)

John Bokosou of the National Agricultural Research Institute interviewing a landowner family near Burit, East New Britain, to get their thoughts on chromolaena and the gall fly biological control agent, and how they are affecting their farm. (Photo: M. Day) and one in Nairobi (2010). A paper was also presented at the Australian and New Zealand Biocontrol Conference in Sydney in 2008. Information gained from this project was also included in chapters in two books on weed biocontrol.

A training workshop on biocontrol of weeds, with reference to chromolaena, was held in Lae, PNG, in 2003 and attended by PNG provincial officers, as well as researchers from Solomon Islands. The workshop covered the theory behind weed biocontrol, as well as information on the chromolaena biocontrol agents, with visits to selected field sites to view chromolaena infestations and the effect of the gall fly. The workshop was particularly useful as it provided training for provincial officers not well versed in weed biocontrol. More importantly, it increased awareness of the problems of chromolaena to the researchers in Solomon Islands, where chromolaena is not yet present. A comprehensive manual was produced for the workshop and distributed to the participants. Seminars covering the project were also presented to researchers in several Queensland government departments, the Queensland Entomological Society and at Kasetsart University, Thailand.

As biocontrol agents had to be imported and reared through one generation to remove possible parasites before their field release, post-entry quarantine had to be upgraded and rearing facilities built. A building with several rooms was upgraded so that it could be used as a post-entry quarantine facility. The insect-rearing facilities for biocontrol agents released from quarantine were constructed from an old shed used for rearing ducks. Insect cages were constructed in Australia and sent to PNG. These buildings and cages are now being used by other projects.

Adoption—how the project outputs are being used

Information on the distribution and significance of chromolaena as a weed and its effect on food security in PNG was used by quarantine and DEC authorities when conducting risk assessments on potential biocontrol agents being considered for importation. In all cases, the three agents were considered damaging to chromolaena and safe to release. The information on chromolaena was also used by quarantine authorities in Solomon Islands who now regularly survey the northern islands that neighbour PNG for the weed in an effort to ensure it does not establish in the country.

Information on the distribution of chromolaena and the status of the gall fly is still being used by NARI officers to both check whether the gall fly is present in various regions and conduct opportunistic releases of the gall fly if it is not present. Information on whether chromolaena is being controlled is also being collated. NARI officers, when travelling on behalf of the mikania biocontrol project, are often advised of the status of chromolaena in provinces they are visiting.

Landowners have reported that the gall fly has made a substantial difference and some are still moving the insect around to new areas. Other landowners report that they are now reducing the levels of burning or leaving patches of chromolaena in land not needed for farming to ensure populations of gall fly are maintained.

Jenitha Fidelis of the Cocoa and Coconut Institute collecting information about chromolaena and its biological control from landowners near Burit, East New Britain. (Photo: M. Day)

Information on the effect of the gall fly on chromolaena in PNG has been presented at numerous conferences and workshops and has been published in several proceedings. The information has been used by several organisations overseas. For example, based on the results in PNG, the gall fly was imported into East Timor in 2005. It was also imported into Thailand in 2009, following a visit by researchers from Kasetsart University. Following an international workshop in Kenya in 2010, an application to import the gall fly into that country was submitted.

Infrastructure such as quarantine and rearing facilities built during the project has been utilised by other projects in NARI that require sealed, airconditioned rooms or large, covered areas to maintain plants or insects. The mikania biocontrol project is located at NARI's Lowland Agricultural Experimental Station at Kerevat, East New Britain, but used the facilities built for chromolaena for a short period. Cages built to rear the agents have been utilised for rearing other insects.

Adoption of the project was enhanced by the production and distribution of a brochure detailing the weed and the agents. Several stories were published in two national newspapers and as well as on the radio. During project visits to release or monitor agents, project staff engaged provincial officers and community groups to inform them about the project, its objectives and results. Numerous papers were presented at international workshops and included in published proceedings to inform the scientific community on the success of the chromolaena project.

Despite these efforts, communication within PNG can be difficult, with unreliable phones and frequent power outages. Some places are just very remote. Consequently, the gall fly could not be released in all areas of PNG, but it is hoped, with time, that it will disperse to new places by itself.

Impact—the difference the project has made or is expected to make

The degree of benefits of the project vary with land use and climate. Control or significant reductions of the weed were reported in most provinces where chromolaena was present. Control was reportedly quicker and more complete in some provinces than in others. In New Ireland, which was one of the first provinces to receive the gall fly, very good control was observed and socioeconomic impact studies suggested that the landholders are benefiting from the gall fly's introduction. In other, drier provinces, such as Morobe, control was slower and less complete. In West New Britain, which is considerably wetter than most other provinces, control was not as good and chromolaena remains a problem. This is because the gall fly needs sunny days with temperatures over 30°C to mate. Cloudy, wet days result in lower temperatures and less time for mating. The gall fly failed to establish in Western province, as the only release site was slashed soon after the gall fly was released. However, the gall fly was recently released there again by mikania biocontrol project staff visiting the province.

Provinces aside, 69% of landowners who had chromolaena on their farms have reported some benefits as a result of the gall fly. However, the degree of benefits from the gall fly vary considerably with land use. Subsistence farmers who rely heavily on weeding by physical means such as slashing are probably the greatest beneficiaries in terms of percentage gains. This is in part due to the low inherent incomes and the high degree of manual labour involved in subsistence farming. Surveys found that weeding times were cut by up to 50%, which similarly reduced labour costs. Coupled with reduced time spent weeding, productivity (and therefore food security) and income both increased. As populations of chromolaena were controlled, there was less competition against crops such as taro, cassava, pawpaw and banana. However, the major benefit is apparently that, with reduced time required to maintain food gardens, landholders are able to increase the size of their blocks, thus increasing yield and income.

Commercial farmers also benefited from reduced herbicide costs and thus returned higher profits, while plantation owners were able to access coconut plantations to harvest fallen nuts. Controlling chromolaena in pastures meant that stocking rates could be increased. However, if other weeds were not managed at the same time, they would just replace chromolaena as it was controlled.

Other benefits that were not so obvious were that there were fewer places for snakes and pigs to hide once the chromolaena was controlled and so farmers did not have to erect fences around food gardens to keep out wild pigs. Some farmers reported a reduction in wounds from bush knife cuts, as there was a reduced need to slash chromolaena in food gardens. Chromolaena has a very thick and tough stem which makes slashing harder and also blunts knives quicker, adding to the risk of injuries.

The adoption study team near Matanakalah, New Ireland; L–R: Jenitha Fidelis (Cocoa and Coconut Institute, CCI), John Bokosou (National Agricultural Research Institute, NARI), John Joseph (CCI), Anna Kawi (NARI) and Richard Dikrey (Papua New Guinea Oil Palm Research Association). (Photo: M. Day)

Reduced populations of chromolaena also increased safety for pedestrians. Chromolaena was often found growing along roadsides and is considerably harder to slash than grasses. This meant that villagers often had to walk on the road to and from food gardens, increasing the risk of being hit by motorists.

It is anticipated that the benefits of this project will continue to flow through the community. Biocontrol is a self-sustaining control method, with the gall fly continuously suppressing populations of chromolaena, although both populations may fluctuate with time. It is also anticipated that the gall fly will continue to spread naturally throughout areas where chromolaena is present or into which it may spread. In addition, it is expected that landowners will continually move the gall fly into new areas themselves once they are aware of its benefits.

At a much wider level, organisations in other countries will continue to consider introducing effective agents to control chromolaena as a result of publications or presentations reporting the research conducted in PNG or other countries. Through various international workshops and publications, the news of the outcomes of the project in PNG has resulted in other countries also introducing the gall fly. The gall fly was introduced into East Timor in 2005 and Thailand in 2009. An application has recently been submitted to introduce the gall fly into Kenya. In addition, China, Taiwan and Palau have all expressed interest in importing it.

Reducing aflatoxin in peanuts using agronomic management and biocontrol strategies in Indonesia and Australia (CP/1997/017)

Rao Rachaputi and Graeme Wright

Project number	CP/1997/017
Project name	Reducing aflatoxin in peanuts using agronomic management and biocontrol strategies in Indonesia and Australia
Collaborating institutions	Australia: Department of Employment, Economic Development and Innovation (DEEDI), Queensland—formerly the Department of Primary Industries; Department of Agricultural Chemistry and Soil Science, University of Sydney Indonesia: Indonesian Legumes and Tuber Crops Research Institute (ILETRI); Southeast Asian Regional Centre for Tropical Biology (SEAMEO BIOTROP), Bogor; Faculty of Agricultural Technology, Gajah Mada University, Yogyakarta; Balai Pengkajan Teknologi Pertanian (BPTP) (Assessment Institute for Agricultural Technology)
Project leaders	Australia: G.C. Wright Indonesia: A. Rahamianna
Duration of project	1 July 2001 – 1 December 2006 (3 years plus a 2-year extension)
Funding	A$2,844,146 (ACIAR contribution: A$953,736)
Countries	Australia, Indonesia
Commodity	Peanut
Related projects	CS1/1984/019, CP/1988/034, PHT/1988/006, PHT/1991/004

Motivation for the project and what it aimed to achieve

Aflatoxin is a carcinogenic, immune-suppressing and anti-nutritional natural contaminant produced in peanut kernels when they are infected by the soil fungi *Aspergillus flavus* or *Aspergillus parasiticus* under conditions of severe drought and elevated temperatures. Aflatoxin contamination is a major human food and animal feed quality problem throughout the world. The worldwide increase in incidence of diseases caused by the hepatitis B and C viruses is increasing the importance of aflatoxin as a potential health risk since the toxin is implicated in predisposing people who ingest large quantities of aflatoxin to liver diseases. These health concerns are driving a desire to significantly decrease the levels of aflatoxin allowed in foods worldwide.

In Indonesia, over 800,000 tonnes of peanuts are produced annually and consumed domestically. The demand in Indonesia is far greater than the domestic supply, with the consequence that Indonesia is one of the world's largest importers of peanuts. Nearly all peanuts are consumed as a food and represent a vitally important part of the Indonesian diet by providing a rich source of protein, oil and vitamins, especially for the poorer sections of the community.

Aflatoxin can directly affect the health of peanut consumers in Indonesia. Because food safety and security systems are poorly developed or absent, any aflatoxin contamination that occurs is commonly undetected. There is a lack of detailed knowledge on the nature and extent of the problem in the peanut food chain, and hence of potential strategies needed to minimise exposure for Indonesian consumers. The project originated from concerns about the health effects of aflatoxin in the Indonesian food chain and the need to better understand where there might be critical control points that could be targeted to minimise its impact.

Given the critical importance of the aflatoxin problem for human health (in Indonesia) and farmer and industry viability (in Australia), it was clear that both countries shared a common interest in conducting research, development and extension to minimise its effects in the food chain. The Indonesian and Australian governments considered that research to minimise in-field and postharvest aflatoxin contamination in peanuts was a very high priority, and hence supported the project.

The broad aim of the project was to minimise, and eventually eliminate, aflatoxin contamination in Indonesian and Australian peanuts through research, development and extension of appropriate on-farm and postharvest management practices.

In Indonesia, the project focused on identifying the major points of aflatoxin contamination in the Indonesian food chain as a precursor to developing relevant management and varietal interventions to minimise its incidence. In Australia, the project concentrated on a range of in-season harvesting management approaches along with new research to assess the application of biocontrol technology using non-toxigenic strains of the *A. flavus* fungus.

The project also had a strong capacity-building component by providing training to Indonesian scientists in peanut agronomic management, crop modelling, aflatoxin analysis using enzyme-linked immunosorbent assay (ELISA) systems and related mycotoxin research methodology.

The collaborative project was initiated and built on previously successful collaboration that developed during the ACIAR projects listed in the project details above.

The main agencies involved in Indonesia were:

- Indonesian Legumes and Tuber Crops Research Institute (ILETRI)
- Southeast Asian Regional Centre for Tropical Biology (SEAMEO BIOTROP), Bogor, Indonesia
- Veterinary Research Institute (BALITVET), Bogor, Indonesia
- Faculty of Agricultural Technology, Gajah Mada University (GMU), Yogyakarta, Indonesia
- Balai Pengkajan Teknologi Pertanian (BPTP) (Assessment Institute for Agricultural Technology).

In Australia, the main agencies involved included:

- Department of Employment, Economic Development and Innovation (DEEDI), Queensland
- Department of Agricultural Chemistry and Soil Science, University of Sydney.

Outputs—what the project produced

The project uncovered compelling evidence on the alarming extent of aflatoxin contamination in Indonesian peanuts through implementing strategic surveys and quantifying aflatoxin levels at various points throughout the peanut supply chain. The results clearly showed that the main point of contamination occurs in the retail sector and particularly in the 'wet' markets.

High *A. flavus* contamination in fresh peanut kernels at the farm and collector level clearly demonstrated that, while aflatoxin levels may be low on farm, the high levels of kernel *A. flavus* infection (up to 100% in certain situations) can subsequently lead to a rapid increase in aflatoxin levels under poor storage conditions.

The varietal trials conducted by ILETRI led to the identification of a new variety (GH 51) with tolerance to aflatoxin contamination. This variety is in the final stages of multilocation testing by Garuda Food Ltd before being released for commercial production in Central Java.

A computer-based decision-support tool ('Whopper Cropper') for assessment of preharvest aflatoxin risk throughout Indonesian peanut production areas was developed and supplied to collaborating Indonesian scientists.

Biocontrol technology using non-toxigenic strains of *A. flavus* to control on-farm aflatoxin contamination was tested in Australia and shown to have highly variable results, depending on initial native inoculum levels in the soil and those achieved after application of the biocontrol treatment.

A low-cost ELISA analytical system to detect aflatoxin B_1 was established at three Indonesian research centres and project scientists were trained in the ELISA analysis and associated quality-assurance (QA) checks.

Socioeconomic and peanut supply-chain surveys conducted within different peanut production regions highlighted a potential link between socioeconomic status and human health impacts in Indonesia. There is huge potential for the poorer sections of the Indonesian community to become exposed to and ingest higher levels of aflatoxin, owing to either lower prices charged for visually affected (and hence high aflatoxin contaminated) kernels, or the crushing of these highly contaminated kernels into peanut sauces (e.g. *satee*, *bumbu pecel*) that are sold at lower prices in the traditional 'wet' markets.

A market trader in Pati, Central Java, grading fungal-affected and healthy peanut kernels. (Photo: G. Wright)

The project successfully initiated an aflatoxin-awareness program by disseminating aflatoxin-related information at field days, in brochures and through participation in high-level government meetings, which subsequently led to the establishment of a large national program named the 'Aflatoxin Forum Indonesia' (AFI).

Capacity developed by the project

Project personnel acquired skills in aflatoxin and *A. flavus* analytical techniques, including ELISA methods and QA systems, which resulted in the reporting of high-quality aflatoxin data in peanut supply-chain surveys.

Project scientists have developed an improved understanding of the factors affecting aflatoxin contamination in the field, in storage and throughout the supply chain.

The project has been successful in creating a network of researchers, and extension and policy agencies working on aflatoxin throughout Indonesia, which has subsequently led to significant exchange of information and ideas related to research on aflatoxin, and mycotoxins more generally.

The project has led to an improved organisational capacity to undertake strategic and applied research on aflatoxin, as evidenced by significant external funding secured by project personnel for aflatoxin risk studies after completion of the project.

Adoption—how the project outputs are being used

Researchers and policymakers are making use of the information generated in this project on aflatoxin contamination in the Indonesian peanut food chain. ILETRI, SEAMEO BIOTROP and GMU collaborators are now considered aflatoxin experts at the national level, and are regularly invited to give talks, seminars and other presentations at regional and national food safety conferences and workshops, to raise awareness about the aflatoxin contamination problem in the peanut supply chain.

The finding that high on-farm levels of *A. flavus* contamination are the key source of subsequent postharvest aflatoxin contamination is being used by researchers, but its significance as the major cause of aflatoxin production under poor storage conditions and the subsequent occurrence of the toxin in peanut food products in the retail and consumer end of the supply chain is grossly underestimated by all sectors of the peanut food chain.

As a result of varietal trials conducted within this project, a new peanut variety (GH 51) developed at ILETRI with reputed tolerance to aflatoxin contamination has been identified. Garuda Food has indicated it will commercialise this variety and has initiated field trials at various locations to assess its yield and aflatoxin contamination.

A computer-based decision-support tool for assessing aflatoxin risk in Indonesian peanut production areas has been developed, but it is not being used widely by researchers due to unavailability of the high-quality climate data required to run the peanut/aflatoxin model simulations for various target locations.

Evaluation of biocontrol technology to control on-farm aflatoxin in Australia will remain as a research output, and is unlikely to be adopted commercially due to major concerns with reliability, liability and cost-effectiveness.

Low-cost ELISA systems to detect aflatoxin B1, established at three Indonesian research centres, have had significant adoption by project researchers and research institutions. SEAMEO BIOTROP and BALIVET, in particular, routinely use this technology for aflatoxin monitoring in the peanut and other crop supply chains. Scientists from GMU have developed further capacity in aflatoxin research and will soon be identified as an accredited laboratory for aflatoxin analysis in Indonesia. Staff at various research centres have received QA training.

Dissemination of information on aflatoxin incidence and its management generated by the project has led to significant adoption by research and extension agencies, as well as to the creation of the large AFI extension network program. AFI involves all peanut supply-chain stakeholders as well as government policy officers. It will play a key role in developing and implementing policy measures aimed at keeping aflatoxin levels below a set maximum residue limit (MRL), without creating panic among supply-chain players and consumers.

Impact—the difference the project has made or is expected to make

The quantification of actual, and potential for, aflatoxin contamination throughout the peanut food chain has established a clear link between agriculture and human health. This presents compelling justification for further action from national and provincial governments to develop and implement appropriate policy measures to reduce its impact throughout the Indonesian community.

Expertise in aflatoxin research gained by project scientists enabled them to work with the National Agency for Drug and Food Control (NAFDC) to assess the risk to consumers from long-term ingestion of high levels of aflatoxin-contaminated peanuts and maize. As a result of the increased awareness on impacts of aflatoxin on human health and alarming levels of aflatoxin contamination in the peanut food chain, the Government of Indonesia has formally announced a revision of the MRL for aflatoxin in human food to 15 parts per billion. This regulatory change was a first for the country, and was made in close consultation with Indonesian project scientists. However, the next step is to develop and implement strategic operational policy measures for implementing this MRL, without causing undue financial stress for peanut traders and fear among the community.

Expertise developed by project scientists has resulted in the establishment of a national/international proficiency testing system for aflatoxin, as part of the Centre of Excellence on Mycotoxin Studies (CEMYCOS) involving five institutions: GMU, SEAMEO BIOTROP, BALITVET, NAFDC and Singapore company Romer Labs). This QA system will greatly improve the accuracy of aflatoxin/mycotoxin testing in Indonesia.

The broad membership of AFI, which includes researchers, private research and development (R&D) agencies, grower groups and food and drug regulatory authorities from the central government, allows effective exchange of information on aflatoxin research and the management and impacts of the toxin.

The project resulted in significant benefits for the Australian peanut industry:

- It identified that the DEEDI-developed peanut variety Streeton is tolerant to aflatoxin contamination. This tolerance has been associated with various physiological traits, including better dehydration tolerance, quicker and more uniform pod drying and superior shell integrity. This has resulted in a major varietal shift in the dryland peanut region from longer duration, drought-susceptible types such as NC 7 (22–24 weeks to maturity) to earlier maturing, drought tolerant types such as Streeton (18–20 weeks) and led to the recent release of two new, ultra-early, high oleic varieties, Walter (2007) and Tingoora (2010), which take only 15–16 weeks to mature.
- The R&D conducted within the project led to the formulation of an integrated agronomic package for on-farm aflatoxin-minimisation practices. The package was widely implemented by dryland peanut growers, with the Peanut Company of Australia supporting price incentives for adoption of the aflatoxin management practices. This research demonstrated that aflatoxin contamination can be minimised but not eliminated by following these best-management practices.
- The project led to the development of a computer-based aflatoxin monitoring and management decision-support system to assess on-farm aflatoxin risk using in-season weather data plus crop and soil parameters, in conjunction with the Agricultural Production Systems Simulator (APSIM) peanut crop model. This ultimately led to the development of 'AFLOMAN', a user-friendly internet-based aflatoxin monitoring and decision-support system for growers—see www.apsim.info/afloman.
- The project led to the fostering of collaboration with the University of New South Wales (Dr Robert Driscoll and Dr George Srzednicki) to develop a computer-based peanut-drying model that can assist in minimising postharvest aflatoxin levels and quality losses in peanuts associated with under- or overdrying. It is expected that the model will significantly improve the performance of drying machines in the Australian peanut industry.

Management strategies for enhanced fisheries production in Sri Lankan and Australian lakes and reservoirs—extension project (FIS/2001/030)

Sena S. De Silva

Project number	FIS/2001/030
Project name	Management strategies for enhanced fisheries production in Sri Lankan and Australian lakes and reservoirs—extension project
Collaborating institutions	Australia: Deakin University Sri Lanka: Kelaniya University; National Aquaculture Development Authority (NAqDA); National Aquatic Resources Research and Development Agency (NARA); University of Peradeniya
Project leaders	Australia: Sena S. De Silva, Deakin University Sri Lanka: Upali S. Amarasinghe, Kelaniya University
Duration	1 January 2001 – 30 June 2005
Budget	Total A$390,183 (ACIAR contribution: A$295,183) (FIS/1994/040 was extended and given a new number, FIS/2001/030. The budget for FIS/1994/040 was $420,880.)
Countries	Australia, Sri Lanka
Commodity	Fish
Related projects	FIS/2001/013, FIS/2005/078

Motivation for the project and what it aimed to achieve

The project 'Management strategies for enhanced fisheries production in Sri Lankan and Australian lakes and reservoirs—extension project' (FIS/2001/030) was a logical extension of a previous project (FIS/1994/040) with the same primary name that had begun in 1997. An independent review in 2000 strongly recommended continuation of certain facets of the initial work, and the new 'extension' project (FIS/2001/030) was completed in 2005. Related projects designed to enhance reservoir fishery production were also undertaken subsequently in Vietnam (FIS/2001/013: Culture-based and capture fisheries development and management in reservoirs in Vietnam) and Laos (FIS/2005/078: Culture-based fisheries development in Lao PDR), primarily driven by the success of the work in Sri Lanka and acceptance by other governments in the region that culture-based fisheries (CBF) are an appropriate strategy to improve fish yields in rural areas, benefiting these communities.

In particular, the management strategies for enhanced fisheries production in Sri Lankan and Australian lakes and reservoirs project entailed two major components in Sri Lanka:

1. development of improved management measures for the existing reservoir capture fisheries
2. development of CBF using hatchery-bred juveniles stocked in non-perennial/seasonal reservoirs (locally referred to as village tanks), including related work on improvements to cage rearing of hatchery-bred juveniles in perennial reservoirs.

A partial harvest from a culture-based fisheries reservoir 4 months after stocking. Depending on the size of the water body, such partial harvests will be carried out as water levels begin to recede. (Photo: S. De Silva)

Component 1 set out to validate a geographical information system (GIS)–based model developed for yield prediction for capture fisheries in perennial reservoirs. In the validation, data collated by the NARA, the research arm of the Ministry of Fisheries and Aquatic Resources Development, were used to add rigour to the fishery yield-prediction models developed. The validated models were to be used for introducing improved, science-based management measures for sustained use of the reservoir fishery resources.

The overall aim of component 2, on CBF, was to develop a best-practice model for popularising CBF in seasonal tanks/non-perennial, small water bodies (estimated to total around 30,000 ha) in the dry zone of Sri Lanka, aligning it with one of the major inland fisheries development strategies adopted by the Government of Sri Lanka and other regional governments (e.g. Vietnam and Lao PDR), and associated development agencies active in Sri Lanka (e.g. the Rural Development Project of the North Central Province and the Asian Development Bank). That is, the aim was to promote the optimal and sustained use of seasonal reservoirs for fish production by local communities, using a stock and recapture (CBF) strategy.

Outputs—what the project produced

Development of predictive yield models (component 1)

(a) Using GIS, predictive yield models were developed in which the fish yields were found to be closely related to catchment characteristics, such as forest cover, grasslands etc. Statistical robustness of the developed models was enhanced by applying the datasets independently collected by NARA. The robustness and acceptance of the models were tested through publication of the findings in peer-reviewed major international fisheries journals.[1]

(b) The findings of the models on potential yield and the optimal number of craft that should be permitted to operate in each of the large perennial reservoirs (>750 ha) were provided to NAqDA for perusal, consideration and implementation.

Culture-based fisheries development (component 2)

GIS-based modelling expertise was used to develop guidelines for selection of non-perennial reservoirs for CBF developments, and a set of science-based criteria was developed for determining optimal stocking densities, species combinations etc.

1 Nissanka C., Amarasinghe U.S. and De Silva S.S. 2000. Yield predictive models for the Sri Lankan reservoir fisheries. Fisheries Management and Ecology 7, 425–436.

De Silva S.S., Amarasinghe U.S., Nissanka C., Wijesooriya W.A.D.D. and Fernando M.J.J. 2001. Use of geographical information systems as a tool for fish yield prediction in tropical reservoirs: case study on Sri Lankan reservoirs. Fisheries Management and Ecology 8, 47–60.

Amarasinghe U.S., De Silva S.S. and Nissanka C. 2002. Evaluation of the robustness of predictive yield models based on catchment characteristics using GIS for reservoir fisheries in Sri Lanka. Fisheries Management and Ecology 9, 293–302.

Based on the above, farmer-based trials were successfully completed (two cycles). Subsequently, all the information was collated and disseminated in printed and electronic (DVD) form. Most of the findings were published in peer-reviewed international journals,[2] thereby supporting their scientific robustness. One of the most significant achievements of the project was bringing about a policy change through the amendment of the Agrarian Act No. 240 of 2000 that legalised fishery-related activities in minor, non-perennial reservoirs. This, in turn, enabled the communities to access insurance schemes, and to make suitable modifications to the water bodies to facilitate fishery-related activities, such as placing netting around sluices to prevent fish losses.

Adoption—how the project outputs are being used

Predictive yield models (component 1)

According to NAqDA sources, the managerial measures are now practised in most of the 130,000 ha of perennial reservoirs in which there are fisheries. As the reservoirs are densely distributed, requests to fishers to move from one reservoir in which the numbers operating were more than desired to another where the fishing pressure could be stepped-up were generally met.

The adoption of the project findings has been a component of a suite of measures that has been introduced by NAqDA, including the strict implementation of the fishing gear regulations and so forth. Overall, there has been a significant increase in inland fish production as result of all these measures (Table 1). A recent detailed study on two reservoirs has shown the measures that lead to the increased fish production,[3] a trend that is likely to continue. In addition, the project permitted the retesting of the establishment of a fishery for 'minor cyprinids'—indigenous, self-recruiting, small fishes. As a consequence, NAqDA is in the process of permitting the establishment of a fishery (on a trial basis) and the required amendments to the gear regulations have been put forward. These developments will likely lead to a further increase in fish production.

2 Jayasinghe U.A.D, Amarasinghe U.S. and De Silva S.S. 2005. Limnology and culture-based fisheries in non-perennial reservoirs of Sri Lanka. Lakes and Reservoirs: Research and Development 10, 157–166.

Jayasinghe U.A.D, Amarasinghe U.S. and De Silva S.S. 2005. Trophic classification of non-perennial reservoirs utilized for the development of culture-based fisheries, Sri Lanka. International Reviews of Hydrobiology 90, 209–222.

Wijenayake W.M.H.K., Jayasinghe U.A.D., Amarasinghe U.S., Athula J.A., Pushpalatha K.B.C. and De Silva S.S. 2005. Culture-based fisheries in non-perennial reservoirs in Sri Lanka: production and relative performance of stocked species. Fisheries Management and Ecology 12, 249–258.

Jayasinghe U.A.D., Amarasinghe U.S. and De Silva, S.S. 2006. Culture-based fisheries in non-perennial reservoirs of Sri Lanka: influence of reservoir morphometry and stocking density on yield. Fisheries Management and Ecology 13, 157–164.

3 Kulatilake M., Liyanage H.S.W.A., Fernando W.M.J.R., Chandrasoma J. and Van der Knaap M. 2010. Development of co-management in the inland fisheries in Sri Lanka: case studies of Senenayake Samudra and Mahavilachchiya reservoirs. Aquatic Ecosystem Health and Management 13, 281–287.

Table 1. Trends in inland fish production in Sri Lanka

Year	Production (tonnes)	Year	Production (tonnes)
1999	31,450	2005	32,830
2000	36,700	2006	35,290
2001	29,870	2007	38,380
2002	28,130	2008	44,490
2003	30,280	2009	46,560
2004	33,180	2010	52,410

Source: based on data from <http://www.naqda.gov.lk/inland_Aquaculture.php>

A silver carp at harvest, weighing approximately 1.5 kg, which it attained in 6 months from the time of stocking (at 10–20 g). Silver carps are one of the main species used in culture-based fisheries in Sri Lanka and elsewhere in the region. (Photo: S. De Silva)

Culture-based fisheries development (component 2)

The informational material developed for the project and used widely for promoting CBF among rural communities also stimulated the production by NAqDA of educational videos on CBF that were broadcast nationally at prime times. All these videos are also used by NAqDA for transmission of information at village-level meetings on extension of CBF practices.

The methods based on GIS for selection of non-perennial reservoirs are being used by NAqDA, which is pursuing development of CBF through the dry zone of Sri Lanka as a major development strategy for food-fish production in rural areas. The number of farmer communities undertaking CBF development in the water bodies allocated to them for management has increased significantly over the years, with a consequent increase in food-fish supplies and income generation for the communities. The encouragement initiated by the project to make savings from the first year harvest toward procurement of fingerlings for the next cycle and so on, is a principle that was also encouraged by NAqDA when it started on CBF development and extension. Much progress has been made in this regard, bringing self-sufficiency to communities to meet seed-stock needs.

Impact—the difference the project has made or is expected to make

The adoption of the managerial measures, apart from increasing reservoir fish production and its sustainability, also has had an indirect impact on the strengthening and functioning of the reservoir fishery societies and, indeed, have stimulated the formation of societies where these were lacking. Currently, 46 reservoir fishery societies are established and functional, covering 40 reservoirs with a total area of 74,463 ha (NAqDA, pers. comm.). These societies function as 'watchdogs' for each of the reservoirs, ensuring proper management.

NAqDA has proceeded to make a policy change, and new inland fishing gear regulations (Fisheries and Aquatic Resources Act No. 2 of 1996) are to be enacted soon, permitting a well-managed fishery for minor cyprinids to be established in medium and large perennial reservoirs in Sri Lanka. This will result in a substantial increase in reservoir fish production, provide rural populations with an alternative, nutritious, low-cost food-fish source and additional livelihood opportunities, and contribute to food security.

Component 1 of project has had spillover impacts, such as stimulating other donors to recognise the importance of reservoir fisheries as a provider of livelihoods, rural income generation and improvement of nutrition in rural populations in Sri Lanka and elsewhere in the region. In this context, the Icelandic International Development Agency (ICEIDA) funded 'Strategies for development of Asian reservoir and lake fisheries', a regional project coordinated by the Network of Aquaculture Centres in Asia–Pacific, 2007–2010 (details at: <http://www.enaca.org/modules/inlandprojects/index.php?content_id=4>).

All this has raised the profile of Asian reservoir and lake fisheries, which, overall, are a very significant contributor to global inland fish production of 10 million tonnes/year. This will encourage and facilitate research and development (R&D) in this sector, thereby in the long term resulting in increased fish yields and sustainability of the sector.

The major impact of component 2, CBF, has been through more communities embracing the activities, resulting in significant income gains to them and increased food production (Figure 1). Bearing in mind that the introduction of CBF to farming communities is a relatively slow process, the trend is encouraging and significant. If, as is expected, this trend continues, with NAqDA emphasising and recognising CBF as a major strategy for increasing inland fish production, particularly in rural areas, inland fish production is likely to exceed marine production by 2015, as planned by the Government of Sri Lanka (Dr Damitha de Zoysa, Secretary, Ministry of Fisheries and Aquatic Resources Development, pers. comm., December 2010). These developments also have triggered individual and/or corporate (e.g. fishery societies) entrepreneurship to embark on fry-to-fingerling rearing as a means of livelihood support, thereby aiding the removal of the bottleneck affecting fingerling availability for CBF.

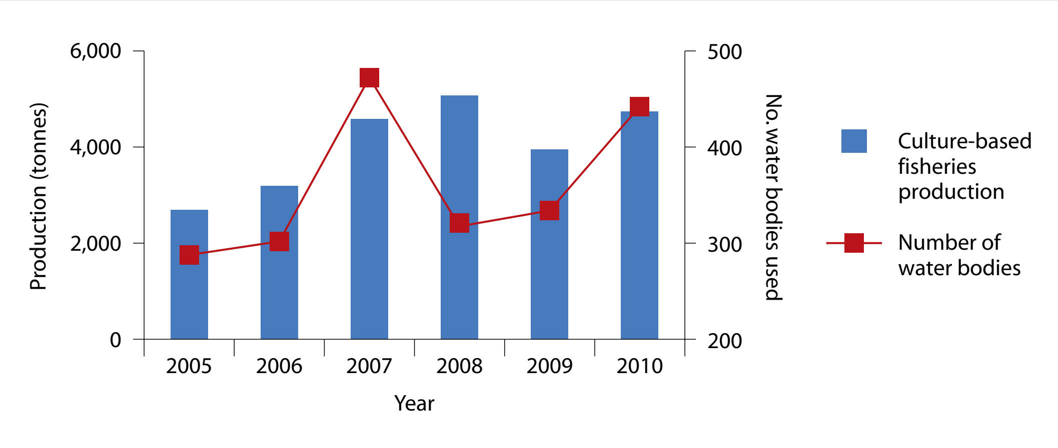


Figure 1. Trends in culture-based fisheries (CBF) production and water-body use for CBF in Sri Lanka.

Realisation of the importance of CBF as a strategy for increasing food-fish production and contributing to income generation and improvements of livelihoods has spread far and wide in the region. This new activity led to a request to ACIAR from Vietnam and Lao PDR for support for R&D on CBF in those countries, resulting in ACIAR-funded studies that have had similar outcomes to those reported for Sri Lanka. Cambodia and Indonesia also have sought such support. All in all, there is a marked recognition in Asia that CBF are a most appropriate strategy for food-fish production that will contribute to improving the livelihoods and nutrition of rural populations.

This component also had spillover effects: the Norwegian Agency for Development (Norad), recognising the importance of CBF as an important rural activity, has funded a study to evaluate the climate change impacts on CBF; this is an important and a useful study, particularly so as the whole CBF cycle of activities is dependent on climate—primarily the rainfall patterns. It is expected that as a result of this study a re-evaluation will be made on the methods/criteria used for determining the suitability of perennial water bodies for CBF.

The importance of CBF to Sri Lankan fisheries production is further evidenced by the fact that NAqDA is planning to provide statistics on CBF production as a separate entity, an initiative that has been welcomed by the Food and Agriculture Organization of the United Nations (FAO) Statistical Collection unit (NAqDA Chairman, pers. comm.). This is perhaps the first step in the recognition of CBF as a significant contributor to global food-fish production.

In some countries, such as Lao PDR, the whole village community participates in harvesting culture-based fisheries. Households often purchase nominally priced 'tickets' to participate. The household is free to sell or use the catch, and the ticket sale proceedings are used for communal activities, including improvements to dykes, sluices and other water-body utilities. (Photo: S. De Silva)

An unquantifiable but very significant impact of the project was capacity building among researchers, extension officers and fisheries inspectors of NAqDA on CBF and fisheries management per se and, even more importantly, among the many hundreds of farmers who were rice cultivators formerly, who were literally co-opted into CBF activities through the respective cultivation committees of each of the non-perennial reservoirs. Former project research staff continue to collaborate with NAqDA on continuation of CBF activities in the country, albeit to varying degrees. Importantly, CBF has become a component of the curriculum at under- and postgraduate level in a number of universities, training the scientists who can occupy the job opportunities that will arise as CBF and inland fisheries as a whole become increasingly important to the economy of the country.

Perhaps the only deficiency in the project and the adoption of its results is a lack of understanding of gender engagement in the activities, and the benefits to females. This is a lapse in inland fisheries research in general although it is estimated that the nearly 60 million people who are involved in it globally are mostly women and rural poor.[4] It is suggested that, now that both minor cyprinid fisheries are to be legalised and CBF is on a firm footing, a small study dedicated to gender issues in these activities would be useful.

4 Beard T.D., Arlinghaus R., Cooke S.J., McIntyre P., De Silva S., Bartley D. and Cowx I.G. 2011. Ecosystem approach to inland fisheries: research needs and implementation strategies. Biology Letters, at <http://dx.doi.org/10.1098/rsbl.2011.0046>.

Biology and status of the prawn stocks and trawl fishery in the Gulf of Papua (FIS/2002/056)

David Milton

Project number	FIS/2002/056
Project name	Biology and status of the prawn stocks and trawl fishery in the Gulf of Papua
Collaborating institutions	Australia: Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine and Atmospheric Research; University of Tasmania Papua New Guinea: Papua New Guinea National Fisheries Authority (NFA)
Project leaders	Australia: Dr David Milton Papua New Guinea: Mr Augustine Mobiha
Duration of project	1 July 2003 – 31 December 2006
Funding	Total A$ 849,051 (ACIAR contribution: A$479,679)
Countries	Papua New Guinea, Australia
Commodities	Prawns and other fishes
Related projects	FIS/1996/081, ASEM/2002/050

Motivation for the project and what it aimed to achieve

The Gulf of Papua (GOP) prawn fishery is one of the most valuable fisheries in Papua New Guinea (PNG). Catches have fluctuated widely and there has been limited success in assessing sustainable yields. The trends in catches and catch rates in the fishery were declining in the early 2000s. To maintain their economic viability, fishers were increasing their illegal trawling inshore within the 3 nautical mile (5.6 km) traditional fishery zone. In the late 1990s, irate villagers took the situation into their own hands and boarded vessels illegally fishing within the traditional fishery zone and confiscated their catch. Fishery-independent surveys were needed so the PNG NFA could understand the reasons behind this conflict and the effect of this illegal fishing on the prawn stocks.

The previous GOP prawn fishery management plan was gazetted in 1997. It advocated the development of a 20-vessel inshore fishery for traditional owners. Eager provincial politicians were beginning to actively canvass for funding for such a fishery in the early 2000s. Scientists at NFA were concerned about the potential for this fishery to catch recruits of the offshore commercial fishery and thus lead to overfishing of the prawn populations. In order to assess these concerns and establish the effect of any new inshore fishery on the existing commercial fishery, a detailed analysis of existing commercial logbook catch data was needed, along with fishery-independent surveys to map the distribution and abundance of adult and juvenile prawns in the GOP.

Outputs—what the project produced

Technical outputs

There were several technical outputs from the project:

- demonstration that the densities of immature and adult prawns were 30% higher within the 3 nautical mile traditional fishery zone, and that about one-third of the prawn catch has come from that zone since the fishery began
- access to the 3 nautical mile traditional fishery zone by the industrial fishery will not increase the risk of overfishing if the total catch remains below 480 tonnes of banana prawns
- the prawn species composition within the fishing grounds was strongly structured in relation to terrestrial run-off and bottom sediment type
- immature prawns are recruited to the fishery throughout the year, form a substantial component of the catch and are impossible to avoid, but the economic return from the fishery could increase if fishing within the 3 nautical mile traditional fishery zone occurred after midyear (July), as fewer immature prawns are present then
- the maximum biological yield of the two target species in the fishery was estimated to be 480 tonnes of banana prawns and 110 tonnes of black tiger prawns.

Lunchtime for the project team during the annual project coordination meeting in October 2004, which was held at Loloata Dive Resort off Port Moresby, Papua New Guinea. (Photo: D. Milton)

Policy outputs

The main planned policy outputs from the project were:

- recommendations to NFA on new management measures to improve the economic and biological sustainability of the industrial prawn trawl fishery. These recommendations have all been incorporated in a new GOP prawn fishery management plan that was gazetted in 2008.
- advice on the feasibility and viability of an inshore small-vessel fishery operated by the traditional resource owners. This fishery was not considered feasible due to the rough weather in the region and the relatively high cost of entry. Alternative access arrangements were proposed whereby industrial vessels fished within the traditional fisheries zone after negotiating an acceptable access fee. These arrangements have been included in the new management plan, but have not been taken up by the fishery to date.
- a mechanism for NFA to set the total allowable catch from the fishery and to adjust it based on the catch of the previous year.

Capacity building

The capacity of fisheries management and data management staff within NFA was greatly enhanced through their involvement in the project. The NFA fishery managers now have the capacity to plan, organise and undertake fishery-independent surveys in any fishery. NFA has undertaken two fishery-independent surveys in the GOP prawn fishery since the project was completed. One of the staff employed on the project has now become a manager of sedentary fisheries and undertakes similar surveys for bêche-de-mer (sea cucumber).

Data-checking and quality-assurance routines developed by the project are still being used in the entry of the GOP prawn fishery logbook data. Licensing staff have expanded their use of these approaches to their management of data from several other marine fisheries in PNG. The logbook database is being maintained and kept up-to-date by entry staff through processes developed during the project. NFA has the capacity to implement the total allowable catch estimation if required.

Adoption—how the project outputs are being used

The main technical and policy outputs from the project have been used to develop a new GOP prawn fishery management plan. This plan was gazetted in late 2008 and includes all the major recommendations from the project. The new plan has made several changes to the management regulations of the fishery from the previous plan of 1997. The old plan had recommended 15 fishing licences. This has been reduced to 10, to maximise the economic yield from the fishery. These licences will now be valid for 5 years, which is a substantial increase from the annual licence that was available under the previous plan. This change was intended to increase the value of the licence and thus allow operators to borrow funds against this value and upgrade fishing vessels under more favourable financial terms. Access to the 3 nautical mile traditional fishery zone is no longer illegal under the new plan if operators negotiate an access agreement with the traditional resource owners. This change is intended to (a) legalise access for the industrial fishery to the more productive inshore waters and (b) provide some income for remote coastal communities from the trawling that has occurred in their waters.

Since the project, the costs of fishing have continued to increase and prawn prices have remained stable. This has forced the least efficient operators out of the fishery as their economic return declined. In 2011, the fishery still has 15 licences, but only six vessels are actively fishing. The fees for the remaining licences have

Mr Barre Kare, Prawn Fisheries Manager, National Fisheries Authority of Papua New Guinea, with several red snapper caught during a fishery-independent prawn trawl survey in the Gulf of Papua, Papua New Guinea. (Photo: D. Milton)

Mr Barre Kare and Ms Luanah Yaman from the National Fisheries Authority of Papua New Guinea surveying a typical prawn trawl catch with one of the fishing crew during the fishery-independent prawn trawl survey in the Gulf of Papua in 2005. (Photo: D. Milton)

been paid but the vessels have remained in port. Thus, although the reduction in licences outlined in the new management plan has not been implemented, the economics of the fishery has had the desired effect of reducing effective fishing effort. It also has meant that the active fishers have had higher catch rates and their profitability has increased. Two new vessels have been purchased by a new company that entered the fishery in 2009 and these are proving much more reliable and effective than the other, older vessels.

Impact—the difference the project has made or is expected to make

The main direct impacts of the project have been in the changes in the management structure of the fishery (through its management plan) to improve its economic and biological sustainability. These changes have not all been completely implemented, and the economic environment of the fishery has also remained subdued. These external factors have a strong influence on incentives to adopt the outputs fully. This is particularly true of the negotiated access provisions in the new management plan. These provisions have the ability to generate an economic return to coastal communities from their traditional resources extracted by the industrial fishery. Rather than being a source of tension between coastal communities and the fishing industry, these access agreements can facilitate and improve the economic returns to the industry by increasing access to the larger prawn resources inside the 3 nautical mile traditional fishery zone. However, the industry is wary of entering any agreements, due to the unrealistic expectations of the coastal communities involved. The likely financial returns may not be sufficient to cover the access fees demanded. The fishing fleet of six vessels currently active probably has high catch rates without the additional expense (risk) of negotiating access to the inshore zones. Thus, the current economic environment is constraining the fishery and stopping the community from gaining any income from the

Ms Luanah Yaman from the National Fisheries Authority of Papua New Guinea showing the bottom fishing gear on the prawn trawl net used during a project fishery-independent survey in 2005. (Photo: D. Milton)

exploitation of their prawn resources. The price for prawns would appear to need to increase substantially before there was sufficient incentive for additional investment in the fishery and negotiation of an access agreement.

The most effective adoption of outputs from the project has been within the management of the fishery by NFA. The changes made to the prawn fishery daily logbook entry system and the quality-control checks implemented by the project have been very successful. These are major advances from the data system in place at the inception of the project. At that time, the method of entering the logbook catch data was so detailed and complex that the entry staff could not keep up with the rate of logbook submissions. The project was instrumental in streamlining the entry forms to allow processing of the critical data for population assessment in a timely manner. The quality of these data has also been greatly enhanced through the provision of new data check systems that have dramatically reduced the number of errors in the logbooks. Furthermore, the new systems have led to improved liaison between the licensing section in NFA and the fishing companies. Logbook returns being completed by fishing skippers have much fewer errors, and specific concerns or inconsistencies can be readily dealt with in a very short time.

High-performance eucalypts and interspecific hybrids for marginal lands in south and eastern South Africa and south-eastern Australia (FST/1996/124)

Peter Kanowski and Stephen Verryn

Project number	FST/1996/124
Project name	High-performance eucalypts and interspecific hybrids for marginal lands in south and eastern South Africa and south-eastern Australia
Collaborating institutions	Australia: Australian National University (ANU); Commonwealth Scientific and Industrial Research Organisation (CSIRO); Forests NSW South Africa: Council for Scientific and Industrial Research (CSIR) Environmentek; University of Stellenbosch (US)
Project leaders	Australia: Professor Peter Kanowski (ANU), Dr Chris Harwood (CSIRO); Mr Michael Henson (Forests NSW, New South Wales) South Africa: Dr Steve Verryn (CSIR); Professor Gerrit van Wyk (US)
Duration of project	1 July 2002 – 31 March 2007
Funding	Total A$2,8094,96 (ACIAR contribution: A$1,024,637)
Countries	Australia, South Africa
Commodity	Timber
Related projects	FST/1996/125, FST/1998/096

Motivation for the project and what it aimed to achieve

The project was motivated by the challenges faced by farmers in the more marginal (lower rainfall, poorer sites) environments of southern Australia and South Africa in accessing eucalypt germplasm suitable for commercial tree-growing on their properties. South African tree breeders had developed hybrid breeds that showed promise on these sites, but they were based on a limited genetic base; Australian work with eucalypt genetic improvement of pure species and hybrids was less advanced, but breeders had access to a much wider range of germplasm. In both countries, there were strong policy imperatives and emerging commercial opportunities to expand afforestation in these marginal environments.

The project had a lengthy gestation. Scientists from three of the research agencies involved (CSIR, CSIRO and the University of Stellenbosch) had prior working relationships around eucalypt genetic resources and breeding; those from ANU and Forests NSW had been working on related topics. All parties were brought together to develop the project by ACIAR's Forestry Program Manager.

In these contexts, the project aimed to: enhance the genetic base of South African eucalypt breeding populations; test new pure and hybrid genetic resources in both countries; develop new technologies to propagate eucalypts; improve knowledge of the reproductive biology of some species and of breeding strategies for hybrids; and build the capacity of scientists and organisations to continue work that developed eucalypts for marginal farmlands.

Outputs—what the project produced

The project produced principally technical and capacity outputs, but also some policy outputs.

Technical outputs

Technical outputs comprised genetic resources and breeds, propagation systems and genetic knowledge.

Genetic resources

The project introduced into South Africa the first comprehensive pedigreed genetic resources of four eucalypt species of current or potential commercial importance: *Eucalyptus cladocalyx, E. gomphocephala, E. longirostrata* and *E. urophylla*. These resources are significant because of the current or prospective roles of each of these species in South Africa and the limited base populations from which South African breeding populations had been developed.

The project supported production of about 200 hybrid families of crosses between South African *E. grandis* parents, the parental species for most commercially important eucalypt hybrids in South Africa, and a broad sample of *E. camaldulensis* provenances. Small numbers of other hybrids (*E. grandis* × *E. resinifera* and *E. grandis* × *E. tereticornis*) were also produced, but attempts to generate new hybrids with *E. cladocalyx* and *E. gomphocephala* were not successful. These hybrid families are important because interspecific eucalypt hybrids are demonstrably superior to pure species on many South African sites, but exploration of the

Eucalyptus grandis × *E. camaldulensis*, developed by the project, at a trial site at Milverton, Limpopo province. The 5-year-old trees show significant genetic variation. In the picture are (left) CSIR tree breeder Christopher Komakech and former CSIR Project Manager Dr Stephen Verryn. (Photo: P. Kanowski)

potential of these hybrids has been constrained by limited access to the genetic resources of parental species. Project provision of 45 families from seven provenances of *E. camaldulensis* represented the first broad sample of *E. camaldulensis* parents available to South African breeders for testing in hybrid combination.

Propagation systems

Eucalypt vegetative propagation technologies were developed on a pilot scale by both CSIR and the University of Stellenbosch. CSIR developed three prototypes of a low-technology portable propagator intended to be suitable for use by community-based or small-scale enterprises, and the University of Stellenbosch developed a system for greenhouse production of rooted cuttings.

Genetic knowledge

There was relatively little knowledge of the reproductive biology of *E. cladocalyx* and *E. gomphocephala* before the project; this information is essential for tree-breeding work. The project alleviated this deficiency, more fully for *E. gomphocephala* than for *E. cladocalyx*. A substantial component of the project focused on refining genetic analysis techniques appropriate for hybrid datasets, and on applying those methods to analyses of existing datasets ('data mining') and selection of hybrid families. The outputs from this work were significant contributions to knowledge on these topics. A lesser element of the work involved creating novel, advanced hybrids; this work was conducted but results await detailed analysis.

Capacity outputs

Capacity building was a significant activity undertaken to enhance the knowledge and skills of forestry scientists. The capacity built comprised:

- enhanced knowledge about the reproductive biology of a number of eucalypt species, and about the nature of hybridity in eucalypts

- better software for the genetic analysis of hybrid populations, and experience of using that software
- enhanced learning resources for forest geneticists and tree breeders
- the incorporation of this information into the knowledge, skills and networks of the 'next generation' of forest geneticists, in both southern Africa and Australia
- prototype benchtop propagation facilities at CSIR, and greenhouse propagation systems at the University of Stellenbosch
- strengthened linkages between South African and Australian scientists.

Policy outputs

The policy outputs comprised those generated by project work on germplasm diffusion and adoption pathways. This work identified different situations for which different pathways would need to be developed, and identified specific actions that should be undertaken, in partnership with government and the forestry sector, to foster adoption. These were in the demonstration and promotion of improved genetic material, the exploration of the potential of smallholder tree-growing in South Africa's Eastern and Western Cape provinces, and the prospects for small-scale forestry as part of the land-reform process.

Controlled pollination of eucalypts is a process fundamental to the creation of eucalypt hybrids. (Photo: CSIR)

Participants in one of the tree-breeding courses that were assisted by the project. (Photo: CSIR)

Adoption—how the project outputs are being used

Project outputs associated with genetic resources of pure species and hybrid breeds remain at the intermediate stage, because of the extended times inherent in the biology and various phases of testing and breeding of eucalypts. In this context, adoption is proceeding as anticipated, and can be expected to progress to final user stage over the next 5 years. Project outputs associated with propagation technologies have not progressed beyond the stages at which they were developed in the project, either because they have not been a priority (benchtop systems) or have satisfied researchers' requirements (glasshouse systems). Project outputs associated with genetic knowledge have been adopted by the next and final users; that is, those agencies and organisations involved in breeding eucalypts in South Africa and Australia. Human capacity developed by the project has been well utilised in tree-breeding activities in southern Africa (Mozambique, South Africa, Zambia, Zimbabwe) and Australia, and in other countries in which project staff or training course participants work; these include Brazil, India, Kenya and Sri Lanka.

The underlying policy and commercial settings favouring and constraining adoption remain as they were at the time of project design and implementation. Thus, CSIR and the companies it partners in tree improvement are incorporating genetic resources project outputs into breeding and testing populations, and the genetic knowledge the project generated is being utilised in design and implementation of breeding strategies. Farmer-based tree planting in South Africa and Australia has not yet expanded in the marginal lands targeted by the project, and this has limited the immediate adoption of project outputs, although this is expected to change in the medium term.

Impact—the difference the project has made or is expected to make

Because of the inherent time lags in pathways from project activities to final users, project outputs have not yet influenced tree-growing by smallholders in South Africa. However, project outputs have enhanced the genetic resources that breeders are developing to meet smallholder needs and the breeding strategies used to generate advanced breeds.

The policy and commercial contexts for smallholder tree-growing in the regions of South Africa at which project work was directed remain positive, and the economic and social needs of smallholders in these regions remain acute. The expansion of commercial forestry can take place on any scale only in Eastern Cape and northern KwaZulu-Natal provinces, and can be accomplished only by small-scale growers. There also remains potential for small-scale tree-growing in Western Cape province, but the potential there is lower and the markets different from those elsewhere. As noted at the time of project development, both these environments are unsuitable for the established commercial tree species in South Africa. Climate change projections also suggest an emerging role for hybrid taxa, such as those developed or tested by the project, adapted to harsher environments. This anticipated afforestation is not expected to have adverse environmental impacts because it is restricted to those areas in South Africa where tree-growing has been assessed as being environmentally benign.

Community-level impacts, in terms of the adoption of new and improved genetic resources deriving from those developed by the project, and/or resulting from new or improved breeding strategies developed as a result of project activities, are not likely to be realised for at least 5 more years. By that time, the combined effects of implementation of Black Economic Empowerment and land reform policies in South Africa, the potential of smallholder tree-growing on marginal lands to contribute to economic and policy objectives, the strategic opportunities for commercial forestry investments in South Africa, and risk management for climate change, are likely to favour adoption of project outputs. The magnitude of the impacts of adoption of tree-growing by smallholders in those disadvantaged areas where it is not currently practised is difficult to quantify, but has consistently been recognised in policy reviews and planning in South Africa to be one of the few forms of economic development possible in these severely disadvantaged areas.

Concomitantly, in Australia, major policy initiatives promoting tree-growing on marginal farmlands for carbon sequestration and other benefits are currently in development. When they are implemented, they can be expected to reverse the disengagement of public policy and investment from tree-growing on marginal Australian farmlands that has characterised the period since the project concluded.

Management of postharvest diseases of tropical and subtropical fruit using their natural resistance mechanisms in Sri Lanka, the Philippines and Australia (HORT/1997/094)

Greg I. Johnson

Project number	HORT/1997/094
Project name	Management of postharvest diseases of tropical and subtropical fruit using their natural resistance mechanisms in Sri Lanka, the Philippines and Australia
Collaborating institutions	Australia: Department of Employment, Economic Development and Innovation (DEEDI), Queensland—previously the Department of Primary Industries and Fisheries Sri Lanka: Department of Agriculture, University of Peradeniya Philippines: The 2005 extension also included the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development and the University of the Philippines, Los Baños
Project leaders	Australia: Dr Lindy M. Coates and, part-time, Dr Elizabeth Dann Philippines: Dr Chrys Akem
Duration of project	1 July 2002 – 30 June 2007
Funding	Total A$1,875,420 (ACIAR contribution: A$991,909)
Countries	Sri Lanka, Australia (Philippines only after 2005)
Commodities	Mango, banana
Related projects	PHT/1983/056, PHT/1984/044, PHT/1993/093, PHT/1993/877 HORT/2003/071, HORT/2005/154, HORT/2005/153, HORT/2006/111, HORT/2005/157, SMAR/2007/193, HORT/2007/067, HORT/2006/146, HORT/2010/030, HORT/2010/006, HORT/2010/001

Motivation for the project and what it aimed to achieve

In the past three decades, many countries in Asia have promoted horticulture and export market development to increase the income of farmers as they diversify from cereal cropping. Mango and banana are important crops in much of tropical and subtropical Asia, providing income and nutrition through fresh and processed product. However, their intrinsic short shelf life and susceptibility to fruit rots reduce marketability and profits. As a consequence, the development of field and postharvest measures to reduce disease and extend shelf life of mangoes and, at times, bananas, have been a major theme of ACIAR's collaborative research investment in horticulture. Controlling or reducing disease relies on integrated crop and postharvest management, with attention to fungicide application, crop hygiene and nutrition, and the management of ripening, to optimise advantages conferred by the plant's natural resistance factors that prevent and delay disease development until the fruit ripen.

Recognising the need to reduce reliance on fungicides and enhance attention to fruit resistance and other factors, a 1997 ACIAR workshop convened in Thailand reviewed the resistance of subtropical and tropical fruit to disease, and subsequently led to the development of this project. The project capitalised on high-level expertise in mango and banana fruit resistance factors in the Sri Lankan research team, and the Australian scientists' experience with defence activators and knowledge of practical disease control and extension for the mango industry, to strengthen capabilities for managing postharvest diseases of tropical and subtropical crops using their natural resistance mechanisms.

The project evaluated the prospect of utilising inherent plant defence mechanisms in the management of postharvest diseases, focusing on mango (Australia, Sri Lanka) and banana (Sri Lanka). The key diseases were anthracnose in mango and banana, caused by *Colletotrichum gloeosporioides* and *C. musae*, respectively, and stem-end rot in mango, caused by fungi in the family Botryosphaeriaceae (*Neofusicoccum* spp., *Lasiodiplodia theobromae* etc.). A significant component was the identification and evaluation of activators of plant defences under field conditions. The activators were known resistance-inducing agents, including

Sri Lankan project leader, Professor Nimal Adikaram. (Photo: A.W. Cooke, DEEDI) acibenzolar-S-methyl (Bion®), and elicitors derived from fungal pathogens (in banana). Another component was to characterise some of the key biochemical defences contributing to the resistance, and to identify treatments, varietal properties or other agronomic practices that may influence their relative effectiveness. The final key objective was to enhance the capacity of project teams to conduct plant defence research, and provide information to respective industries via workshops and field days.

Outputs—what the project produced

Technical outputs

1. Increased understanding of the effects of defence activator treatments in mango and banana

In Sri Lanka and Australia, some treatments that activate or enhance the natural defence systems in plants, including acibenzolar-S-methyl (Bion®), salicylic acid and ultraviolet C light (UVC), showed some potential for enhancing and extending disease control for mango and banana when used within an integrated system.

The project concluded that further field trials should focus on the incorporation of Bion® into field disease-management programs, but its registration and adoption remains the decision of Syngenta, the company marketing the product. Other defence activators should be assessed as they become available. Postharvest UVC treatment should be assessed under commercial packing-line conditions.

2. Increased knowledge of how crop nutrition management and rootstock choice in mango influence postharvest disease levels

In Sri Lanka and Australia, excessive application of nitrogen during crop production was shown to result in higher levels of anthracnose in ripening mango fruit, while on low-nutrient-status soils in Sri Lanka, increased potassium nutrition reduced postharvest disease in bananas. The project concluded that the information on the level of nitrogen fertiliser application in banana and mango growing could have immediate impact if made widely available to growers and other agricultural and extension staff. In Australia, rootstock choice was shown to have potential for disease reduction.

3. In Sri Lanka and Australia, knowledge of the constitutive defences against fruit diseases and varietal differences in mango and banana was enhanced, and some insights into practical application of this knowledge were obtained.

Mango. Until this project was undertaken, mango fruit resistance to disease had been associated with the levels of resorcinols in fruit peel. The project has expanded knowledge of the role and interactions of resorcinols and cultivar differences in mango fruit resistance to anthracnose and stem-end rot, and implicated other mechanisms as preformed (galloyltannins) and induced (superoxides, H_2O_2, hypersensitive response, chitinases, peroxidase) defence mechanisms.

A significant 'world first' demonstration from Sri Lanka was to show that the galloyltannin class of compounds was a major component contributing to antifungal activity in mango peel extracts. The Sri Lankan team had first detected these compounds in 1986, but they needed the support (and equipment) from ACIAR to progress the research. The role of galloyltannins in disease resistance has not previously been reported in plants. However, they have been reported by others in studies on mango chemistry. As well, mango latex was shown to possess chitinase activity and the ability to decompose fungal spores.

Building on previous work in ACIAR projects, retention of long stems in fruit was shown to reduce disease levels in fruit by ensuring retention of antifungal resorcinols for a longer time after harvest.

Banana. In Sri Lanka, leading-edge research focused on the induced defences in banana. The occurrence of several phenylphenalone-type phytoalexins, accumulating in response to infection of banana fruit by *Phyllosticta musarum*, the pathogen causing the mild symptoms of freckle disease, confirmed earlier work by the Sri Lankan group. In subsequent research, the compounds were partially characterised, and freckle infection was also shown to induce other biochemical defences, such as pathogenesis-related proteins, phenolics and other structural defences. Most significantly, freckle infection, and the consequent induction of defences, reduced anthracnose development during ripening.

The project concluded that:

- global knowledge of natural plant defence systems and their regulation in mango and banana had been significantly enhanced by the project, and the capacity of all project teams to conduct such research had been elevated
- the cultivar × disease-resistance work could have a short-term impact if growers/industry used project information to choose or develop varieties with higher disease resistance
- assessment of fruit defence chemicals should be a routine component of disease resistance screening and postharvest storage research

Mango nursery-stock production in Sri Lanka using modern grafting techniques. (Photo: G.I. Johnson, H4D)

- in the longer term, the selection and adoption of more resistant rootstocks (mango) will be beneficial, and the understanding of biochemical defences could lead to the development of assays for screening germplasm for resistance as part of a breeding program.

Capacity outputs

Capacity building and training featured strongly in the project: PhD studies by seven students, four in Sri Lanka, and three in Australia, and an MSc in Sri Lanka, contributed significantly to project outputs. The benefits of their study and on-the-job training have also extended beyond the project, as demonstrated by their subsequent publications and research, and/or successful employment at universities. Field days (two in Sri Lanka, annually in Australia) and training activities (three workshops in Sri Lanka, two in Australia) extended outputs to the broader industry in Sri Lanka and Australia. Benefits also accrued for Indonesia and Bangladesh, the home countries of two of the students who studied in Australia.

Adoption—how the project outputs are being used

Based on project outputs and the registration of the defence-boosting treatment acibenzolar-S-methyl (Bion®) for use in Australia as a seed dressing in cotton, research to assess the application potential of defence activators has continued on mango, avocado and lychee in Australia, and on mango in the Philippines. Bion® is regarded as having potential in Australia as a combination treatment in situations of high disease pressure (e.g. during nursery propagation; after heavy rainfall; before a long storage period). However, in the Philippines, the results were variable and it was concluded that the treatment may not be cost-effective in the short term.

Following on from the project, Australian assessment of the utility of ultraviolet light treatment for control of postharvest diseases on mango or avocado has not been promising but did have some value on citrus.

While assessing defence-boosting treatments, two new diseases (mango malformation and *Cladosporium* inflorescence blight[1]) were recorded in Sri Lanka, with the latter a first record on mango in Sri Lanka.

In Sri Lankan research, some additional insights have been gained into how defence-activator treatment of bananas enhanced disease resistance.

Based on project outputs and other related Australian research, crop-management strategies and improvement in postharvest disease control through nutrition management and rootstock choice continue to be developed for commercial application in tropical and subtropical horticulture. Nutrition management and rootstock selection for disease resistance are also being assessed or promoted in ACIAR project activities in partnership with Pakistan and the Philippines.

1 Also reported by: Guillen-Sanchez D. de J., Yanez-Morales M., Teliz-Ortiz D., Siebe-Grabach C. and Bautista-Banos S. 2007. Morphological and molecular characterization of *Cladosporium tenuissimum* Cooke (Deuteromycotina: Hyphomycetes) on mango tree panicles: symptoms, pathogenicity and severity of the fungus. Fruits (Paris) 62, 361–368.

Rice planting in Sri Lanka. Mango production can provide additional income for rice farmers. (Photo: G.I. Johnson, H4D)

The importance of avoiding excessive nitrogen application during crop production to help optimise postharvest ripening and disease management has been extended to the Australian mango industry through the 'Better mangoes' program funded by Horticulture Australia.

In Sri Lanka, further work on banana has shown that the uptake of potassium in banana, and its effect on disease resistance, differed according to initial soil potassium status. Enhanced levels of potassium also resulted in flowering 5 weeks earlier than usual.

Knowledge of the constitutive defences against fruit diseases in mango and banana has been further extended, and peer-reviewed publications are making the information widely available. The findings and approaches to resorcinol assessment have also been adopted in the Australian mango-breeding program.

In Australia, as a spillover under ACIAR project HORT/2007/067[2] in the Philippines, further work to assess the retention of long stems as a means of reducing disease by retaining antifungal resorcinols in the fruit has given variable results. In Sri Lanka, retention of latex by harvesting fruit with long stalks reduced anthracnose development.

2 'Improved domestic profitability and export competitiveness of selected fruit value chains in the southern Philippines and Australia'

Since the completion of the project, further research by the Sri Lankan team has detected six phytoalexins in the peel of banana cultivar 'Embul', of which four compounds had not been reported previously. As well, the antifungal activity in eight local banana varieties following freckle infection has been assessed. However, not all observed affects correlated with cultivar resistance/susceptibility.

The global knowledge of natural plant-defence mechanisms and what affects them has been significantly enhanced by this project, and the skills and capacity of all project teams to conduct such research have been elevated.

Impact—the difference the project has made or is expected to make

This project has not yet had any substantial impact on the local farming community in Sri Lanka. The most significant impact of the project has been enhancement of research capacity, and of basic knowledge for international research on mango and banana disease-resistance mechanisms. As well, the project has yielded new insights into the changes in constitutive and induced defence mechanisms as fruit ripen and develop disease, with effects influenced by cultivar, field nutrition and rootstocks, and into the use of defence-boosting treatments.

This knowledge has already been incorporated into the teaching of plant pathology in Sri Lanka, and made accessible to a wider audience through scientific publications, review papers and international conference and workshop presentations. As a consequence of their achievements in the project, the PhD graduates in Sri Lanka have moved into teaching and research positions within Sri Lanka, while those from Australia are now continuing research and/or teaching in Queensland, Indonesia and Bangladesh. All of the graduates are using the knowledge and skills gained in the project in their new roles.

Bagging of individual mango fruit to prevent attack by fruit fly and control damage by physiological and pathological disorders. (Photo: G.I. Johnson, H4D)

Key outputs of the research on mango and banana defence systems were presented in two papers by Professor Nimal Adikaram and Dr Elizabeth Dann at the International Congress of Plant Pathology in 2008. Outputs of the work were also incorporated into a review of postharvest handling and quarantine treatments for mango by Drs Greg Johnson and Peter Hofman in the 2009 revision of the CABI monograph *The Mango*.

Knowledge from the project is also influencing the direction of mango breeding and storage research in Australia and globally, with renewed interest in incorporating aspects of the work into future ACIAR project planning. Recent interest in the measurement of the resorcinols and other defence mechanisms in mango as part of ACIAR project research was stimulated when Professor Adikaram from Sri Lanka and (former PhD student of the project) Dr Zainuri from Indonesia participated in an ACIAR-organised mango disease workshop in Darwin in May 2011. Professor Adikaram presented two review papers on mango defence systems at the workshop.

Crop-management impacts

The banana and mango nutrition findings have been incorporated into recommendations for farmers in Sri Lanka, and there has been a minor level of adoption by farmers who are producing mango for the export market, with prospects for wider adoption as Sri Lankan horticulture begins to modernise. In Australia, the nutrition recommendations have been widely adopted by mango farmers, and the information on the relative susceptibility of mango cultivars and the differences in resorcinol levels has influenced approaches to the breeding program.

Defence-boosting impacts

Information about the potential of defence-boosting treatments, particularly use of acibenzolar-S-methyl (Bion®), has supported continuing evaluation of their use in Australia. Selected defence-boosting treatments have also been tested in the Philippines (where Bion® is registered for use on mango), with mixed results.

Mango defence systems

The global research interest in resorcinols is primarily due to their presence in grains, poison ivy, cashew shell and other plant products, and their allergenic effects on humans. Thus, potential spillover of the mango defence-system research includes enhanced understanding of a group of compounds that are human allergens. However, for horticulture, the most significant opportunity is the considerable potential for enhancing mango disease control through greater understanding and management of resorcinol levels in fruit.

Coconut tissue culture for clonal propagation and safe germplasm exchange in Indonesia, Vietnam, Papua New Guinea and the Philippines (HORT/1998/061)[1]

Steve Adkins

Project number	HORT/1998/061
Project name	Coconut tissue culture for clonal propagation and safe germplasm exchange in Indonesia, Vietnam, Papua New Guinea and the Philippines
Collaborating institutions	Australia: School of Agriculture and Food Sciences, University of Queensland (UQ) Indonesia: Indonesian Coconut and Other Palms Research Institute (ICOPRI) Papua New Guinea: Cocoa and Coconut Institute (CCI) Philippines: Philippines Coconut Authority, Albay Research Center (PCA); University of the Philippines, Los Baños, Institute of Plant Breeding (UPLB) Vietnam: Research Institute for Oils and Oil Palms (RIOOP)
Project leaders	Australia: Professor Steve Adkins (UQ) Indonesia: Dr Hengky Novatianto (ICOPRI) Papua New Guinea: Dr Mathias Faure (CCI) Philippines: Ms Erlinda Rillo (PCA); Dr Pablito Magdalita (ULPB) Vietnam: Mrs Vu My Lien (RIOOP)
Duration of project	1 July 2002 – 31 December 2005

1 While the project covered four countries, this report focuses on the Philippines and Vietnam. For information on PNG and Indonesia, see pp. 31–36 in Pearce D. and Templeton D. (eds) 2010. Adoption of ACIAR project outputs: studies of projects completed in 2005–06. Australian Centre for International Agricultural Research: Canberra.

Funding	Total: A$1,315,332 (ACIAR contribution: A$805,329)
Countries	Australia, Papua New Guinea, Indonesia, Vietnam, Philippines
Commodity	Coconut
Related projects	HORT/2006/006

Motivation for the project and what it aimed to achieve

Coconut (*Cocos nucifera*) is a tropical palm grown by more than 11 million smallholder farmers in more than 90 countries around the world. In recent years, coconut production has declined in the South-East Asian and Pacific regions because the majority of palms there are now becoming too old for optimal fruit production and, as well, are being affected by a number of new devastating pests and diseases. Thus, the replanting of this region with new, high-yielding, disease-resistant cultivars will be an important part of re-establishing the traditional coconut-based farming system of the region.

ACIAR project HORT/1998/061, 'Coconut tissue culture for clonal propagation and safe germplasm exchange', was designed to underpin an earlier established International Coconut Genetic Resources Network (COGENT) program of International Coconut Genebanks (ICGs) by providing them with a series of new tissue-culture techniques that could be used for the safe collection, conservation and utilisation (replanting programs) of the region's unique coconut genetic resources.

The agencies involved with the project were selected because of their strength in coconut tissue culture and their close association with the newly developed COGENT ICG program. The partner organisations included the Cocoa and Coconut Institute of Papua New Guinea (PNG) (formerly known as the Cocoa and Coconut Research Institute, host to the South Pacific ICG), the Indonesian Coconut and Other Palms Research Institute (host to the Southeast and Southern Asian ICG), the Research Institute for Oils and Oil Palms (formerly known as the Oil Plant Institute of Vietnam), the Philippines Coconut Authority, Albay Research Center, and the University of the Philippines Los Baños, Institute of Plant Breeding. The Australian partner was the School of Agriculture and Food Science (formerly known as the School of Land, Crop and Food Sciences) of the University of Queensland which had gained an international reputation for high-quality coconut tissue-culture work. Before the creation of the project, all partner organisations had undertaken collaborative work on coconut tissue culture and had been involved in staff exchange programs. The project content was finalised after consultation with Dr Ponsciano Batugal, the then Director of COGENT, a trip to consult with scientists within Centre de Cooperation Internationale en Recherche Agronomique pour le Développement, the French international agricultural research and development agency, and following attendance at the International Symposium on Coconut Biotechnology, held at CICY[2], Mérida, Yucatán, Mexico, 1997. This symposium was attended by all the major international players in coconut tissue culture, and through a consultation and modification process the final project proposal was developed.

2 Centro de Investigación Cientifica de Yucatán

Professor Steve Adkins (UQ) and Mrs Vu My Lien (RIOOP) evaluating a flowering 4-year-old high-value coconut palm (Makapuno variant) that had been raised using the embryo culture technique. (Photo: courtesy S. Adkins)

The project was designed to complement coconut production in the South-East Asian and Pacific region in four main ways:

- first, through the development of an improved method for embryo culture so coconut elite germplasm could be collected and exchanged nationally or internationally, or routinely revived after cryopreservation. This work was undertaken in all partner organisations.
- second, by contributing to a worldwide attempt to develop methods to rapidly clone true-to-type coconut palms. Such a method could then be used to mass-propagate planting materials from elite, disease-resistant germplasm in the replanting process. Aspects of this work were undertaken in two partner organisations in the Philippines and Australia.
- third, by the development of a technique that could assess the degree of genetic stability found in palms that had come through tissue culture. This work was undertaken by two partner organisations in the Philippines and Australia.
- finally, by creating a network for the exchange of information and skills, and provision of equipment needed for the future operation of all partner tissue-culture laboratories.

Outputs—what the project produced

The project resulted in four major technical outputs—three intended and one unanticipated. The first was the development of a highly efficient embryo-culture technique for coconut that raised the efficiency of producing healthy palms growing in soil from the pre-project success rate of 20% to the post-project success rate of 80%. The same technique shortened the time to undertake this process by about 4 months (from 12 to 8 months), thus reducing certain inputs and making the process more cost-effective.

The second was the development of a clonal-propagation technique for coconut that was capable of producing clonal plants at a moderate level of efficiency. For the first time, true clonal plants were produced from somatic inflorescence tissues rather than the pre-project approaches that used zygotic embryo tissues, which do not produce true-to-type plants.

The third output was the development of a genetic-fidelity test/diagnostic for coconut that was capable of identifying 'off-types' that may have been produced by the tissue-culture approaches, especially clonal propagation. The diagnostic developed was the first of its kind for coconut, and was able to show that there was no measurable genetic change to be found in the regenerated plants coming from embryo culture, clonal propagation or following cryopreservation.

The unintended output was the development of an approach to better propagate high-value coconut mutant varieties. Such coconut types fetch a very high price on the local market as a fresh fruit because of the tasty endosperm and/or aromatic water, but their production is limited due to flaws in their germination process in nature. All partners are now using the embryo-culture technique developed in this project to raise these plants. Such plants are also now being used to establish research in the Philippines and Vietnam from which plantlets will be developed for sale to farmers who, in turn, will produce fruit for national and international markets.

These technical developments provided the partner organisations with the confidence to embark on coherent strategies for the collection and conservation of coconut germplasm from remote national and some international sources. By providing a safe, moderately efficient clonal-propagation protocol, it is now possible to target new elite germplasm (Kopyor, Garuk, Makapuno and Aromatic) for multiplication and for the future establishment of new, elite variety plantations.

The commitment shown by all partner organisations following these technical developments has led to policy changes that have resulted in further resources being provided to continue the work after the ACIAR project had finished. The Philippine Government provided funding to set up many hectares of Makapuno coconut in several districts, and several private laboratories were established to provide Makapuno seedlings for sale to farmers. Similarly, in Vietnam, funding was provided by the government to set up several hectares of Makapuno and Aromatic coconut in one district and a private laboratory is supplying farmers with both kinds of seedlings.

Finally, the development of close working relationships between all partner institutions has led to a shared understanding of the technical and cultural issues needed to further progress the collection, conservation and use of coconut germplasm. This strong working relationship was facilitated through joint research experimentation and publication, aided by sharing and exchange of developed technology and coconut genetic material, while taking advantage of opportunities for presenting work at scientific and industry meetings.

A small coconut plantation established using the high-value variant Makapuno, seedlings of which had been raised using the embryo-culture technique. (Photo: S. Adkins)

Adoption—how the project outputs are being used

The first project output—a highly efficient embryo-culture technique, is in its final form and is being used by all partner organisations to collect and conserve coconut germplasm, and to multiply planting materials of high-value coconut varieties. This approach (or a slight modification of it) is also being used by other countries (e.g. India, Sri Lanka, Côte d'Ivoire, Brazil) in their coconut improvement programs. The new technique has been adopted in two ways; first, to raise plants from imported and nationally collected germplasm (the original aim of the project) and second, for the propagation of the high-value coconut mutant varieties.

The second output, a clonal-propagation technique for coconut capable of producing clonal plants at a moderate level of efficiency has been adopted by one partner organisation (Australia) and work is underway to improve the approach with a view to mass-propagate the high-value coconut mutant varieties. This technique is still undergoing experimental improvement and therefore has not yet been widely adopted. When in an improved form it is anticipated that all coconut-producing countries will want to adopt this approach to rapidly raise large numbers of elite coconut seedlings.

The third project output, a genetic-fidelity test for coconut that is capable of identifying 'off-types' is in its final form but has, as yet, been little used for its original purpose as only a few clonally propagated plants have so far been produced. In Australia, however, the technique has being used to analyse plants that have come from cryopreserved embryos, a new methodology the team has developed for the long-term conservation of coconut genetic resources. This technique is likely to find its way into the hands of the private companies that will want to mass-propagate elite coconut varieties, especially when clonal propagation is to be used.

Since the completion of the project in 2005, all partner organisations have continued their investment in coconut farming system improvement. The newly found confidence with coconut tissue culture has caused three of the partner organisations to expand their research programs in this area. In the Philippines, the streamlining of the production of Makapuno plantlets has led to establishment of plantations of this variety. These will produce fruit in less than 3 years time. Fruit of earlier established Makapuno are already available and are demanding A$1.20 per kg of endosperm on the open market. A range of products being made from Makapuno (e.g. jam, biscuits, sweets and ice-cream) will ensure the demand for Makapuno will grow over the coming years. In Vietnam, a private laboratory has been set up that has produced several hectares of Makapuno and Aromatic coconuts, which are now beginning to produce fruit. At present, Makapuno are demanding a high market price (A$6.00 per fruit) while Aromatic fetches A$1.50.

The features of the project that supported good adoption were the ongoing, close communication between the partner organisations and the appreciation of the community requirements for productive outcomes. The close interactions that took place between the partner organisations and their local coconut farming communities led to the discovery of new high-value coconut varieties, Garuk in PNG and Aromatic in Vietnam. At the time of these discoveries, the communities were unaware of the potential value of this kind of fruit type on the fresh fruit market.

Impact—the difference the project has made or is expected to make

A common view before the project was there was just one profitable use for coconut and that was for copra production and, since copra production could not be readily increased, there was no real future for coconut. The project has changed this perception: coconut is now seen by farmers as being a viable crop in their region.

The newly developed tissue-culture approaches have made it relatively easy to collect, exchange and use new coconut germplasm. As a result, farmers are now able to gain access to elite disease-resistant planting materials, or to other varieties that have a tasty endosperm and command a high market price but are impossible to germinate in nature. The livelihood consequences of moving to growing either new elite, disease-resistant varieties for copra production or high-value varieties include significantly greater incomes for farmers, the partial removal of income risk, the provision of a healthier living environment, and the continued production of a high social status plant that provides so many other by-products for the home.

Postharvest handling and disease control in melons in China and Australia (HORT/1998/140)

Robyn McConchie

Project number	HORT/1998/140
Project name	Postharvest handling and disease control in melons in China and Australia
Collaborating institutions	Australia: University of Sydney; University of Queensland; Sydney Postharvest Laboratory Pty Ltd China: Gansu Agricultural University; China Agricultural University; Xinjiang Agricultural University; Xinjiang Department of Plant Protection
Project leaders	Australia: Dr Robyn McConchie China: Professor Ma Keqi
Duration of project	1 January 2002 – 30 June 2007
Funding	Total: A$1,582,366 (ACIAR contribution: A$966,247)
Countries	Australia, China
Commodity	Melons
Related projects	PHT/1996/152

Motivation for the project and what it aimed to achieve

In both China and Australia, fungal fruit rots caused by *Rhizopus*, *Alternaria*, *Geotrichum* and *Fusarium* species are the major diseases causing postharvest losses in melons. Control of these diseases in Australia is dependent on postharvest treatment with fungicide dips and the provision of suitable packaging and storage conditions. In China, however, there are very few postharvest interventions, such as cooling, to prevent rots developing during long-distance transport. With continuing pressure for the withdrawal of postharvest fungicides and the development of resistance to fungicide treatments, new options are needed to reduce reliance on fungicide use and maintain quality during transport and marketing.

Plants protect themselves from disease by means of a range of natural defence mechanisms. Recent research has shown that a range of chemicals that boost the natural defence mechanisms in plants may reduce disease losses in melons. Plants treated with activators of natural defence develop systemic acquired resistance (SAR) and have enhanced protection against infections by viruses, bacteria, fungi and nematodes. SAR has been intensively investigated for disease control in many crops.

The aim of this project was to further develop preharvest strategies that boost natural defence mechanisms in melons, so as to protect them from postharvest disease. The project also developed and tested postharvest technologies to enhance disease control and to maintain quality during the long-distance transport required in China and Australia to reach retail markets. Supply-chain analysis was used to determine the effect of the recommended technological interventions on the profit margins of melon growers, to encourage adoption by farmers in China and Australia.

Outputs—what the project produced

The project investigated novel and environmentally sustainable methods for disease control of Hami melons in China and rockmelons in Australia. Access to global markets is highly dependent on adhering to specific requirements of minimal or no pesticide use. The timing of this work was therefore critical in that there has been a strong impetus to find alternatives to traditional fungicide protocols for disease protection of all perishable crops. This project made a substantial contribution to that task.

Technical outputs

The project led to a clear demonstration that SAR has an important and practical place in commercial integrated disease management for melon fruit (and foliage). Preharvest application of SAR activators significantly reduced postharvest rots of melons in both Australia and China. A major outcome of this project was the discovery of markers to identify induction of SAR. These included pathogenesis-related (PR) proteins, physical changes in cellular structures and other biochemical changes. Through identification of these biochemical and physical changes, researchers were able to better understand defence mechanisms in melons. For the first time, antifungal compounds were isolated from SAR-induced leaves and fruit of Hami melons and rockmelons. In practical terms, SAR elicitors and 'generally regarded as safe' (GRAS) chemicals were successfully incorporated into traditional commercial spray programs,

Melon seedlings for winter melon production are held in mudbrick and plastic greenhouses. Professor Chen Nanlai from Gansu Agricultural University is in the foreground. (Photo: R. McConchie)

although lack of registration of the activators has to date prevented them from being used by farmers. In the past 12 months, however, Syngenta, in conjunction with the University of Sydney, is now seeking registration of the chemical BION® as a seed treatment for cucurbits.

Other technical outputs included knowledge of techniques for improved postharvest handling of melons, especially in China. An evaporative coolroom was built as a pilot facility to demonstrate to farmers the importance of cool-chain management. While the infrastructure for cool-chain management was not widely available during the project, protecting fruit from high temperatures in the field and during transport became an important consideration for maintaining postharvest quality of the fruit. Farmers also became aware of the need to harvest fruit at optimal sweetness to meet consumer requirements while at the same time minimising postharvest decay caused by fungal rots.

Marketing outputs

Supply-chain analysis was undertaken in both the Australian and Chinese industries, identifying areas for improvement. While the concepts of supply chains and relationship building within a supply chain were new in China, farmers quickly adopted strategies that would provide them with increased returns and greater security of income. Farmers formed grower organisations to take advantage of economies of scale in marketing, and implemented quality standards for sweetness, colour, firmness and shape, to provide greater consumer satisfaction and improved market price. A brand name introduced by farmers in the Minqin region in Gansu province was registered, which successfully provided market differentiation for their product. The research that led to the success of the Gansu supply chain was widely reported in China, stimulating strong interest in supply chains and marketing for enhancing the value of other crops.

Both the scientific and economic research generated a large amount of new and important information, much of which has been collated, analysed and published in peer-reviewed journals and extension literature. At the completion of the project, there were over 25 refereed journal articles, 26 conference presentations and papers, and 8 industry articles.

Capacity outputs

In China, the most significant capacity was generated among farmers in terms of understanding and appreciating supply-chain concepts and how their disease- and quality-management practices can influence consumer acceptance and price. In this regard, they quickly grasped the need for quality assurance, branding, promotion and marketing as tools to improve income. Before the project, farmers had little control over the price they received for their product and had no knowledge about how their product

Mudbrick and plastic greenhouses are solar heated during daytime and insulated at night by thermal blankets rolled down from the top. (Photo: R. McConchie)

Melon seedlings are delivered to farmers in heated trucks to avoid chilling injury in –20°C winter temperatures. (Photo: R. McConchie)

performed in the marketplace. Through developing information networks on the best cultivars to grow, developing a brand name and working cooperatively to initiate supply chains to market their products, farmers were able to significantly improve their incomes.

Delivery of extension services by the Department of Agriculture was substantially enhanced through exposure of staff to the numerous workshops given by Australian counterparts, which used participatory techniques that incorporated adult-learning techniques. These were novel concepts for the Chinese university and extension staff at the start of the project but they quickly adopted the approach with farmers in their own outreach activities. Evaluations clearly showed that farmers responded positively to the opportunity to express their views and have greater ownership of the agenda of extension activities.

The project also provided an opportunity for training of a large number of postgraduate students in China and Australia. There were over 33 postgraduate students trained on this project, injecting significant scientific and economic expertise into both research communities. The involvement of young students and staff was particularly important, as it presented a unique opportunity to collaborate nationally and internationally and further refine their scientific and English skills. The project also hosted an Australian Youth Ambassador, who was instrumental in strengthening the communication bridge between researchers in China and Australia. Collaboration between the participating Chinese universities was also strong, involving combined training and study visits to each other's regions. These new collaborations resulted in the development of ongoing research linkages between the three universities in China.

Mr She (left), Head of the Sho Cheng Farmers Association, showing boxes branded 'Fine Quality Melon' and 'Farmers Co-operative Minqin, Gansu province'. (Photo: R. McConchie)

Adoption—how the project outputs are being used

Adoption of project outputs has been significant, particularly in China. Where possible, outputs from all three objectives of the project, i.e. disease management, postharvest handling and supply-chain management, have been adopted by farmers and resulted in improved product quality in the marketplace. A direct consequence has been incomes increasing by a factor of four. A major change has been the growth of the melon greenhouse industry in both Xinjiang and Gansu. A visit by researchers from Gansu Agricultural University to Australia in 2006 identified new technologies in the seedling industry that were taken back to Sho Cheng and adopted. The beneficiary of that technology transfer is now earning ¥200,000 per year, which is a relatively high income.

In terms of continuing research, the original project (2002–07) has led to the development of several large-scale Chinese programs in research and extension on melon postharvest handling, induced defence to control disease and supply-chain analysis. Researchers in China who were involved with the project have all received government recognition and substantial funding to continue the excellent outcomes of the ACIAR project.

Of great importance to the Australian industry is the pending registration of BION®. In Australia, BION® was the most successful candidate for inducing SAR in melons and is currently being trialled at the University of Sydney for commercial registration by Syngenta for use on cucurbit crops. The successful outcomes of 2002–07 project led directly to continuation of SAR research at the university and to Syngenta to consider registration of its product for cucurbits.

Impact—the difference the project has made or is expected to make

Through adoption and development of supply-chain management, farmers have increased power in marketing their produce and hence receive higher incomes. Before the project, collectors viewed the melons in the field and may or may not have decided to buy the product. Farmers had no bargaining power over price, or whether or not their crop would be sold. Through developing relationships with collectors and other supply-chain members and improving quality, farmers have developed greater power in the marketing chain. Other interventions adopted by farmers, such as disease-management strategies and cool-chain management, have also benefited them, contributing significantly to improved product quality and shelf life. With 50% of the income in Minqin county derived from melons, and up to 75% in some districts of Xinjiang, the benefits of this project to farmers have been substantial.

This project was a launching pad for a new direction in research in induced resistance and postharvest and supply-chain management at Gansu and Xinjiang agricultural universities. Since the project completion in 2007, the careers of the universities' staff have been on an upward trajectory, evidenced by staff promotions, awarding of prizes, significant grant funding to continue their work, graduation of many students and publications in peer-reviewed journals. The success of the project was used as leverage to acquire government funding for new buildings and laboratories, and support for development in the rural communities. The project graduated 33 research students from Australia and China, who variously were awarded PhD, MSc and Honours degrees. They have gone on to careers as university lecturers, especially in China, and industry, contributing substantially to the pool of research scientists.

China's wealth is rising rapidly, with increased incomes apparent right across the country. Although there remains a large income discrepancy between the urban and rural populations, and between the western and eastern provinces, it was clearly evident that the central government has been supporting development and improved living conditions for those in the western provinces, including Xinjiang and Gansu, where this project was implemented. Farmers are receiving substantial subsidies for land levelling, improved water resources, low interest rate loans for greenhouse construction, incentives to form regional farmer cooperatives, improved transport infrastructure and social support for health insurance. Farmers are no longer taxed but given direct subsidies to hire tractors and refrigerated storage. Ownership of motorbikes, tractors and cars is tangible evidence of increased farmer income.

The growth in greenhouse production has resulted in a significant increase in profitability, as farmers are able to spread their income across the year and avoid production gluts during peak outdoor production periods in the summer. For example, in Minqin, average melon farmer profits have risen to ¥4,000 per mu (0.067 ha) compared with ¥1,000 per mu in 2005. With the increased attention to quality and consumer preferences, and better postharvest care, farmers have quadrupled their incomes.

Rural communities have indirectly benefited from the increased financial status of the farmers. Increased farmer income has had a multiplier effect, increasing wealth for allied industries. New infrastructure, such as coolrooms, has also provided new jobs for community members.

In Xinjiang, melon fields are irrigated by the ancient underground Karez water system built around 200 BCE. (Photos: R. McConchie)

Lucerne adapted to adverse environments in China and Australia (LPS/1998/026)

Alan Humphries

Project number	LPS/1998/026
Project title	Lucerne adapted to adverse environments in China and Australia
Collaborating institutions	Australia: South Australian Research and Development Institute (SARDI); University of Tasmania (UT); Department of Agriculture and Food, Western Australia (DAFWA) China: Beijing Forestry University (BFU); Gansu Grasslands Ecological Research Institute (GGERI); Gansu Agricultural University (GAU); Grassland Research Institute (GRI); Shandong Academy of the Agricultural Sciences (SAAS)
Project leaders	Mr Geoff Auricht (SARDI) Professor Sergey Shabala (UT) Mr Roy Latta (DAFWA) Professor Lu Xinshi (BFU) Professor Wang Yanrong (GGERI) Professor Cao Zhi zhong (GAU) Professor Xu Zhu (GRI) Professor Liu Zhaohui (SAAS)
Duration of project	1 January 2001 – 31 December 2006
Funding	Total: A$2,904,911 (ACIAR contribution: A$1,283,854)
Countries	Australia, China (Lao PDR)
Commodity	Lucerne (alfalfa)

Motivation for the project and what it aimed to achieve

Lucerne (*Medicago sativa*) is a high-quality perennial forage legume that is an important component of the feedstuff for the meat and dairy industries in China and Australia. In China, meat and dairy consumption is growing at an exponential rate and, as a consequence, the agricultural systems that support these industries also need to respond with rapid growth. In 2001, lucerne (the main sown pasture legume) was grown on 1.33 million hectares (ha) across 14 provinces, but its adoption was strongly limited by the poor yield of local varieties. Cultivars were derived from local 'wild type' ecotypes with a restricted genetic base. Almost 10 years later, the area has doubled to 2.6 million ha. Lucerne is used in the north-east for grazing, in the north-west for hay and seed, in the central region for hay, and in parts of southern China (e.g. Guizhou province and the Yellow River Delta) for grazing and hay. Tolerance to salinity and soil acidity limit performance in southern China, while improving drought and cold tolerance are critical factors in the northern and western provinces.

The role of summer active perennials to alleviate dryland salinity caused by rising groundwater is the main driver for increasing lucerne production in Australia. In 2001, 1.8 million ha of lucerne were sown, a figure that has doubled in the past 10 years. The area under threat of dryland salinity exceeds 30 million ha in the Murray–Darling Basin and Western Australia, and already several million hectares are affected. In addition to salinity, new lucerne cultivars developed for these environments must also cope with increasing acidity, often associated with high levels of aluminium.

A research student measures the height of new *Medicago sativa* subsp. *varia* breeder lines under development in Inner Mongolia by the Grasslands Research Institute. (Photo: Yu Linqing)

Lucerne flowering during seed production in the commercialisation of the Zhonhcao No.3 variety. (Photo: Yu Linqing)

Lucerne is a key component of the development of sustainable grazing, cropping and land conservation systems for both countries. It improves soil fertility, provides protein-rich forage that improves the quality of livestock and milk production, and mitigates the effects of dryland salinity. The project aimed to improve the adaptation of lucerne in China and Australia through the development of germplasm and novel screening techniques. The project targeted acidity/aluminium and salinity tolerance as critical factors limiting lucerne use and persistence in large areas of both countries, and also targeted cold tolerance and yield improvement in China.

The project aimed to train Chinese scientists in practical principles of plant breeding, and to provide extension activities in China targeting improved and expanded lucerne production through use of trials as demonstration sites and the preparation of technical publications and short courses. A network of more than 30 collaborating scientists in China contributed to the project objectives. The meetings, training courses and regular communication built into this project ensured that the outputs and knowledge were shared across the group and with the wider scientific community.

Outputs—what the project produced

The most significant output from this project was improved scientific and technical capacity for lucerne breeding in China and Australia. Training provided to Chinese scientists has enabled the development and expansion of forage breeding programs at each institution, which continue to draw benefits from this project. The scientists in each province who previously had distant relationships and, in many cases, had never met, now collaborate on several projects funded by the Ministry of Science and Technology of the central government.

This increase in capacity and collaboration has led to the release of five new lucerne cultivars in China. The cultivars have been selected directly from the germplasm evaluated in this project, or have been made possible from the training provided in the project. Two of the ACIAR trials sown in 2001 still exist some 10 years later (in Gansu and Hohhot) and provide a valuable resource for planned future plant-breeding activities. Three of the five cultivars look to exploit improved winter production matched with cold tolerance, while the remaining two have further increased cold and drought tolerance in winter-dormant germplasm to expand lucerne into the harsher climates where before it was rarely grown.

The ACIAR project developed screening techniques for tolerance to soil acidity, salinity and cold. The hydroponic screening system developed to improve the tolerance of lucerne to soil acidity has been used by SARDI lucerne breeder Alan Humphries for the past 9 years, and will contribute strongly to the release of a new lucerne variety in 2013. The salinity tolerance screening system has also been used by GGERI and SARDI to evaluate the salt tolerance of current varieties, and there are plans for SARDI and GGERI to collaborate in 2012 to expand salt tolerance screening capacity.

Adoption—how the project outputs are being used

Project varieties have been released but are in the seed multiplication phase before being made available to farmers. The commercialisation process is different for each institution. GRI is commercialising its variety Zhonhcao No. 3 using its own resources. Its seed will be made available for large national projects sowing lucerne and for sale to the public. This process guarantees adoption, as future government funding will be used to demonstrate the variety on a large scale. An example of this is the 3,400 ha of lucerne planted at Duoulan banner (region).

Other institutions, such as BFU (varieties BL201,202,203) and GGERI (variety Ganong No. 5), will sell the rights to commercialise their varieties to a private company. This process may see these varieties become even more broadly adopted, but there is also a risk that either no company will be found, or that their ability to produce and distribute the variety will be limited. Each of the institutions remains active in providing training to farmers and agronomists on how to grow lucerne and feed it to animals to improve production. It is estimated that over 650 village farmers and agronomists are trained by SAAS, GAU, GGERI and GRI each year.

The project participants have continued to build on their English-language skills and scientific knowledge. Every scientist has advanced in their career, with a promotion to a leadership role or completion of a doctorate. This includes Dr Wang Xia Jun's promotion to professor and Hu Xiao Wen's promotion to associate professor at GGERI. They are the youngest staff in the history of GGERI to gain these positions. Dr Du Wenhua from GAU is another young scientist to be appointed to a chair, while Dr Yu Linqing, an experienced scientist and leader of the forage breeding program at GRI, has recently completed his PhD and now manages a group of eight students.

Seed production of new drought- and cold-tolerant lucerne variety Zhonhcao No. 3 produced by the Grasslands Research Institute in Huhehot, Inner Mongolia. (Photo: Yu Linqing)

Impact—the difference the project has made or is expected to make

This project has been successful at developing scientific plant-breeding capacity and connecting researchers who previously worked in isolation. The funding environment in China for agricultural research is now very healthy. This is particularly so for lucerne, following the milk contamination scare in 2008, which highlighted the need to have a high protein feedbase to underpin milk quality. The ACIAR project has provided start-up funding for these programs, and provided a succession plan for the development of new scientists where there was none.

The commercial release of high-yielding, cold-tolerant lucerne varieties for Gansu, Inner Mongolia and neighbouring provinces will make a large difference in the productivity of the grasslands, where these new varieties offer twice the yield of traditional varieties. Where lucerne is being sown for the first time, it will make a large improvement to the quality of the feedbase. This will have a direct impact on the burgeoning meat and dairy industries, which have been increasing in production exponentially in Inner Mongolia for almost a decade.

Fertiliser trial of *Medicago ruthenica* in Inner Mongolia. This species is under development by Dr Wang Zhaolan for extreme environments requiring a plant that can survive very low temperatures, long periods of drought and uncontrolled grazing. The dual-purpose species is being developed for soil rehabilitation and extensive rangeland agriculture. (Photo: Wang Zhaolan)

In Gansu, there have been attempts to maintain work for individual families in regional communities by allowing them to retain the ownership of their two or three cows within larger herds that are managed by the community. This structure allows for greater control of milk quality while maintaining income for regional families. In other areas, small producers have become specialised fodder producers for neighbouring companies with large herds (several thousand head of cattle). The increase in yield of new varieties demonstrated over thousands of hectares at Duoulan banner has made lucerne a highly valued commodity in this region. The growth of the lucerne fodder industry will also deliver important sustainability benefits by improving soil structure and fertility as it grows in rotation with cereal crops.

One of the varietal releases from this project, BL202 from BFU, is a creeping rooted form of lucerne that provides dual benefits of production and conservation. This variety will be used in grassland reclamation projects in northern and western China to provide groundcover and reduce wind erosion.

The prominent performance of lucerne lines with more winter activity at the evaluation sites in Shandong province (Dezhou and Dongying) has challenged producers to consider more winter-active varieties that offer improved early spring growth and faster recovery. Australian varieties are proving to be well suited to fast-turnover production systems in the more temperate and southerly provinces, and such developments have opened up substantial trade opportunities for Australian seed companies. The future release of an acidity-tolerant lucerne cultivar and associated rhizobium strain will create further opportunities to expand lucerne into southern China.

The importance of lucerne in China and Australia is forecast to continue to grow as meat, dairy and cropping industries look for more productive options to improve efficiency and meet growing consumer demand. There are now over 3 million ha of lucerne planted in China, and a network of scientists armed with the skills and knowledge to deliver adapted and productive varieties to meet future demand.

Cocoa fermentation and drying and genotype quality assessment in Papua New Guinea (PHT/1995/136)

Yan Diczbalis

Project number	PHT/1995/136
Project name	Cocoa fermentation and drying and genotype quality assessment in Papua New Guinea
Collaborating institutions	Australia: Department of Employment, Economic Development and Innovation (DEEDI), Queensland; University of New South Wales (UNSW) Papua New Guinea: Cocoa and Coconut Institute (CCI); Papua New Guinea Cocoa Board
Project leaders	Australia: Neil Hollywood Papua New Guinea: Dr Samson Laup
Duration of project	1 January 1998 – 31 December 2004
Funding	Total: A$2,765,680 (ACIAR contribution: A$1,266,691)
Countries	Australia, Papua New Guinea
Commodity	Cocoa
Related projects	Australian Agency for International Development (AusAID)—Cocoa Quality Improvement Program

Motivation for the project and what it aimed to achieve

The process of producing cocoa includes harvesting of cocoa pods from the trees, removing the seed (wet beans) from the pods for fermentation, and drying to produce the base product of fermented dried bean. In Papua New Guinea (PNG), cocoa is an important export crop valued in 2009 (Cocoa Board) at 359 million kina (approximately A$191 million) annually and supplying approximate 1.5% of the world's cocoa. Cocoa production and subsequent bean fermentation and drying have traditionally occurred in large-scale fermentation and drying facilities established during the colonial period in a plantation environment where plantations and smallholder producers supplied a centralised fermentary with 'wet bean'. Following PNG's independence in 1974, cocoa production gradually diversified from a centralised plantation and fermentary environment to smallholder producers, many of whom commenced fermenting and drying their own cocoa to capture a better return for their production than they could get from selling wet beans. Dried bean quality deteriorated, with problems including part-fermented beans due to substandard fermentations, acidic beans because of extended fermentation time with daily turning of the beans, which increases acetic acid, and smoke taint of dried beans due to poor management of wood-fired dryers. Despite these issues, PNG cocoa is generally regarded as a 'fine flavour' cocoa and is in high demand on the world cocoa market. Fine flavour cocoa beans are produced from Criollo or Trinitario cocoa-tree varieties, while bulk cocoa beans come from Forastero germplasm. The flavour status of cocoa

Typical smallholder cocoa fermentation and drying operations. Clockwise from top left: attempted wet-bean fermentation in a partly filled box, the depth of the beans being much less than the recommended 50 cm, resulting in a poor fermentation; a wood-fired kiln, leaking smoke under the drying bed; sundrying, when possible, to complete the drying process before bagging. (Photos: Y. Diczbalis)

Commercial 'cascade style' fermentary and diesel-fired heated drying beds owned by cocoa buyers and exporters, NGIP-Agmark at Talin, Kokopo. This unit can ferment up to 20 tonnes of wet bean per week. (Photo: Y. Diczbalis)

is reviewed regularly by buyer and producer members of the International Cocoa Organization (ICCO). Despite the 'fine favour' status of PNG cocoa, the price received by growers is generally determined by the standard of the fermented dried bean and the world price. A grower's beans are determined by sampling to be either 'good fermented beans', 'fair fermented beans' or 'reject beans', with the price paid for the beans determined by these gradings. Hence, fermentation and drying play a significant role in the return growers receive for their produce. Currently, approximately 85% of dried cocoa bean is produced by smallholders.

In response to reports of poor cocoa quality, Leon Bridgland, a former director of the Lowland Agricultural Experimental Station (LAES) in Keravat, East New Britain, brought together a group of agricultural scientists, cocoa industry leaders and cocoa board representatives in 1992 to discuss the concept of a cocoa quality improvement project. This led to the establishment of the AusAID funded Cocoa Quality Improvement Program (CQIP) that ran from 1993 to 1996 and developed into the ACIAR-funded 'Cocoa fermentation and drying and genotype quality assessment project', which ran from 1998 to 2004. DEEDI, which incorporates the then Queensland Department of Primary Industries (QDPI), was the project leader for both experimental periods. The aim of the project was to establish the effectiveness of novel cocoa fermentation and drying techniques for use by smallholder farmers in PNG. Additional work was also conducted to test and identify those cocoa genotypes from CCI breeding program that had the best quality attributes.

Outputs—what the project produced

Project technical outputs included:

- fermentation techniques for small-scale fermentations from 10 to 250 kg of wet bean suited to smallholder producers
- modelling of solar dryer wing collectors to allow for efficient transfer of heat to the drying bed
- solar-powered dryers that dried wet bean faster than traditional sundrying and had the advantage of protecting the bean from wet weather and operating successfully in high rainfall environments (< 2,800 mm/year)
- on-farm adaptive trials of mini-box fermentation and solar dryers and comparison of basic chemical attributes of new technology ferments and drying with PNG plantation cocoa samples. Some 762 samples were evaluated. The sampling and analysis demonstrated that
  - smallholders fermented inadequate quantities of beans, particularly in the off-peak seasons, for the conventional 7-day fermentation—this led to putrefaction of beans, off flavours and a higher pH range
  - almost all the kiln-dried cocoa was contaminated with smoke
  - farmers who used the mini-box fermentaries for a 5-day ferment and solar dryers as per instructions obtained good-quality cocoa.

Design evolution of the small-scale solar dryers from a wood-framed A-frame dryer, to a combination solar/kiln pipe unit, to the more durable, steel-framed, hinged-flat-roof design. (Photos: Y. Diczbalis)

Solar dryer at Vudal University (Keravat Campus) with a 3 m × 10 m drying area, built by the project in 1997, capable of drying 3 tonnes of wet bean at one time. (Photo: Y. Diczbalis)

- development and modification of solar dryers suited to smallholder cocoa producers, including the development of a combination solar/kiln dryer. The new dryers have a concrete base with a flat clear polyvinyl chloride (PVC) hinged roof based on a steel rather than a wooden frame. The new design performed well and has advantages in ease of maintenance and operation.
- identification of cocoa breeding lines from CCI that met the minimum bean quality standards required by buyers. Thirty-two lines were evaluated for bean size, shell percentage, fat content and yield (kg/ha) expressed as dry bean, cotyledons and fat. Fourteen hybrid clones were released by CCI in 1999. The clones were ranked into vigour categories of small (5 cultivars), intermediate (4 cultivars) and large (5 cultivars). All of the released clones exceeded minimum standards for cocoa flavour, acidity, bitterness, astringency and fruitiness. The bulk of material released had higher chocolate flavour notes than the commercial cocoa produced at the time on Tavilo plantation (CCI, Keravat).
- construction of demonstration combination dryers in a range of PNG cocoa-production regions
- production and distribution of popular cocoa extension materials 'Joseph and Lucy Grow Cocoa' and its pidgin version 'Iosep I planim Kakao' which included project recommendations on small-scale fermentation and solar drying

- publication of a number of interim technical reports and the following two reports in the Cocoa Growers Bulletin
  - Hollywood N., Brown S. and Toreu B. 1996. A design for improved efficiency in solar drying of cocoa. Cocoa Growers Bulletin 50, 38–45.
  - Hollywood N. 1998. The effect of fermentation time and washing of cocoa prior to drying on cocoa quality in Papua New Guinea. Cocoa Growers Bulletin 51, 23–32.

Project policy outputs included:

- a draft of the PNG cocoa inspectors manual and export regulation manual which embodied fermentation and drying guidelines developed by the project for consideration by the PNG Cocoa Board
- CCI involvement in an ICCO four-country (PNG, Venezuela, Ecuador, and Trinidad and Tobago) project on cocoa fine flavour quality evaluation.

Improved knowledge and capacity generated included:

- awareness of fermentation techniques suited to smallholder cocoa producers—this has been extended within the PNG cocoa research and extension community
- awareness of bean drying alternatives to kiln drying suited to wet growing regions where conventional sundrying is difficult
- cocoa quality quantification techniques.

Adoption—how the project outputs are being used

The principal project outputs, which include development of small-scale fermentation technology and solar and/or combination solar/kiln dryers, have not been adopted by the general cocoa community.

There are a number of factors affecting the adoption of the technical outcomes of the project:

- Commercial growers and bean buyers suggested that there was little understanding of the outputs of the project. A common complaint was that commercial interests have not seen a final report or had the technology explained in a workshop or similar extension venue. The Cocoa Growers Association would support uptake of the technology at the farmer level once the issue of the Cocoa Board legislation was updated. All commercial bodies highlighted a lack of communication between CCI and themselves.
- Project fermentation and drying technology has not been approved and incorporated in the Cocoa Board's 'Cocoa inspectors and assessors manual'. Hence, there is currently no legal avenue for a new fermentary based on 'new' technology or for existing registered fermentaries that wish to incorporate the new technology to take it up.
- Another issue limiting potential uptake is that the current price for cocoa is historically high (approximately US$3,200/tonne or 7–8 kina/kg) and cocoa currently has a ready market. Nevertheless, improved quality could lead to improved returns for growers.

The capacity developed by the project is still largely present within CCI. However, a lack of internal funds prevents the institute staff from continuing the work and extension of the technology.

Tom Need from Sarang village uses conventional but well-managed fermentation and kiln-drying techniques to produce a high-quality dried bean. (Photo: Y. Diczbalis)

Impact—the difference the project has made or is expected to make

To date, the project has had little impact, primarily due to the lack of adoption. Smallholder cocoa farmers, who now account for nearly 90% of production of PNG cocoa, have the most to gain from the adoption of the technology that arose from the project. The project was unashamedly geared towards smallholders, to enable them to ferment and dry beans to a high quality, thus allowing them to maximise their returns. Larger scale plantations or third-party fermentaries and drying facilities can also utilise the technology to ensure the production of a high-quality dried bean.

The solar-drying technology has the added benefit of being environmentally beneficial by reducing the need to harvest forest trees to fuel the wood-fired kilns and reducing the need to utilise expensive diesel fuels in the larger commercial drying units. The reduction in the use of wood and diesel direct-fired kilns would also lead to the production of dried cocoa beans without the risk of contamination with polycyclic aromatic hydrocarbons (PAHs). PAHs occur as by-products following combustion of fossil fuels or organic biomass and have been identified as carcinogenic. The solar drying, and to a lesser extent the combination solar kiln units, developed by the project have the potential to reduce PAH contamination in dried cocoa beans.

The production of high-quality dried beans will, in an environment that recognises quality with clear price signals, lead to improved returns to producers who meet or exceed quality guidelines. The genetic make-up of the planting material used in PNG supports the classification of PNG cocoa as 'fine flavour', but more can be done to ensure that this genetic advantage is maximised via the utilisation of the most appropriate fermentation and drying technology.

During the conception and initial phases of the project, the benefits to Australia were seen principally in the potential for Australian cocoa buyers and chocolate producers to have access to better quality beans. In the interim period, a feasibility study into the potential for a northern Australian cocoa industry has led to the development of an embryonic industry in Far North Queensland (Innisfail to Mossman). Cocoa bean fermentation and drying are particularly relevant to an Australian industry in which the small production and high labour costs necessitate the incorporation of the best technologies to ensure the production of a high-quality dried bean.

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