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AN ECONOMIC EVALUATION OF POSTHARVEST TROPICAL FRUIT RESEARCH: SOME PRELIMINARY RESULTS

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1. INTRODUCTION

As most economies develop there is an important trend to specialisation in the production of most activities. Associated with this trend is the increased importance of trade. This trade occurs usually within a country to begin with but eventually becomes international as well. In most economies the agricultural sector plays a major role in the early stages of the development process. As domestic and international trade in agricultural products expands, increased importance is placed on the postharvest sector, in the form of, for example, assembly, transport, storage, grading and processing of produce.

As the demand for postharvest sector products and services expands there are increased incentives to improve the technologies available in this sector. Research is an important source of these improved technologies. Since many postharvest activities are undertaken by private businesses and many of the technologies used in this sector can be patented, the private sector often plays an important role in providing this postharvest research effort. However, there is still a range of production constraints which are only likely to be resolved through public sector supported research. The results from these types of research are not appropriable by those undertaking the research and, therefore, the private sector may under-invest in these areas. This paper assumes a case has been established for public sector funding of tropical fruit postharvest research and the question is how do decision-makers ensure that these funds are allocated effectively.

With the growth of economies in tropical regions of the world has come an increase in the demand for a range of fruits grown in these regions. Increased trade within and between countries has created an incentive for improvements in many aspects of the postharvest activities associated with these fruits. During the last decade or so there have been increased public sector research efforts which have focused on postharvest activities for tropical fruit.

Increasingly public research institutions are placing more importance on efforts to evaluate the impact of the research they fund. The information generated by these evaluations has been found to make several important contributions, these include: it provides a useful basis for supporting cases for continued and increased government funding of research; it provides information which can support decision-making within research institutions; and often, if undertaken with constructive interaction between economists and technical scientists, it can improve the nature and focus of the research projects. Evaluation of farm level research was first undertaken in the 1950s and a now considerable set of these evaluations has been completed for a range of commodities and countries. Evaluation of postharvest research has only received attention during the last 10 years. As far as we are aware there have been no published studies which have focused on postharvest tropical fruit research.

Given the growing interest in postharvest tropical fruit research, as is evidenced by the papers included in these conference proceedings, it seems important to devote some effort to determining what the impact of this type of research has been or is likely to be. This paper provides a preliminary attempt to look at this issue. It provides a brief review of methods for evaluation of agricultural research, especially postharvest research. A summary of some of the past attempts to evaluate postharvest research is presented and briefly discussed. None of these studies has considered projects which focus on tropical fruit. In the rest of the paper the results of a preliminary

analysis of 6 collaborative postharvest tropical fruit research projects are discussed. A model which suits evaluation of these postharvest tropical fruit research projects is chosen and the implications of the preliminary results from its application are discussed.

2. METHODS FOR EVALUATING POSTHARVEST RESEARCH AND SOME PAST APPLICATIONS

2.1 A brief overview of the development of methods for evaluation of research

Development of methods for the evaluation of agricultural research began with the early work by Schultz (1953) and Griliches (1958). This early work focused on farm level research activity and projects. A review of these farm level evaluation methods is given in Norton and Davis (1981). Summaries of the returns from research estimated by some of these studies have been summarised in, for example, Ruttan (1982, pp242-6). Many of the early evaluations were undertaken by economists outside the research organisation where the research was undertaken. Recently there has been an increased emphasis by research institutions to generate these evaluations to support decision-making. Examples are Davis and Ryan (forthcoming), GRDC (1992) and Johnston et al. (1992).

It was not until the early 1980s that attention was focused on the need to consider postharvest separately from farm level research. Freebairn et al. (1982) first raised the issue of the need to consider a revised, although theoretically related, form of methodology to estimate the returns to postharvest research, or as they called it market-service-sector research. This initial paper has generated significant interest in this area. Although the model Freebairn et al. (1982) developed was an important improvement on the temptation to simply use the retail value of the increase in output as the benefits to research, it was soon found that the question of the impact of and benefits from postharvest research can be quite complex. Developments by Alston and Scobie (1983), Freebairn et al. (1983) and Holloway (1989) have been important. Alston (1991) provides a comprehensive review of research evaluation methodology which includes, and places in perspective, postharvest research.

Perhaps one of the more critical implications which have come from these developments is the potential importance of the distribution of the gains from postharvest research. With farm level research it is generally accepted that if the results of research are applicable to a farmer or group of farmers and they adopt the resultant technology then those farmers, at least, will always gain from the research. This is not to say that some farmers will not lose from research. The farm level analyses have shown that if the technologies are not appropriate to a group or groups of farmers and if the research impact causes a fall in the product price (which is likely to occur in most circumstances) then these farmers can be worse off with the research rather than if it had not been undertaken. On the other hand, the above studies have shown that it is quite possible for all farmers to lose from the impact of postharvest research on the commodity they produce. This will not always be the case, however, it has been shown that the types of conditions required for this result are found in some circumstances. In summary: while society generally will gain from most successful farm level and postharvest research in some cases some groups (especially perhaps farmers) might be worse-off because of the research.

2.2 Past applications of postharvest research evaluation methods

The early postharvest research evaluation papers concentrated on developing the methodology. When applications were included they were generally hypothetical rather than relating to a specific research project or outcome. Several subsequent studies have applied the methodology to specific research issues and in some cases projects. Table 1 provides a brief summary of 14 of these studies. These will not be discussed in detail here. One important feature is the considerable variability in both the evaluation method used and the types of results reported. Only 5 out of the 14 provided a complete assessment which included an assessment of the lags from the commencement of the research and the adoption levels and patterns as well as the annual welfare impacts of the research. These five are listed at the top of Table 1 and in the order of the highest to lowest internal rate of return (IRR). The rates of return reported range from 29 to 143% which are similar to the types of returns reported for farm level research. The other studies have reported estimates of the annual welfare gains to the countries indicated from the research. Some of these are estimates of the potential gains rather than those to a specific completed project. There are some very large estimates reported, especially for the livestock sectors. One of the 14 reported negative returns to the project and two found it difficult to apply the available methods to the research project considered.

Care is required in drawing general conclusions from these studies since the methods and format for presentation are not necessarily comparable. Literature reviews especially such as that provided by Alston (1991) have been very useful in guiding the choice of methods for evaluating research. However, so far the classification has been based on the economic characteristics only. During the process of applying research evaluation methods at a project level at ACIAR (and this experience has been confirmed by other institutions) it has been found that it is important to be able to select an evaluation method which best suits the type of research being undertaken as well as the economic characteristics facing the production of the commodity the research will eventually influence. This is especially important as there appears to be a gap in the literature regarding the most appropriate procedures for estimating the research impact parameters which are included in the economic models. The nature of these parameters will depend on the type of research. Davis (1992) and Davis and Lubulwa (1993) have discussed this issue and suggested several possible research classification areas. They related the methodology classifications, suggested by Alston (1991), to these research area classifications. A summary of the section of the discussions from these papers relevant to postharvest research is provided in Table 2. This emphasises that the type of model is likely to vary with the type of postharvest research.

Davis (1992) allocated ACIAR's postharvest research projects to these groups and found that the majority fell in the wastage reduction group. In Table 2 (last column) the areas considered in this Conference are also compared with these research area groups. Again it appears that the major emphasis or areas of interest are in the wastage reduction research area.

The recent versions of the multi-regional vertical market models as outlined in Alston (1991) are becoming relatively complex, especially from an economic perspective. Yet procedures for estimating the research impact parameters included in them are not very well developed. Davis (1993) discusses this and suggests a simpler model which focuses on waste reduction at the postharvest level as an alternative for this sub-set of research projects.

Table 1. Summary of some postharvest research evaluation studies

Description	Commodity	Country	Research type	Net present value ($M)	Internal rate of return (%)	Benefit-cost ratio	Comments	Source
Suppression of Grain Dust	Wheat	Australia	Wastage	14.5	143	54:1		GRDC (1992)
Integrated Pesticide Use in Grain Storage	Rice	Malaysia/Philippines/ Australia	Wastage-Storage	24.3	43			Chudleigh (1991)
Stored Grain Under Plastic	Rice	South East Asia/ Australia	Wastage-Storage	9.2	38			Ryland (1991)
Reduced Amylose in Rice	Rice	Indonesia	Quality	117.0	37		Only Annual Benefits reported	Unnevehr (1986)
Reduced Amylose in Rice	Rice	Philippines	Quality	227.0	29		Only Annual Benefits reported	Unnevehr (1986)
Pigmeat Fat Reduction	Pigs	USA	Quality	977.5			Present Value of year 5 benefits no research costs	Lemieux and Wohlgenant (1989)
Reduction in Dark-Cutting in Beef	Beef	Australia	Quality	905.0			Potential Benefits no research costs	Voon and Edwards (1990a)
Boxed to Tray Ready Beef Processing	Beef	USA	Processing	845.6			Annual Impact no research costs included	Mullen et al. (1988)
Increased Protein Content in Wheat	Wheat	Australia	Quality	447.0			Potential Benefits no research costs	Voon and Edwards (1990b)
Reduced Backfat Depth in Pigs	Pigs	Australia	Quality	66.0			Potential Benefits no research costs	Voon and Edwards (1990c)
Wool Carding Improvement (Sirocard)	Wool	Australia	Processing	21.9			Benefits only no research costs included	Mullen and Alston (1990)
Component Pricing and Grading	Soybeans	USA	Grading/Quality	-12.6			Annual Impact no research costs included	Updaw (1980)
Wheat Quality for Middle East	Wheat	Australia/Middle East	Quality	?			Qualitative assessment only	GRDC (1992)
Safe Storage of Oilseeds	Rapeseed	Australia	Wastage-Storage	$5/t			Impact per tonne only assessed	GRDC (1992)

Table 2. Summary of possible postharvest research area classifications

Research Classification Area	Type of Evaluation Model (Based on Alston (1991))	Comments	Matching themes in the Chiang Mai Conference Proceedings
Post-farm-gate			
Wastage reduction	Multi-regional vertical market model	Wastage reduction version can be useful simplification.	. Harvesting . Diseases and Disorders . Storage . Ripening . Disinfestation
Processing methods	Multi-regional vertical market, probably factor-biased, model	Private sector relevance could be important since most research gains are appropriable.	Processing
Transport	Multi-regional vertical market model	Private sector relevance could be important since most research gains are appropriable.	Transportation
Farm & off-farm			
Product quality	Multi-commodity, related in consumption, vertical market model	Care is required if a simple increase in price model is used.	Harvesting
New product	Single or multi-regional, multi-commodity supply shift model	Quantity associated with minimum TAC[a] required. Care is required as estimates are subject to more error.	
Policy/regulation	Value of information with saving in dead weight loss model.	Model not well developed and few applications.	Regulation
Environmental issues	Single or multi-regional, multi-commodity supply shift model	Other areas also involve environmental issues.	
Human health	Labour supply shift, demand for health services	Models not well developed or applied.	
Institutional analysis	Value of information with saving in dead weight loss model.	Model not well developed and few applications	Marketing

[a] TAC stands for Total Average Cost

This section has briefly reviewed research evaluation methods and their application to postharvest research. A summary of past applications indicates that there have not been any evaluations of tropical fruit (or any fruit) research projects. An attempt to classify (tropical fruit) postharvest research into research areas suggests that many of the research projects in this area focus on what might be regarded as wastage reduction issues. A wastage reduction evaluation model proposed by Davis (1993) might be the most appropriate method for evaluating these projects. This model is used in the evaluation of a set of six postharvest tropical fruit projects to illustrate the application of this model and draw some preliminary implications about the possible returns to this area of research.

3. OVERVIEW OF ACIAR'S POSTHARVEST TROPICAL FRUIT RESEARCH PROGRAM

Four completed ACIAR projects and two projects which are still in progress are assessed in the paper. Table 3 summarises the commodity coverage of, and the solutions explored under the 6 projects. A brief summary of each project (PN = project number) is given below.

3.1 Use of calcium to inhibit ripening and senescence of fruits (PN8319)

This project investigated whether the process of postharvest application of calcium by vacuum infiltration can be used in Indonesia and Australia to extend storage life of mango, avocado, papaya, guava, melons, rambutans, mangosteen, longans, and lychees at storage temperatures ranging from 25 to 30˚C. While Hass avocados did not respond well to calcium infusion, data on Australian Fuerte avocados showed that calcium treatments led to an average shelf life extension of about 3 to 5 days or 32 to 55% over the average shelf life of 9 days for Fuerte without the treatments. However ACIAR (1986) noted that:

> In Australia, Fuerte is an early variety for which growers get a good price before the better varieties become available. They are therefore interested in faster ripening using ethylene but are not likely to be interested in delaying ripening with calcium infusion.

The project demonstrated that calcium infiltration could delay ripening in some varieties of avocado in Australia and Indonesia and in some papaya varieties. However for the treatment to have commercial application it was considered that better control of rotting was necessary.

3.2 Postharvest physiology of, and technology for, bananas in South East Asia (PN8355)

This project was confined to bananas. Research was conducted in Malaysia, Philippines, Thailand and Australia. Commercially viable handling technology for banana was successfully developed (Lizada et al. (1987)). This technology involved better control of ethylene to delay ripening of bananas under modified atmosphere storage, and use of fungicides to control stem-end rot. Four handling trials had proven the technology feasible for the export of bananas from Malaysia and the

Philippines by sea to Hong Kong and Japan[1]. ACIAR (1986, p43) reached similar conclusions but noted that there was still a need for
research on banana

[1] See ASEAN Food Handling Newsletter, April 1987, p11.

Table 3. Commodity coverage in ACIAR's[a] postharvest tropical fruit research

Project Number	8319	8355	8356	8844	9313	9105
Solutions explored in the project	Vacuum infiltration of fruit with calcium	Postharvest technology for bananas	Chemical controls to fruit disease	Cool storage, CA[b] and chemical controls	Non-chemical controls of fruit disease	Edible coatings for shelf life extension
Country focus	Indonesia, Australia	Malaysia, Philippines, Australia	Malaysia, Philippines, Thailand, Australia	Thailand, Australia	Thailand, Australia	Thailand, Australia
Mango	✓		✓	✓	✓	✓
Avocado	✓[c]			✓	✓	✓
Longan			✓	✓	✓	
Lychee			✓	✓	✓	✓
Rambutan				✓	✓	
Mangosteen			✓	✓	✓	
Durian				✓		
Green Coconut			✓	✓		
Papaya	✓					
Banana	✓	✓				

[a] The projects were collaboratively funded by ACIAR and participating institutions in Australia and South East Asia.

[b] CA is controlled atmospheres.

[c] A tick indicates that the fruit in question was studied as part of the project, but it does not necessarily imply that the study led to some useful technology for postharvest handling of the fruit. The commodities are not equally applicable to all countries. Details about the fruits on which different countries focused are given in Tables 8 to 13.

pathology problems on response to modified atmospheres and on low cost ethylene absorbents.

3.3 Chemical controls of fruit disease (PN8356)

Research under this project was conducted between 1983 and 1987 with the aim of investigating postharvest characteristics of mangoes, longan, lychee and mangosteen in Australia and the South East Asian region. The project demonstrated that during controlled atmosphere storage, a dual treatment of hot water followed by prochloraz was required to control stem end rot, anthracnose and alternaria rot. The project in addition verified the efficacy of hot benomyl and prochloraz sprays for the control of anthracnose with negligible impact on fruit quality, and demonstrated that hot benomyl controlled some types of stem end rot. Postharvest research into other tropical fruits in Thailand under PN8356 produced results indicating that sulphur dioxide fumigation increased the storage life of lychees to at least 90 days. For mangosteen, storage at 5°C in 5% carbon dioxide and 5% oxygen gave one month storage.

3.4 Cool storage, controlled atmospheres and chemical controls (PN8844)

This project was funded by ACIAR from 1989 to 1992 and focused on mangoes, lychee, longan, rambutan, mangosteen, and durian. A review by Alexander (1991) concluded that the project achieved major results in the following areas:

- new technologies with early commercial application particularly in relation to export marketing of longans, lychees, mangoes, and durian;

- results of scientific merit, particularly in relation to controlled atmosphere storage of different varieties of mangosteen, rambutan, mango, lychee and longan; the development of harvesting indices for lychee, durian, longan, rambutan and mango; the biology and control of mango stem end rot and other postharvest diseases; and mango sap burn; and

- the development of sulphur dioxide fumigation technology for the control of postharvest disease in exotic tropical fruits, external browning in trimmed green coconuts and measures to limit lychee and rambutan skin colour loss in storage.

3.5 Non-chemical controls of fruit disease (PN9313)

While PN8356 and PN8844 focused on the use of fungicides in the control of tropical fruit disease, PN9313 will study the mechanisms of tropical fruit resistance to disease and the development of strategies that minimise the use of chemicals in the control of tropical fruit diseases and pathogens. This is partly in response to international community pressure which continues to rise for the reduction in the use of postharvest chemicals on fruit. Partly the project is meant to build on pioneering discoveries made within ACIAR PN8844 regarding the infection processes of stem end rot fungi. Potential benefits from this project include the following:

- watering regimes suitable for stimulation of flowering and reduction in stem end rot losses in tropical fruit (mango, lychee) may be developed.

- Screening procedures for the selection of stem end rot resistant cultivars may be developed. The results could underpin development of control recommendations for stem end rot of avocado, carambola, mangosteen and rambutan, commodities for which there are no satisfactory stem end rot control measures at present, and alleviate reliance on postharvest fungicides (in mangoes).

3.6 Development of simple edible coatings for the postharvest life extension of fruit (PN9105)

This project aims to develop edible coatings that will extend the postharvest life and maintain the quality of fresh fruits handled under ambient or low temperature conditions in Thailand and Australia. The coatings, which serve to modify atmospheres within the produce, are simple to apply, non-toxic, accessible and affordable to the user. Produce dipped in the coatings, which are water soluble, is coated with a natural microfilm, which is odourless, tasteless and invisible. The coatings can be applied at any stage, can be washed off with water later and are compatible with the commonly used fungicides. The project will involve further research and development on properties of the films, including mechanical (eg thickness and strength) and barrier attributes (eg permeability to water vapour, oxygen and carbon dioxide). The coatings will be tested under a range of climates and handling conditions to optimise the effectiveness and commercial suitability of different coatings on different produce. The project will also investigate disease control in tropical fruit which is a major constraint in the commercial application of coating and film technologies, particularly in the tropics.

4. FACTORS THAT INFLUENCE THE LEVELS OF THE POTENTIAL IMPACTS OF RESEARCH

The potential impacts of postharvest tropical fruit research depend on the following factors:

- the size of the tropical fruit industry in the countries included in the research projects and the proportion of that industry which is likely to be affected by results from the research project;

- whether the project has led or is likely to lead to changes in commercial practice or in new applicable technology; and

- the adoption pattern.

4.1 Industry size

As an indication of industry size, Tables 4 and 5 show the amounts of farm level quantities produced and the farmgate prices of tropical fruits in the 5 countries covered in this paper. The list of fruits is not exhaustive, only covering those fruits that were included in the projects under assessment.

Table 4. Tropical fruit produced in South East Asian countries and Australia (tonne, 1991)

Fruit	Indonesia[a]	Malaysia[b]	Philippines[c]	Thailand[d]	Australia[e]
Mango	640 457	15 014	346 000	894 266	11 918
Avocado	91 420	na	22 000	na	12 005
Longan	na	na	na	86 563	na
Lychee	na	na	na	24 357	635
Rambutan	355 792	37 193	na	577 790	29
Mangosteen	na	7 026	na	90 263	na
Durian	205 389	118 313	21 380	539 133	na
Green Coconut	na	na	124 818	97 783	na
Papaya	352 651	71 918	100 000	408 038	4 472
Banana	2 471 925	134 940	3 545 000	43 487	165 057

Sources:

[a] Personal communications from Drs Wuri Wuryani and Malang Yuniari based on data held by the Indonesian Statistical Centre, the Department of Agriculture, Indonesia.

[b] Federal Agriculture Marketing Authority, Malaysia (1992).

[c] Food and Agriculture Organization of the United Nations (1991) and Philippine (National) Statistical Coordination Board (1992).

[d] Personal communication from Dr Sonthat Nanthachai based on data held by the Department of Agriculture Extension, Thailand and the Department of Export Promotion, Thailand.

[e] Australian Bureau of Statistics (1992).

na: not available.

Table 5. Farmgate prices for selected tropical fruits in South East Asian countries and Australia ($A/tonne)

Fruit	Indonesia	Malaysia	Philippines	Thailand	Australia
Mango	590	719	834	1 153	1 611
Avocado	324	na	459	na	1 170
Longan	na	na	na	1 499	na
Lychee	na	na	na	1 845	na
Rambutan	528	528	na	519	1 150
Mangosteen	na	618	na	1 153	na
Durian	1 017	1 305	1 216	1 009	na
Green Coconut	na	na	519	519	na
Papaya	251	270	410	519	598
Bananas	339	337	159	433	904

Sources: as for Table 4, except for Australia. Australian prices were estimated using data supplied by the Queensland Department of Primary Industries.

na: not available.

4.2 'Before research' practices

The adoption pattern for any technology depends on the type, level, cost and effectiveness of technology used before research. Recent reviews (ASEAN (1989) and FAO (1990)) of tropical fruit postharvest practices in the 5 countries in this study give an indication of the types of technology being used in these countries.

Indonesia

FAO (1990, p123) concluded that in Indonesia, postharvest measures are applied haphazardly, proper storage is generally not carried out to any extent, packaging is limited to traditional packaging methods, harvesting is not based on maturity indices and, in many areas, fruits are not given any special treatment during transportation. However, valuable fruits for export and inter-island trade are stored in cool storage facilities during transportation and storage. The handbook on the postharvest handling of fruit in ASEAN countries, ASEAN (1989), notes that benomyl or sportax dips are recommended for controlling fungal disease in bananas and mango in Indonesia.

Malaysia

A large proportion of farmers in Malaysia produce mangoes and other fruit primarily for family consumption. Only 3% of farmers produce fruit solely as a source of income (Tjiptono et al. 1984). FAO (1990, p129) concludes that Malaysia is still a net importer of fruits. With respect to the type of technology discussed in this paper, ASEAN (1989), indicates that benomyl dips are used to control fungal disease in banana and mango in Malaysia for export produce.

Thailand

FAO (1990, p152) states that refrigerated storage rooms are in common use for many types of fruits in Thailand. However, the same study suggests that growers are inadequately trained in pre-harvest techniques, that poor postharvest handling of fruit and incorrect handling of fruit reduces shelf life in Thailand resulting in high losses. Thompson (1990) observed that hydro-cooling is used in Thailand for longan and lychees. The ASEAN handbook, ASEAN (1989), notes that hot water treatment of fruit and benomyl dips are used to control fungal disease in bananas and mango in Thailand.

Philippines

Mendoza (1981, p44) reports that in the Philippines

- storage and transport facilities with appropriate temperature and relative humidity controls are virtually non-existent in the production areas;

- there is little provision for temperature, humidity and decay controls under traditional ripening practices;

- harvesting indices for fruit are not used by farmers. Thus the time and method of harvesting usually favour mechanical injuries, occurrence of physiological disorders and other blemishes; and

- use of unsuitable containers bring about large wastage due to abrasion, compression and heat injuries.

However, ASEAN (1989) indicates that dipping fruit in benomyl and other fungicides and polyethylene bags are used to control fungicides in bananas. There are indirect signs that ACIAR-sponsored research has influenced commercial practice in some South East Asian countries. For example, ASEAN (1989) cited Lizada et al. (1984), a research output of PN8356, as a basis for the recommendation for control measures for chilling injury in mango in the Philippines.

4.3 Adoption patterns

The general picture which emerges is that the technologies arising from ACIAR projects are used in South East Asia in handling produce for distant markets. Distant markets could be regional, national or export markets. Table 6 summarises the different projects in terms of the projects' impacts on commercial practice.

Table 7 summarises estimates of the percentage of fruit that is sold in distant markets and might benefit from the types of technologies developed in the 6 projects discussed in this paper.

5. QUANTIFICATION OF THE IMPACTS OF NEW POSTHARVEST TECHNOLOGY

The impacts of the technologies developed by the tropical fruit postharvest research projects include:

- reductions in total wastage of fruit which in turn leads to increases in the retail supply of fruit - this is the aim of all the projects discussed here;

- changes in postharvest costs as a result of adopting the research results; for example, a technology may increase costs because it requires more postharvest inputs (more fungicides, or increased labour or new machinery); on the other hand postharvest costs may be reduced by making it feasible to reduce the dependence by fruit shippers on expensive faster modes (mostly air) and to shift to slower but cheaper modes (shipping) in the transportation of fruit to distant markets;

- decreases in retail prices of fruit. The research extends the shelf life of fruit which leads to an increase in the quantity of fruit available at retail, which in turn leads to a fall in the retail price of fruit;

- increases in the total demand for fruit. The assumption is that as retail prices of tropical fruits fall, these fruits become affordable to consumers who could not afford fruit previously.

Table 6. Six ACIAR projects and tropical fruit postharvest technology

Project No.	PN8319	PN8355	PN8356	PN8844	PN9313	PN9105
Solution devised	Vacuum infiltration of calcium	Postharvest technology for bananas	Chemical controls to fruit disease	Cool storage, CA, and chemical controls	Non-chemical controls of fruit disease	Edible coatings for shelf life extension
When did the project finish?	1987	1987	1987	1991	1996[a]	1994[a]
Has the research solution been translated into a technology in South East Asia ?	Not yet	Yes	Yes	Yes	Not yet	Not yet
Basis for the assessment	Dr C Yuen, Department of Food Science and Technology, University of New South Wales Personal communication	Thompson (1990, 14)	Thompson (1990, 12) ASEAN (1989)	Thompson (1990, 15) ASEAN (1989)	Not applicable	Not applicable
Comments	Still requires to develop a machine embodying the technology	Used mainly for banana exports	Used to control disease in mango and banana	Used extensively in transportation of fruit over long distances	Research in progress	Research in progress

[a] Planned completion date.

Table 7. Fruit sold in distant markets for countries involved in the projects (percent of national fruit production)

Fruit	Indonesia	Malaysia	Philippines	Thailand	Australia
Mango	15-20[a]	16[b]	3.8[c]	13 (0.36% export)[d]	93[e] (6% export)
Avocado	10-15[f]	na	0[c]	na	90[f] (1% export)
Longan	na	na	na	8.8 (8.8% export)[d]	na
Lychee	na	na	na	2.0 (2.0% export)[d]	na
Rambutan	na	6[b]	na	6 (0.04% export)[d]	100
Mangosteen	na	19[b]	na	19 (0.23% export)[d]	na
Durian	10-15[f]	31[b]	0[c]	23 (0.52% export)[d]	na
Papaya	10-15[f]	38[b]	0[c]	27 (4.05% export)[d]	90
Banana	10-15[f]	25[b]	20[c]	20 (22% export)[d]	90[f] (0% export)

Sources:

a Tjiptono et al. (1984, 3).

b Federal Agriculture Marketing Authority (1992).

c Philippines Bureau of Agricultural Statistics (1989).

d The figures in brackets are based on data supplied by Dr Sonthat Nanthachai based on information held by Department of Agriculture and Extension, Thailand and Department of Export Promotion, Thailand. The other figures in this column are averages of the entries for the other 3 Asian countries.

e Dr Greg Johnson, CSIRO, Division of Horticulture, Queensland. The export figure is from Industry Commission (1993).

f Dr Chris Yuen, Department of Food Science Technology, University of New South Wales.

na Data not available.

- under some conditions, favourable impacts on farmgate prices and farm level production;

- scientific research capacity building in both Australia and the collaborating countries which is achieved during the life of the project through the exchange of skills and knowledge between Australian scientists and scientists in the South East Asia region; and

- the enhancement of the nutritional value of fruit. This benefit is reduced to the extent that postharvest fruit handling technologies require the use of chemicals which have potentially negative but to date undetermined human health effects.

5.1 Reductions in total wastage of fruit

Most of the tropical fruit postharvest research projects affect the wastage rate of fruits. Tables 8, 9 and 10 summarise the estimated impact of research as a result of research in the 6 projects. Only those commodities for which research has had an impact or is expected to have an impact are included in the tables. Three projects are linked since Project 9313 is designed to replace some of the chemical controls developed under projects PN8356 and PN8844. The 'before research' wastage rates for PN9313 are thus the rates that would apply if the chemical controls from PN8356 and PN8844 were not available. This is equivalent to setting the 'before research' wastage rates to the pre-PN8356 rates. The 'before research' rates for PN9313 may not be identical to the pre-PN8356 rates if non-chemical control methods were developed for a fruit under either PN8356 or PN8844.

5.2 Changes in postharvest costs as a result of changes

In order to realise the impacts indicated in Tables 8, 9 and 10, changes in postharvest inputs are often necessary. This leads to changes in postharvest costs. Tables 11, 12 and 13 summarise the changes in input costs that have been estimated as applying to the technology developed in the 6 projects.

5.3 Other assumptions

Three other sets of assumptions have been made in the analysis. These relate to the patterns of adoption of tropical fruit postharvest technology, the elasticity of demand and supply and the discount rate.

Little is known about the pattern of adoption of fruit postharvest technology. For example in an annotated bibliography of 719 studies on worldwide adoption of innovations (Commonwealth Agricultural Bureaux, 1981), there was no study of adoption patterns of fruit postharvest technology. In this paper it is assumed that the process and pattern of adoption for tropical fruit postharvest technology are likely to be similar to those commonly observed for farm level technologies (See Davis et al. (1987, p35). Most of these research projects take 3 years. It is assumed that after the research is completed, about 7 years are needed to develop the research results into a commercially applicable technology. From then on the technology is adopted by a

small proportion of producers or traders. The technology then diffuses to other producers slowly until adoption peaks at a maximum level of adoption. This

Table 8. Impacts of the research projects on fruit wastage rates (percent of fruit produced at farm level) in Australia

Commodities	Wastage before research	Wastage after PN8319	Wastage after PN8355	Wastage after PN8356	Wastage after PN8844	Wastage after PN9313	Wastage after PN9105
Mango	16[a]			16 →9.2[a]	9.2 →7.8[a]	16 →6.6[a]	9.2 →8.5[a,c]
Avocado	55[b]	55 →40[b]				30 →10[c]	30 →15[c]
Lychee	50[c]			50 →40[c]	40 →20[c]	20 →10[c]	30 →10[c]
Rambutan	40[c]				40 →30[c]	30 →20[c]	
Banana	30[c]		30 →10[c]				

Note:
Blanks in the table indicate that the commodity was not affected by the research project. From column 3, the number to the left of the arrow is the estimated wastage rate before research while the one to the right of the arrow is the estimated wastage rate after research.
Sources:
[a] Dr Greg Johnson, CSIRO Division of Horticulture, Queensland, personal communication, August 1993.
[b] Dr Chris Yuen, University of New South Wales, personal communication, September 1993.
[c] Dr Greg Johnson, CSIRO Division of Horticulture, Queensland, personal communication, May 1993.

Table 9. Impacts of the research projects on fruit wastage rates (percent of fruit produced at farm level) in Indonesia, Philippines and Malaysia

Commodities	Indonesia Wastage rates PN8319	Philippines Wastage rates PN8355	Philippines Wastage rates PN8356	Malaysia Wastage rate PN8355	Malaysia Wastage rate PN8356
Mango			24[b] → 14[c]		24[b] → 14[c]
Avocado	56 →36[a]				
Rambutan					36[b] → 16[c]
Bananas		33[b] →13[c]		33[b] →13[c]	

Notes:
Blanks in the table indicate that the commodity was not affected by the research project. From column 3, the number to the left of the arrow is the estimated wastage rate before research while the one to the right of the arrow is the estimated wastage rate after research.

[a] Dr Chris Yuen, University of New South Wales, personal communication, September 1993.

[b] Mendoza (1981, 58, Table 3).

[c] Dr Greg Johnson, CSIRO Division of Horticulture, Queensland, personal communication, May 1993.

Table 10. Impacts of the research projects on fruit wastage rates (percent of fruit produced at farm level) in Thailand

Commodities	Wastage rates PN8356	Wastage rates PN8844	Wastage rates PN9313[i]	Wastage rates PN9105[j]
Mango	30 → 20[a]	20 → 15[d]	30 → 10	20 → 15
Longan	50 → 40[b]	40 → 20[e]	20 → 10	
Lychee	50 → 40[b]	40 → 20[e]	20 → 10	30 → 20
Rambutan		40 → 30[f]	30 → 20	
Mangosteen	50 → 40[c]	40 → 30[g]	30 → 20	
Durian		30 → 20[h]		

Notes:
Blanks in the table indicate that the commodity was not affected by the research project. From column 3, the number to the left of the arrow is the estimated wastage rate before research while the number to the right of the arrow is the estimated wastage rate after research.

[a] Dip in hot benomyl. However, because benomyl is extensively used as a field preharvest spray in Thailand, some resistance to the fungicide has been observed.

[b] Sulphur dioxide fumigation used to control disease, but there were still problems due to SO_2 injury to the pericarp and development of off flavours during storage.

[c] The project developed a better harvesting index.

[d] The project led to the recommendation of an optimal cool storage temperature for mangoes.

[e] Optimum conditions for sulphur dioxide fumigation were established.

[f] Use of plastic over wrapped punnets were recommended to reduce moisture loss and shrinkage at the recommended storage temperature.

[g] An optimal storage temperature was recommended.

[h] A waxing treatment was developed which delayed ripening and cracking of fruit during transport to distant markets.

i The project has commenced (July 1993). A set of screening procedures for the selection of stem end rot resistant cultivars may be developed which could lead to reduced losses in stem end losses in fruit.

j The project is developing edible coatings to extend shelf life of fruit.

Table 11. Impacts of the research projects on fruit postharvest costs in Australia

Commodities	Farmgate price	Postharvest costs	Change in postharvest costs after PN8319	Change in postharvest costs after PN8355	Change in postharvest costs after PN8356	Change in postharvest costs after PN88844	Change in preharvest costs after PN9313	Change in postharvest costs after PN9105
	$A/t (1991)[a]	$A/t (1991)[b]	$A/t (1991)	$A/t (1991)	$A/t (1991)	$A/t (1991)	$A/t (1991)[i]	$A/t (1991)[j]
Mango	1 611	2 449			+11[e]	+6[f]	+72	+9
Avocado	1 170	1 778	[c]				+72	+9
Lychee	1 104	1 678				+0[g]	+72	+9
Rambutan	1 150	1 748				+100[h]	+62	
Banana	904	1 374		+85[d]				

Notes:

Blanks in the table indicate that the commodity was not affected by the research project.

[a] From Table 5 of this paper.

[b] Estimates based on Industry Commission (1993, 97).

[c] Not estimated. Despite the potential delayed ripening benefits in Table 8, the technology is not likely to be adopted in Australia because it works best on an early variety of avocados- Fuerte, for which growers get a good price before the better varieties come on the market. For this variety farmers would like to speed up, not delay, ripening (See ACIAR, 1986)

[d] This change in postharvest costs is due to (i) the cost of 50 sealed polyethylene bags and ethylene absorbents = $A47 (ii) the cost of benomyl = $A4 and (iii) labour = $A34. Labour costs are estimated using relativities in Industry Commission (1993).

[e] The cost of benomyl on the assumption that 1.33 kg of benomyl is needed with 'top up' and 1 litre of non-recirculated prochloraz for about 2750 trays (7 kg each). Cost of benomyl = $A59 a kilogram and cost of prochloraz = $A129/L. (Data supplied by Dr Tony Cooke, CSIRO, Queensland, personal communication, September 1993).

[f] Cost of detergent (eg Agral) to control sapburn.

[g] A more accurate harvesting index was developed and an optimal storage temperature was recommended replacing haphazard practices in existence before research.

[h] This is made up of $A60, the cost of 1000, plastic over wrapped small baskets (punnets) to reduce moisture loss and shrinkage of fruit at the recommended temperature plus $A40 of additional labour costs.

[i] The cost of replacing existing trees with new stem end rot resistant cultivars less the savings in costs of fungicides. The cost of growing trees is based on Industry Commission (1993, 323).

[j] Dr Chris Yuen estimates the cost of edible coatings at about $A4/t. The application of these coatings to fruit is estimated to add another $A5/t in labour costs.

Table 12. Impacts of the research projects on fruit postharvest costs in Indonesia, Philippines and Malaysia

Commodity	Indonesia Farmgate price	Indonesia Postharvest costs	Indonesia Change in postharvest costs after PN8319	Philippines Farmgate price	Philippines Postharvest costs	Philippines Change in postharvest costs after PN8355 and PN8356	Malaysia Farmgate price	Malaysia Postharvest costs	Malaysia Change in postharvest costs after PN8355 and PN8356
	$A/t (1991)[a]	$A/t (1991)[b]	$A/t (1991)	$A/t (1991)[a]	$A/t (1991)[b]	$A/t (1991)	$A/t (1991)[a]	$A/t (1991)[b]	$A/t (1991)[b]
Mango				834	717	+11[d]	719	618	+11[d]
Avocado	324	279	+18[c]						
Rambutan							528	454	50[f]
Banana				159	137	+8[e]	337	290	+18[e]

Notes:

Blanks in the table indicate that the commodity was not affected by the research project.

[a] From Table 5 of this paper.

[b] This is estimated to equal 86% of farmgate price. The estimates for Indonesia and Philippines are respectively developed from Santoso et al. (1990) and Torres et al. (1984), together with information in Tables 5 and 10 in this paper.

[c] Estimate by Dr Chris Yuen, University of New South Wales, Australia. The estimate is based on the assumption that this technology is likely to be used by small producers of avocado in Indonesia, producing about 4t/year of avocado. Calcium is estimated to cost about $A30 per 25 kilogram bag. The technology requires 4% calcium solution, reusable. Thus a 25 kilogram bag of calcium is estimated to be enough for about 10 t of avocados. The cost in the table comprises (i) 10% depreciation on a $A400 simple calcium infiltration machine ($A10/ ton) plus (ii) $A3/t for the cost of calcium, plus (iii) $A5/t added labour costs.

[d] See note (e) in Table 11.

[e] This estimate is derived from Table 11 where it is estimated that the technology developed under PN8355 is likely to increase postharvest costs by 6.2%.

[f] See note (h) in Table 11. This estimate comprises $A45 for plastic overwrapped punnets and $A5 for added labour.

Table 13. Impacts of the research projects on fruit postharvest costs in Thailand

Commodities	Farmgate price	Postharvest costs	Change in postharvest costs after PN8356	Change in postharvest costs after PN8844	Change in preharvest costs after PN9313	Change in postharvest costs after PN9105
	$A/t (1991)[a]	$A/t (1991)[b]	$A/t (1991)	$A/t (1991)	$A/t (1991)[k]	$A/t (1991)[l]
Mango	1 153	992	+11[c]	0[f]	+72	+9
Longan	1 499	1 287	+129[d]	0[g]	+44	
Lychee	1 845	1 587	+129[d]	0[g]	+44	+9
Rambutan	519	446		26[h]	+16	
Mangosteen	1 153	992	0[e]	0[i]	+44	
Durian	1 009	868		9[j]		

Notes:
Blanks in the table indicate that the commodity was not affected by the research project.

[a] From Table 5 of this paper.

[b] This is estimated to equal 86% of farmgate price, based on Santoso et al. (1990).

[c] Cost of fungicide estimated as indicated in note (e) in Table 11.

[d] Cost of sulphur dioxide.

[e] There are no added postharvest costs for adopting a better harvesting and maturity index.

[f] Since cool storage equipment is assumed to be in use already, there are no added postharvest costs for adopting an optimal cool storage temperature.

[g] Zero added postharvest costs for adopting optimum conditions for sulphur dioxide fumigation.

[h] This is made up of $A21, the estimated cost of 1000 plastic overwrapped small baskets (punnets) to reduce moisture loss and shrinkage of fruit at the recommended temperature plus $A5 of additional labour costs.

[i] Zero added cost for adopting optimum cool storage temperature for fruit.

[j] Added cost of waxing fruit is estimated at $A4/ t for wax and $A5/t for added labour.

[k] Cost of replacing existing trees with stem end rot resistant cultivars, based on estimates in Industry Commission (1993, 323) and Dara Buangsuwon (1993, Table 5).

[l] Added cost of edible coatings technology is estimated to be $A4/t for the coatings plus $A5/t for labour.

maximum level of adoption varies depending on the fruit, the country in question and the characteristics of the technology.

The literature on the empirical estimation of elasticities of demand and supply for tropical fruit is limited. The elasticity of demand with respect to own price of fruit has been assumed to be -1.5. This is consistent with the estimate by Santoso and Wahyunindyawati (1992) who estimated the own price demand elasticity of mangoes at -1.6. However, Stuckey and Anderson (1974) estimated the demand elasticity for bananas in Sydney at -0.8. In the sensitivity analysis, a figure of -0.6 has been used to describe a scenario when demand for tropical fruit is inelastic. A relatively inelastic supply curve with an own price supply elasticity of 0.1 is assumed in the analysis.

The discount rate is assumed to be 8%/year. This rate is used to discount both the costs incurred and benefits received over a 30-year time horizon. The research costs which were incurred before 1991 are adjusted to their 1991 values by using inflation deflators between 1983 and 1991.

6. AN EVALUATION OF SIX TROPICAL FRUIT POSTHARVEST RESEARCH PROJECTS

This section presents results from a preliminary evaluation of the ACIAR-funded tropical fruit postharvest research projects. Table 14 describes results of the assessments using information and parameter values in Tables 4 to 13. These tables describe what is referred to below as the base case research impacts.

6.1 Results from the base case analysis

In Table 14, the projects are arranged in descending order of the net present values. The net present value (column 7 of the table) is the difference between the monetary value of benefits and the research costs of a project, over a 30-year period, discounted at a rate of 8%/year. The internal rate of return (column 8 of Table 14) is the rate which would be required to equate the discounted benefits flowing from the project to the discounted research costs. These results depend on a number of factors including:

- the farm level quantities of fruit produced (Table 4) - the larger the volume of fruit produced the larger the potential benefits;

- the proportion of the fruit produced which is likely to be affected by the new technology (Table 7) and the pattern of adoption of the technology;

- the impact of research on wastage rates (Tables 8 to 10) - the larger the reduction in wastage rates as a result of research, the larger the potential gain; and

- the change in postharvest costs (Tables 11 to 13) - the higher the increase in postharvest costs relative to the 'before research' level of postharvest costs, the lower the potential gains.

Table 14. Results from a preliminary evaluation of six tropical fruit postharvest research projects: the base case ($A'000 1991)

Project number	Project title	Consumer benefits	Producer benefits	Total benefits	Total research costs	Net present value	Internal rate of return
PN9313	Non-chemical controls of fruit disease	74 945	5 182	80 127	1 235	78 892	38
PN8355	Postharvest technology for bananas	49 367	2 060	51 427	801	50 627	48
PN9105	Edible coatings for fruit shelf life extension	35 820	7 425	43 246	1 235	42 010	34
PN8356	Chemical controls of fruit disease	33 079	4 500	37 579	1 001	36 578	41
PN8844	Cool storage, controlled atmospheres and chemical controls	17 729	2 243	19 970	1 235	18 735	27
PN8319	Vacuum infiltration of fruit with calcium to delay ripening	3 120	71	3 191	458	2 733	21

Though generally all the projects increased both producer and consumer benefits, consumers gained more than the producers. The main source of the gains to the consumer is the decrease in prices of fruit as the retail supply of fruit is increased. The share of the gains to producers is influenced by the elasticity of demand for fruit. In the base case it is assumed that demand is elastic (own price elasticity of demand of -1.5). However, if demand is inelastic producers may lose as a result of technologies developed under the projects covered in this preliminary evaluation.

6.2 Sensitivity tests

Sensitivity analysis was undertaken to assess how the preliminary base case results in Table 14 would change if the variables in Tables 4 to 13 took on different values.

- wastage rate reductions

In order to assess the sensitivity of the results in Table 14 to the estimated change in wastage rates, the analysis was repeated using the assumption that research leads to twice the reduction in wastage rates used in the base case. Generally, doubling the wastage rate reduction led to a doubling of total discounted benefits but only increased the internal rate of return by about 7%.

- elasticity of demand

When the demand elasticity was reduced from -1.5 to -0.6, the net present values tended to decrease marginally and the internal rates of return were slightly lower than in the base case. More significantly, the model indicates that producers of fruit under conditions of inelastic demand (-0.6) may incur net losses in economic surplus as a result of research.

- change in post harvest cost

The analysis was repeated with the assumption that research leads to a doubling of the base case change in postharvest costs. Generally, doubling of the research-induced change in postharvest costs leads to a small decrease in consumer benefits, a comparatively larger reduction in producer benefits and a reduction in the internal rate of return.

6.3 The distribution of benefits between fruits and collaborating countries

Table 15 shows the distribution of benefits between the different fruits. This rank ordering according to potential benefits of research is similar to the ranking of production levels of the different fruits. For example, the top two fruits in terms of potential benefits are also the top two in terms of production levels in the 5 countries in the study. The fruit with the least potential to generate research benefits is also the one produced in the smallest quantities in the 5 countries.

Finally, Table 16 shows that all countries collaborating in the research projects gain. The relative sizes of the benefits accruing to the different countries is dependent on the relative shares in production of the mix of fruit covered under the given project. The results on the distribution of benefits between different countries reflect the countries which collaborated in the different projects. In the recent past, projects in the tropical fruits postharvest area have

Table 15. The distribution of gross benefits according to fruits covered by ACIAR research projects ($A'000 1991)

Project number	Project title	Mango	Avocado	Longan	Lychee	Rambutan	Mangosteen	Durian	Banana	Total
PN9313	Non-chemical controls of fruit disease	46 068	15 638	3 317	618	8 098	6 388	0	0	80 127
PN8355	Postharvest technology for bananas	0	0	0	0	0	0	0	51 427	51 427
PN9105	Edible coatings for fruit shelf life extension	39 074	3 555	0	616	0	0	0	0	43 246
PN8356	Chemical controls of fruit disease	29 531	0	1 753	183	2 087	4 025	0	0	37 579
PN8844	Cool storage, controlled atmospheres and chemical controls	2 569	0	10 926	2 293	2 860	122	1 200	0	19 970
PN8319	Vacuum infiltration of fruit with calcium to delay ripening	0	3 191	0	0	0	0	0	0	3 191

Table 16. The distribution of benefits between countries collaborating in ACIAR research projects ($A'000 1991)

Project number	Project title	Indonesia	Malaysia	Philippines	Thailand	Australia	Total
PN9313	Non-chemical controls of fruit disease	0	0	0	54 378	25 749	80 127
PN8355	Postharvest technology for bananas	0	4 075	40 679	0	6 673	51 427
PN9105	Edible coatings for fruit shelf life extension	0	0	0	39 320	3 926	43 246
PN8356	Chemical controls of fruit disease	0	2 676	15 899	15 443	3 561	37 579
PN8844	Cool storage, controlled atmospheres and chemical controls	0	0	0	13 893	6 077	19 970

focused on Thailand. This explains the larger share of benefits accruing to Thailand. Similarly, Indonesia has collaborated in one tropical fruit postharvest project to date. Thus the zero entries for Indonesia have no significance other than indicating that Indonesia has not collaborated on 5 of the 6 projects assessed in this paper.

At this stage the potential spillovers to other countries have been ignored. This is due largely to the preliminary nature of the results; it has not been possible yet to collect reliable, verified estimates for the collaborating countries especially regarding adoption levels. It would be too hypothetical to estimate spillovers to non-collaborating countries at this stage. It is important to note that these benefits are potentially available.

7. CONCLUDING REMARKS

This paper has reviewed methods for the economic evaluation of research and their application to postharvest research. A summary of past applications indicated that there have not been any evaluations of postharvest tropical fruit (or any fruit) research projects.

The paper has also illustrated an application of a wastage model in the evaluation of 6 ACIAR tropical fruit postharvest research projects, and it provides some preliminary estimates of the potential benefits of tropical fruit postharvest research.

The basic data required for the analysis is indicated in Tables 1-13. Data on production and price levels are more readily available for the fruits that are produced in large quantities, than they are for the minor fruits produced. Even for the major tropical fruits, it was not possible to get a data set on prices at the different stages in the postharvest marketing chain (farm level, wholesale and retail, at least). Without this type of data, it is not possible to use econometric techniques to estimate own price demand and supply elasticity of the different fruit, let alone determine the changes in demand of one fruit when prices of other fruit change. Cross price elasticities of demand for fruit may be important, for example, when consumers have a fixed budget share for fruit. Thus when prices of tropical fruit decline, consumers reduce consumption of other fruit as they increase their consumption of tropical fruits.

Data on wastage rates and postharvest costs before research were obtained, by elicitation, from postharvest research scientists who worked on the 6 projects. This data could be collected in the research development stages as part of the justification for funding. This would ensure that projects address issues which are both scientifically interesting and economically significant. Estimates of wastage rates and postharvest costs after research could also be collected in the trialing of technologies for commercial use.

While there are many studies of adoption of technology in the agricultural and manufacturing sectors (Commonwealth Agricultural Bureaux, 1981), the study of adoption, and of the factors that affect the level of adoption of fruit postharvest technology has been neglected. Results from such studies would improve the quality of data used in economic evaluations of fruit postharvest research projects.

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Abbreviations

ABS	Australian Bureau of Statistics
ACIAR	Australian Centre for International Agricultural Research
ASEAN	Association of South East Asian Nations
CSIRO	Commonwealth Scientific and Industrial Research Organisation
FAO	Food and Agriculture Organization of the United Nations
GRDC	Grains Research and Development Corporation

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