SHELF-LIFE EXTENSION OF LEAFY VEGETABLES: EVALUATING THE IMPACTS

ACIAR Project PHT/1994/016

Tingsong Jiang and David Pearce
Centre for International Economics
Canberra and Sydney

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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.

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The Manager
Impact Assessment Unit
ACIAR
GPO Box 1571
Canberra ACT 2601
Australia
tel +612 62170500
email <aciar@aciar.gov.au>

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Foreword

ACIAR's impact assessment reports provide information on project impacts which helps to guide future research and development activities. While the main focus of these commissioned reports is on measuring the dollar returns to agricultural research, emphasis is also given to analysing the impacts of projects on poverty reduction.

In both China and Australia, the factor most limiting expansion of the vegetable industry is the short shelf life of the products. Many leafy vegetables, such as pak choy and broccoli, tend to deteriorate quickly after harvest. Commodities such as Chinese cabbage and oriental bunching onions can be stored for long periods over winter but losses during storage could be further reduced. The problem is important because these commodities account for at least 30% of China's total fruit and vegetable production.

The project evaluated in this report examined handling and storage methods in China and Australia for a number of leafy vegetables. Scientists documented deficiencies in handling and storage systems, explored what could be done to extend shelf life, and also identified inherent physiological factors that limited the postharvest life of pak choy and Chinese cabbage.

The project aimed to reduce the after-harvest wastage of leafy vegetables by improving methods to prolong their shelf life.

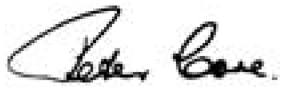
The researchers also investigated what before-harvest factors could affect the postharvest life of pak choy and Chinese cabbage and whether time of harvest had any effect.

When this project was conceived, the profound changes in marketing systems for vegetables in China were only just beginning and consumer demand for minimally processed vegetables was increasing in Australia. This project was therefore timely, and contributed to both technology development and process mapping to identify gaps and needs in the chain between producer and consumer.

The project achieved all its objectives. The most significant impact has been a saving of some 10–20% of total produce because of the introduction of new technology. This evaluation reveals large benefits to Chinese vegetable growers and distributors. Already, benefits have fully covered the research expenses and, over a period of 30 years from 1998, the project is expected to return about A$150 million of benefits to China. Australian vegetable growers and distributors also benefit.

The project enhanced the capabilities of the Beijing Vegetable Research Center and provided training for farmers, traders and supermarket personnel. BVRC is now undertaking key projects to improve the Beijing vegetable distribution system, plan the supply of vegetables for the 2008 Olympics and develop export markets for fresh vegetables.

This report is Number 32 in ACIAR’s Impact Assessment Series and is also available for free download at <www.aciar.gov.au>.



Peter Core
Director
Australian Centre for International Agricultural Research

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
AgVic	Agriculture Victoria
BCR	benefit–cost ratio
BVRC	Beijing Vegetable Research Centre
MAP	modified-atmosphere packaging
MCP	methylcyclopropene, an ethylene [ripening] inhibitor
HUC	Hangzhou University of Commerce
IAA	indole acetic acid
NPV	net present value
PPP	purchasing power parity
QDPI	Queensland Department of Primary Industries (now the Queensland Department of Primary Industries and Fisheries)
RBA	Reserve Bank of Australia
RMB	the Chinese currency, Renminbi, literally meaning ‘people’s currency’. The base unit of the currency is the yuan.
UA	University of Adelaide
ZU	Zhejiang University

Acknowledgments

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Dr Deborah Templeton, Ms Trish Andrew and Mrs Betty Robertson from the Australian Centre for International Agricultural Research (ACIAR) provided background material for the project. Mr Chris Brittenden, Mr Wang Guanglin and Ms Lydia Li from ACIAR's Beijing Office provided valuable assistance while I visited Beijing for the evaluation. The Australian project leader, Dr Timothy O'Hare from the Queensland Department of Primary Industries and Fisheries, read the draft of this report and provided comments, as did Dr Greg Johnson, manager of the ACIAR Postharvest Technology Program and Dr David Raitzer from the Food and Agriculture Organization of the United Nations.

Professor Li Wu from the Beijing Vegetable Research Centre (BVRC) was the Chinese project leader. Together with Dr Wang Xiangyang from Hangzhou University of Commerce (HUC), he helped organise my trip to Beijing and Hangzhou for consultation and site visits, and provided a detailed introduction to the project.

The following people also provided valuable inputs to the evaluation: Associate Professor Zheng Shufang and Professor Gao Lipu from BVRC, Professor Hu Hong from the Chinese Academy of Agricultural Sciences, Mr Yan Hongquan from the Beijing Association of Vegetable Exporters, Mr Lin Yuan from the Beijing Agricultural Bureau, Mr Pei Zhongzhe from Eastern Beijing Grand Canal Distribution Centre of Agricultural Products, Professor Ying Tie-jin from Zhejiang University and Ms Liu Yueping from HUC.

Details of project evaluated

ACIAR project PHT/1994/016	Shelf-life extension of leafy vegetables
Collaborating organisations	Queensland Department of Primary Industries (QDPI), Gatton, Queensland, Australia; Agriculture Victoria (AgVic), Melbourne, Victoria, Australia; University of Adelaide (UA), Adelaide, South Australia; Beijing Vegetable Research Centre (BVRC), Beijing, People's Republic of China; Hangzhou University of Commerce (HUC), Hangzhou, People's Republic of China; Zhejiang University (ZU), Zhejiang, People's Republic of China.
Project leaders	Dr Timothy O'Hare (QDPI); Professor Li Wu (BVRC)
Principal researchers	Dr Amanda Able (QDPI); Dr John Farragher, Mr Bruce Tomkins (AgVic); Dr Andreas Klieber (UA); Mrs Gao Lipu (BVRC); Professor Lian-Qing Shen (HUC); Professor Ying Tiejin (ZU)
Duration of project	1 July 1998–31 December 2002
Total ACIAR funding	A$893,898
Project objectives	• To assess the current Chinese handling systems and identify key processes limiting vegetable shelf life. • To identify changes to the environment (preharvest and postharvest) that can be implemented to retard senescence. • To investigate inherent physiological factors that need to be targeted for further gains in shelf life to be achieved.

Executive summary

Background

China is the world's largest producer of vegetables, and the industry is rapidly expanding. However, postharvest losses of leafy vegetables in China as high as 10–25% have been experienced. It has been conservatively estimated that these would translate to annual economic losses of A$1 billion.

From July 1998 to December 2002, the Australian Centre for International Agricultural Research (ACIAR) funded a project, 'Shelf-life extension of leafy vegetables' (PHT/1994/016), to reduce postharvest losses. The project had three major objectives:

- assessment of the existing Chinese handling systems and quantification of existing handling problems for Chinese cabbage, pak choy, broccoli and oriental bunching onions
- optimisation of environmental conditions to extend shelf life
- identification of inherent physiological factors limiting shelf life.

The project achieved all these objectives. In addition to identifying postharvest problems in China and making a series of breakthrough findings on the factors affecting vegetable shelf life, some practical techniques, such as forced-air pre-cooling, improved postharvest handling systems, controlled water loss and rehydration, and modified atmosphere packaging, were developed and have been widely applied in China and Australia.

The most significant impact of applying these techniques is the reduction in postharvest losses. Some 10–20% of total produce is saved because of the new technology. Associated with the reduction in losses, the environmental costs of urban household garbage have also been reduced. In addition, some social impacts such as capacity building, improved human capital and enhanced networking among researchers, farmers and extension officers have been observed.

This report

This report evaluates the costs and benefits of the project over a period of 30 years from 1998 to 2028. The following approach is adopted. A 'unit net benefit' is first calculated for each technology used in each vegetable according to technical parameters revealed by the project and market information collected from statistics and a field trip. This unit benefit is then multiplied by the projected increase in adoption to reach the total net benefit against the baseline—a counterfactual scenario assuming that ACIAR did not invest in the research project on extending the life of leafy green vegetables. Projections on production and adoption are based on historical trends.

The evaluation of Chinese benefits focuses on Beijing and Zhejiang because there is no indication of adoption of the new techniques in other regions, while in Australia the evaluation is focused on the adoption of modified-atmosphere packaging of leafy Asian vegetables in the fresh-cut industry.

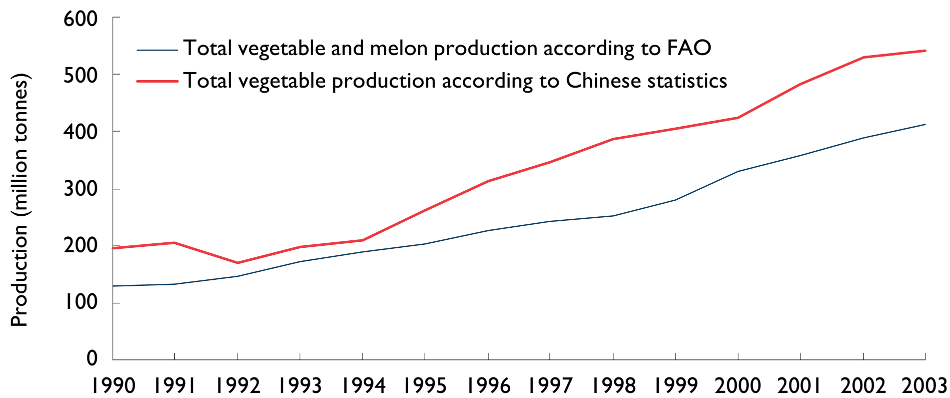
The evaluation reveals large benefits to Chinese vegetable growers and distributors. So far, benefits have fully covered the research expenses. This is a significant achievement given the fact that the project was completed only 2 years ago. Over a period of 30 years from 1998, the net present value (at a 5% discount rate) of the project to China is A$149.8 million, or RMB yuan 912.5 million. Australian vegetable growers and distributors also benefit from the project, receiving a net present value of A$1.6 million. The benefit–cost ratio is 40 and the internal rate of return 52.8%, if both benefits and costs are measured in Australian dollars.

1 Introduction

China is the world's largest producer of vegetables and the industry is rapidly expanding as market distribution within China is liberalised and export markets are developed.

During the past decade, China's vegetable production grew at 9.3% per year. According to Chinese agricultural statistics, China's total vegetable production (fresh and processed) reached 540 million tonnes[1] in 2003 (Figure 1). As a result, its share of world production increased from around 30% in 1990 to almost 50% in 2003. China's share of world fresh-vegetable production increased from 44% in 1990 to 56% in 2003 (Figure 2).

Figure 1. Vegetable production in China, 1990–2003



Data source: FAOSTAT; China Agricultural Statistics.

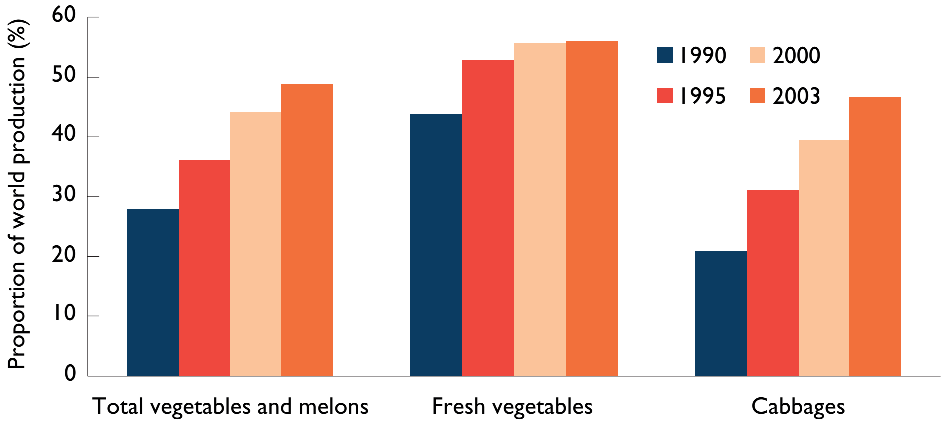
Along with the growth in production, there have been several changes in the marketing of vegetables in China:

- The marketing of vegetables in China has been liberalised, moving from state control to a market-based system.
- The role of supermarkets in vegetable marketing has become increasingly important. In Beijing, it is expected that 70–80% of vegetables will be sold through supermarkets by 2008.
- With the development of logistics and higher incomes, the emphasis of the postharvest handling research has shifted from longer-term storage—for

[1] The FAO statistic for 2003 is 411 million tonnes.

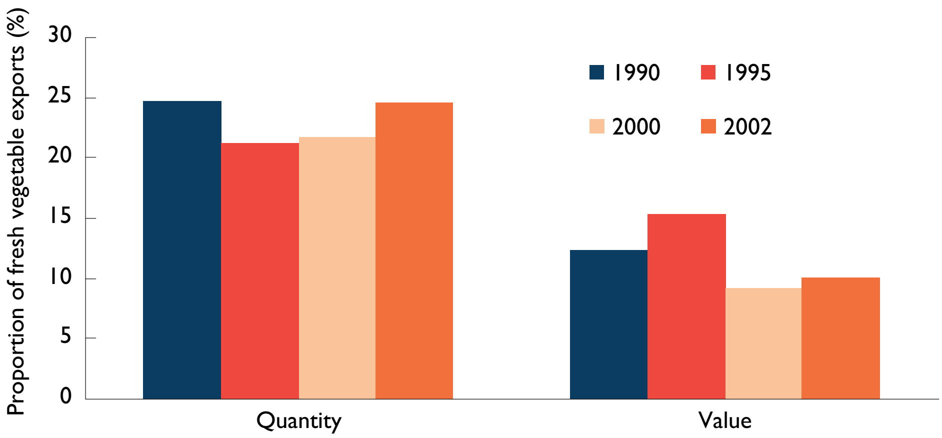
example, households in Beijing once stored Chinese cabbage for the whole winter—to shorter-term storage.

Figure 2. China's share of world vegetable production



Data source: FAOSTAT.

Figure 3. China's share of world fresh-vegetable exports



Data source: FAOSTAT.

Postharvest losses of leafy vegetables in China can be considerable. For example, the losses associated with Chinese cabbage can vary from loss of the outer leaves to whole plant loss. Losses have been estimated at a minimum of 5% per month of storage and a maximum of 10% per month (storage is normally 2–3 months). With pak choy, losses were estimated at a minimum of 10% and a maximum of 25%. Postharvest economic losses of fresh vegetables across China have been conservatively estimated at A$1 billion per annum.

Lack of proper storage technology is one of the factors hindering the growth of China's fresh vegetable exports. Although China's share in world production has increased dramatically as shown in Figure 2, its share in world fresh-vegetable exports has been static since 1990. This is more due to export regulations than to increased domestic demand. Furthermore, China's vegetable exports tend to be low-value-added products. Although China accounts for one-quarter of the world's fresh vegetable exports by volume, their value is only about 10% of the world total (Figure 3).

Extending the shelf life of leafy vegetables was the topic of an ACIAR-funded project (PHT/1994/016). The objective of the project was to remove procedures contributing to postharvest wastage, optimise agronomic and postharvest handling procedures to increase shelf life, and to identify the inherent physiological factors limiting shelf life that should be targeted for future biotechnological control and breeding strategies. The commodities investigated were pak choy, Chinese cabbage, broccoli and oriental bunching onions.

This report evaluates the costs and benefits of the project over a period of 30 years from 1998 to 2028.

2 The ACIAR-funded project and its outputs

Overview of the project

The ACIAR-funded project, 'Shelf-life extension of leafy vegetables' (PHT/1994/016), began on 1 July 1998 and was completed on 31 December 2002. It emphasised the assessment of handling systems to identify problems and to develop optimal and practical techniques for extending the shelf life of vegetables. Four vegetable species—Chinese cabbage, broccoli, pak choy and oriental bunching onion—were chosen for the study. Beijing and Zhejiang were the two study regions in China.

The project was originally planned to run over 3 years from 1 July 1998 to 30 June 2001, with overall ACIAR funding of A$743,985. Following a review of the project in May 2001, ACIAR decided to extend it to 31 December 2002, with additional funding of A$150,000.

Participants in this project included two Chinese laboratories (northern and central China) and three Australian laboratories. The commissioned organisation for the study was the Queensland Department of Primary Industries (QDPI) (now the Queensland Department of Primary Industries and Fisheries). The collaborating organisations were the University of Adelaide (UA) and

Agriculture Victoria (AgVic) (now the Victorian Department of Primary Industries) on the Australian side and the Beijing Vegetable Research Centre (BVRC) and Hangzhou University of Commerce (HUC)[2] in China. Researchers from Zhejiang University joined the team in the extension phase. The project leaders were Dr Timothy J. O'Hare from QDPI and Professor Li Wu from BVRC.

Objectives of the project

The project had three major objectives during the initial 3-year phase:

- assessment of the existing Chinese handling systems and quantification of current handling problems for Chinese cabbage, pak choy, broccoli and oriental bunching onions
- optimisation of environmental conditions to extend shelf life
- identification of inherent physiological factors limiting shelf life.

The aim of the 18-month extension was to verify and apply the findings on vegetable postharvest handling systems made during the first part of the project.

Handling systems assessment

Assessment of handling systems included process mapping, analysis and documentation of the current Chinese handling systems for Chinese cabbage (Beijing, Zhejiang), pak choy (Zhejiang), broccoli (Beijing) and oriental bunching onions (Beijing).

Optimisation of environmental conditions to extend shelf life

Research on optimal environmental conditions for extending the shelf life of vegetables determined the best postharvest practices for the leafy and immature vegetables studied. These practices included:

- optimisation of water relations/nutrition for pak choy and Chinese cabbage
- optimisation of harvest time for pak choy and Chinese cabbage
- ethylene control methods for Chinese cabbage, pak choy and broccoli
- minimisation of moisture loss in pak choy
- heat-shock methodology for broccoli.

[2] With the approval by the Ministry of Education of China, Hangzhou University of Commerce was restructured and renamed as Zhejiang Gongshang University in May 2004.

Identification of inherent physiological factors limiting shelf life

Research on inherent physiological factors that limit the shelf life of fresh vegetables was undertaken to gain a greater understanding of the effect on postharvest outcomes of plant physiology at the individual leaf level. In particular, the team examined the effect of ethylene and other growth regulators, energy substrates and leaf age on the shelf life of pak choy and Chinese cabbage.

Project extension

The project extension was undertaken to confirm the economic feasibility of findings made during the initial phase, to extend information on handling system improvement, and to further develop areas (directly with industry in many cases) where significant advances had been made into a form useful for industry.

For Chinese cabbage, two objectives in China were to achieve:

- comparative returns analysis and extension of handling assessment findings to the Chinese industry, with semi-commercial trials of adjustments in the handling system to demonstrate improved profits
- extension of storage life (by refrigeration) of 'summer' varieties to cater for the premium July–August Chinese market.

For pak choy, the objectives in China were:

- to undertake semi-commercial modification of the handling system to reduce postharvest mechanical damage
- to complete comparative returns analysis and implementation of preharvest shading for premium summer-grown pak choy to improve quality
- to test the use of cheap cooling methods (ice plus insulating covers) for transport during the premium summer season
- to confirm the efficacy of heat-shock in extending shelf life.

For broccoli, the Chinese teams aimed at optimisation, comparative returns analysis and scaling-up of heat-shock methodology for the domestic market.

For oriental bunching onions, the project extension aimed at further development, comparative returns analysis and extension to industry of cost-effective simple insulation techniques for winter storage of product destined for export to Japan.

Project outputs

The project outputs are the tangible products of the research, being mainly better information or better technology for extending the shelf life of leafy vegetables. They are embodied in reports, journal articles, books, articles in farmers' newsletters and training materials. Table 1 summarises the project outputs.

Table 1. Summary of outputs of ACIAR project PHT/1994/016

Objectives	What has been achieved
1. Assessment of the current Chinese handling systems and quantification of current handling problems for Chinese cabbage, pak choy, broccoli and oriental bunching onions	a. Case study selected b. Process flows for each case study mapped c. Each handling system described and documented d. Postharvest losses measured e. Handling systems problems identified f. Potential solutions identified g. Additional research needs and/or directions identified
2. Optimisation of environmental conditions to extend shelf life of Chinese cabbage, pak choy, broccoli and oriental bunching onions	a. Ideal short-term storage temperature for Chinese cabbage identified b. Physiological factors limiting shelf life of Chinese cabbage identified c. Potential of film bags to minimise water loss demonstrated d. Effects of various preharvest factors on Chinese cabbage studied e. Optimum modified-atmosphere composition for stored pak choy identified f. Effect of postharvest blanching on broccoli and pak choy evaluated g. Influence of simulated postharvest mechanical injuries in pak choy evaluated h. Influence of preharvest cytokinin application on postharvest quality of pak choy investigated i. Effect of harvest time-of-day on water relations and energy substrates in pak choy evaluated j. Effect of anti-transpirants on moisture loss retardation evaluated k. Effect of ethylene action blockers on broccoli florets evaluated
3. Identification of inherent physiological factors limiting postharvest life of pak choy and Chinese cabbage	*Pak choy* a. Sugar levels established as major endogenous factor influencing shelf life of pak choy leaves, with much higher levels found in the petiole than the lamina. b. Glucose was the dominant sugar at harvest, being about three times more abundant than sucrose or fructose, but it declined rapidly after harvest with the rate of decline higher at higher temperatures. Onset of leaf-yellowing occurred when the sugar ratios were about 1:1:1. c. The longer shelf life of young leaves compared to old leaves was explained by correspondingly higher sugar levels. d. Endogenous ethylene levels were very low overall but ethylene was observed to increase at harvest, attributed to the wound response, and after leaf-yellowing commenced. e. Exogenous ethylene accelerated leaf yellowing but the effect was blocked by application of 1-methylcyclopropene, an ethylene inhibitor. *Chinese cabbage* f. Water loss, high temperature and ethylene established as main factors limiting shelf life of Chinese cabbage g. Chlorophyll degradation occurred during storage but was evident only in outer leaves and occurred more rapidly at higher temperatures h. Rots were a key factor in product senescence.

Source: Chaplin and Tongdee (2001).

Postharvest process maps for leafy vegetables

Postharvest process maps were produced for Chinese cabbage, pak choy, broccoli and oriental bunching onions at the beginning of the project. Where applicable, the process map was produced for fresh market, storage and/or export of each vegetable species.

One of the most interesting observations was the decline in the amount of long-term storage. Although still comprising a large part of the market, long-term storage has been declining due to the increasing availability of vegetables from southern China, and because increasing numbers of Chinese consumers can afford more expensive vegetables that were previously beyond their capacity to pay. This is particularly the case for Chinese cabbage. Storage of oriental bunching onions continues, as southern areas are unable to produce or supply this crop during winter.

Postharvest losses of leafy vegetables

Through research, the team was able to determine how losses occur, where they occur, and to some extent what percentage of total loss was incurred at each step of the handling system.

Table 2. Harvest and postharvest losses (%) of selected leafy vegetables in China

Vegetables	Harvest loss	Postharvest losses				
		Total	Handling	Storage	Transport	Market
Chinese cabbage						
Beijing						
For the fresh market	5	11–14	3–5		3–4	5
For storage	5	48–62	3–5	40–50	3–4	2–3
For export	5	47–53	47–53			
Hangzhou						
Winter, 25 km to market	5	22.73				22.73
Winter, 180 km to market	5.7	33.3				33.3
Winter, 1600 km to market	6	49.3–61.6		32.7[a]		16.5–28.9
Summer, 800 km to market		41				41
Pak choy						
Winter, 15 km to market	5.7	27.2	2.2			25
Winter, 25 km to market	8.3	28.5	3.5			25
Summer, 15 km to market	7.7	34.5				34.5
Broccoli						
For the domestic market		14.5–22.5	10–15		2	2.5–5.5
For export		6–8	6–8			
Oriental bunching onions						
For fresh market		12–13			5	7–8
For storage		46.5–57		45–55	0.5–1	1

[a] This may include losses during transportation. Sources: Zheng et al. (2001) and Wang and Bagshaw (2001).

Substantial losses occur during both storage and handling of leafy Asian vegetables. Causes of losses tend to be largely of physiological origin. Common reasons for product loss are yellowing, water loss, mechanical damage and exposure to exogenous ethylene. Table 2 summarises the findings in this area.

Factors affecting shelf life

Preharvest factors

The study investigated the effect of preharvest factors such as nutrition, watering, shading and plant age on the subsequent shelf life of leafy vegetables.

Nutrition. The study indicated that applying nitrogen above the optimal rates did not result in reduced shelf life of pak choy.

The spraying of nutrition liquid retarded the rate of colour change (measured as hue angle[3] decline) in pak choy. Potassium sulfate (K_2SO_4) and cytokinin enhanced chlorophyll concentration and extended shelf life. Pak choy sprayed with 50 ppm kinetin 1 hour before harvest had a shelf life of 23 days.

Water stress. Trials of sustained and intermittent water stress indicated mostly negative effects for pak choy. Although shelf life of pak choy could be extended by these stresses, the plant fresh and dry weight is reduced by the application of water stress.

On the contrary, water stress applied during growth does not affect the relative water content of Chinese cabbage leaves immediately after harvest, nor the weight loss of whole heads due to trimming when stored for up to 9 weeks at 0˚C.

Plant age and physiological age of leaves. The age at which pak choy is harvested affects subsequent wilting. Young pak choy plants (20–25 days after emergence) have a high sugar content but are more prone to moisture loss and subsequent wilting. Older pak choy (40 days) are less subject to moisture loss. The age also influences the rate of leaf yellowing. Leaves that are physiologically older yellow more quickly than younger leaves with a similar initial appearance. This was found to be related to initial sugar levels, younger leaves having higher sugar concentrations.

Older leaves in intact Chinese cabbage heads had a greater tendency to yellow than did detached older leaves. Both intact and detached mature leaves showed no apparent changes during the trial period. Detached young leaves, like mature leaves, also showed no obvious changes, but after 1 month the young leaves in intact heads began to swell and expand, with some firm heads ‘exploding’ as a

[3] Hue angle is a measurement of colour in degrees: 0˚ is purple, 90˚ is yellow, 180˚ is blue–green, and 270˚ is blue.

result of the expansion of young leaves. Fifty days later, the senescence of whole head Chinese cabbage was accelerated.

Soluble protein level in both whole heads and detached leaves was highest in young leaves, declining with increasing physiological leaf age. The protein content in older leaves in whole heads fell more rapidly than in other leaves and, after 71 days, almost no soluble protein was detectable in them.

Young leaves maintained a higher sugar content than older and mature leaves of Chinese cabbage.

The vitamin C content in all leaves fell gradually during storage, except in older leaves in whole heads where it fell rapidly after 1 month of storage, coinciding with the expansion of young leaves in the intact heads.

Malondialdehyde, which is a product of lipid (fat) oxidation, can be used as an indicator of senescence. During storage, malondialdehyde concentration in all leaves increased gradually, apart from in older leaves in intact heads where it increased rapidly.

In freshly harvested Chinese cabbage, the distribution pattern of indole acetic acid (IAA) is ‘V-shaped’ from young leaves to old leaves; that is, IAA content initially falls and then rises with the age of leaves. On the other hand, 4 weeks after harvesting, IAA had fallen in the older leaves. The enzyme IAA oxidase can destroy IAA in the tissues and accelerate senescence of the leaves. In Chinese cabbage, it may accelerate leaf abscission (separation of the leaves from the plant). After 4 weeks storage, IAA oxidase activity increases at leaf abscission points, but there is no apparent change in the leaves themselves.

Shading. Shading before harvest had a significant effect on yellowing of pak choy. Also, shaded pak choy was more prone to wilting after harvest, with young leaves losing most moisture. Shading before harvest lowered the initial content of sugar, organic acids and chlorophyll in leaves, and the onset of yellowing occurred more rapidly. Increasing the period of shading before harvest further reduced the initial sugar content of leaves and increased loss of moisture during storage.

However, since average daytime (0800–1800h) temperatures in the field in summer are in the range 26–35˚C, the overall effect of shade cloth was to improve pak choy quality and shelf life.

Harvest factors

Harvest time of day effects on quality. Harvest time of day (dawn/midday/dusk) did not influence quality or storage life of Chinese cabbage. Delaying cooling in the field by a half-hour also had no influence on these parameters.

Pak choy harvested at 0400h and 2000h contained the highest initial and final water contents. Leaves harvested at these times maintained highest water potential.

Postharvest factors

Leaf trimming losses due to ethylene-related leaf abscission are a lower priority than mechanical injury associated with poor handling practices and rots associated with a lack of proper temperature control.

Effects of ethylene and sugar levels on leaf yellowing. Understanding of the senescence process has progressed to the point where the research can be more directly focused on the physiological control mechanisms of yellowing. Sugar levels, rather than ethylene, were found to be the underlying factor controlling yellowing in both broccoli florets and pak choy leaves, thus explaining the poor performance of anti-ethylene agents in extending shelf life. Understanding this mechanism also avoided the potentially expensive error of designing genetically modified broccoli or pak choy based on the premise that low-ethylene production will delay yellowing.

Postharvest wilting of pak choy leaves is primarily due to water loss through the stomata. The percentage of water loss has been measured at 2.8% per hour when held at 35˚C. Complete closure of all stomata occurs between 10 and 15% moisture loss. As expected, wilting occurred more rapidly in leaves with a lower initial water potential.

Leaf yellowing is a factor limiting shelf life of pak choy, occurring most rapidly in the outer, physiologically older leaves. At 20˚C, chlorophyll concentration in the outer leaves dropped from 138 mg/100 g fresh weight to 12 mg/100g fresh weight after 4 days.

Glucose and fructose concentrations decline quickly during storage and appear to be the main energy substrates of pak choy.

However, ethylene plays an important role in the storage freshness of Chinese cabbage, as it is one of the main causes for outer leaves abscissing from the stem during storage. Chinese cabbage has previously been reported to have a climacteric respiratory pattern, but in this study with 'summer' Chinese cabbage no climacteric peaks were discerned. During the first week, heads produced more ethylene, but after 10 days ethylene production became steady at 0.1 µL/100 g/day.

Postharvest lighting. Postharvest lighting also affects the shelf life of pak choy. Leaves stored at 10˚C under normal fluorescent lighting had a shelf life of 10 days, compared with 8.2 days for leaves stored in the dark. However, highintensity lighting (metal halide and high-pressure sodium) significantly reduced shelf life to approximately 6 days, mainly due to 'sunburn' damage.

Packaging. Over-packing of pak choy in China is also a problem that needs to be overcome, possibly by introducing a more friendly form of packaging that is stackable and still relatively cheap.

Impact of outer leaf removal on shelf life of pak choy. Removal of the 4 outer leaves of pak choy plants increased shelf life to over 14 days.

Effects of wounding and mechanical damage. In the wounding experiment, cabbages were subjected to 'cutting', 'dropping', and 'compression' treatments, then stored at 2˚C for up to 9 weeks. No major differences were found between the control and the 'dropping' and 'compression' treatments, but cabbages from the 'cutting' treatment recorded lower ethylene production and trimming losses, and increased weight loss.

The effect of mechanical damage on shelf life of pak choy during storage at 20˚C and 2˚C was studied. Four kinds of damage were induced: bruising, pressing, cutting and stabbing. Severe damage reduced shelf life and hue angle, and increased weight loss.

Effects of storage conditions. Temperature and relative humidity (RH) were found to significantly affect the storage life of oriental bunching onions (Li 2001). Deterioration was more serious at 15˚C and 5˚C than at 0˚C. Storage at –2˚C was satisfactory for long-term storage, with leaves maintaining a good appearance for a further 7 days after withdrawal to 2˚C. Leaves maintained better visual appearance when stored at 95–100% RH than at either 70–80% or 40–50% RH.

Studies have indicated that growing point extension can be reduced by controlled atmosphere storage. Growing points extended 1.2 cm after 5 months at 0°C under controlled atmosphere, in contrast to 5.5 cm under air.

Simulation trials indicated that traditional storage methods (storage of oriental bunching onions in the open air during winter) could not inhibit leaf discoloration or growing-point extension.

For Chinese cabbage, there was little difference between plants stored at 0˚C and 2˚C but, as expected, there were large differences between plants stored at 20°C and the two lower temperatures. One notable difference between plants stored at 0˚C and 2˚C, however, was in the occurrence and severity of patchy papery necrosis, with cabbages stored at 0°C being much worse affected. This supports the idea that this disorder is a form of chilling injury.

Techniques for extending shelf life

The project investigated various techniques for extending the shelf life of vegetables.

Controlled water loss

Controlled water loss to impose a slightly wilted state (2–3% water loss) was imposed following harvest. This was done by laying plants in the sun for 30 minutes. Mechanical damage (snapping of turgid outer leaves) caused by packing shoots into bamboo baskets at harvest was significantly reduced. Subsequent rinsing of plants to remove dirt was also used to re-imbibe shoots with water.

Wilted pak choy could be rehydrated by dipping in water. General appearance, hue angle and original weight could be restored if the moisture loss was less than 10%.

Retention of outer leaves

Traditionally, the outer 9 leaves are removed from Chinese cabbages at harvest. A second trim of 3 leaves is made to remove mechanical injury following transport. The research investigated removing only 6 leaves at harvest, leaving the other 3 leaves to protect against mechanical injury. Consequently, following trimming of 3 leaves after transport, loss of 3 leaves was reduced. This simple change in the handling system has led to an immediate increase in profits for the grower, without any decline in product quality.

Modified-atmosphere packaging

Modified-atmosphere studies with pak choy leaves indicated a range of oxygen and carbon dioxide atmospheres capable of increasing shelf life. An atmosphere of 2% oxygen in conjunction with 5% carbon dioxide was considered most appropriate for commercial use. Shelf life under this atmosphere, as measured by leaf yellowing, was increased by 115%, from 10 days with the control to 14–18 days at 10°C.

Modified-atmosphere packaging (MAP) was found to be extremely effective in retarding yellowing of not only pak choy, but also a range of other leafy brassicas used in the fresh-cut vegetable industry.

For oriental bunching onions, different weights of packaging lead to different oxygen and carbon dioxide concentrations and visual quality during storage.

Packaging in plastic film wrap (clingwrap)

A trial was conducted investigating the use of fully packaged shoots, semi-packed shoots (two-thirds of leaves exposed) and non-packaged pak choy under supermarket conditions (ambient 28˚C). Of the three treatments, semi-packed pak choy performed best. Despite fully packaged pak choy having less water loss, it tended to have more rots than the other two treatments. This simple technology could be transferred across a number of crops, including broccoli, in which moisture loss is a problem between harvest and sale.

Supermarkets preferred the semi-pack option also from an aesthetic standpoint, as the fully packaged shoots tended to fog due to condensation. It was then difficult for the customer to get a clear view of the product.

BVRC has shown film-wrapping to be very effective in reducing moisture loss from the outer leaves of Chinese cabbage. However, rots develop in cabbage heads if they are mechanically damaged. Previously, damaged leaves were removed or dried-out to prevent rot, but films now prevent this. Mechanical injury during handling should be avoided and cheaper methods of temperature control need to be investigated. One simple means of temperature control is to insert bamboo tubes throughout loads. This system of removing heat from loads was not in widespread use, but appeared to be partially effective. Insulated covers, combined with pre-cooling or cooling during transit, may reduce losses.

Anti-transpirants

Anti-transpirants were trialled for pak choy, but their potential for controlling moisture loss was found to be considerably less than film packaging.

Heat shock

Heat shock was found to be effective in extending the shelf life of broccoli. Both ethylene and carbon dioxide production of treated broccoli were lower than in the control, but temperature management during the application of heat shock needs to be refined.

Ice-cooling of pack choy

Ice is a cheap form of cooling to extend shelf life of pak choy, but has not been adopted by growers, for two reasons. First, growers were seldom in a position to easily access ice. Second, loose ice required plastic packing containers which would lead to additional cost to growers. Furthermore, the effect of ice is transitory. Without proper insulating material, ice melted quickly, and temperature returned to near ambient.

Anti-ethylene fumigation

Increasing shelf life by the use of ethylene inhibitors was trialled.

It was found that 1-methylcyclopropene (1-MCP) fumigation was effective at increasing shelf life of broccoli florets by between 20 and 50% over a range of storage temperatures. 1-MCP was found to guard against the deleterious effects of exogenous ethylene, and also reduced endogenous ethylene production. The latter effect appeared to increase shelf life by slowing the rate of floret yellowing. Multiple treatments with 1-MCP did not extend shelf life of broccoli florets beyond that of a single fumigation. Other ethylene inhibitors, such as s-adenosyl methionine and silver thiosulfate, have similar effects on shelf life of broccoli florets. It was also found that MAP was more effective than MCP in extending shelf life.

1-MCP fumigation had only a marginal effect on the shelf life of pak choy stored at 10˚C. It was no more effective at increasing shelf life of pak choy leaves at 20˚C or 2°C than at 10˚C. Similarly, multiple treatments with 1-MCP did not extend the shelf life of pak choy beyond that attained with a single fumigation.

Information dissemination

The findings of the project were disseminated by presenting papers in conferences, conducting extension seminars, and publishing journal articles, books and extension pamphlets. These activities are summarised in Table 3.

Table 3. Communication and information dissemination activities of ACIAR project PHT/1994/016

	Total	1998	1999	2000	2001	2002	2003
ACIAR workshops	1				1		
Farmer/agricultural technician workshop, extension classes	36			1		35 classes with 2380 participants	
Standard pamphlets	1					1	
Newsletter articles	27	3[a]	2	5	6	8	3
Conference presentations	32		4	8	18		2
Books	1					1	
Refereed papers	5		1			1	3

[a] One article was published in 1997. Source: PHT/1994/016 final report.

Capacity building

The project's most significant achievement in capacity building has been in the Hangzhou University of Commerce (HUC, now renamed as Zhejiang Gongshang University). When the project was designed in 1994, there was no postharvest laboratory or infrastructure, and no postharvest courses in the university. Half of the existing chemistry laboratory was converted into a postharvest laboratory at that time.

When the project was approved in 1997, this was the first international project in which the university had participated. The university contributed additional funds to the new postharvest unit for equipment purchase and further upgrading of the postharvest laboratory. In addition, postharvest technology was introduced in to the existing food-science lecture program and has remained there to the present. The reputation of the laboratory resulted in the granting of three government-funded postharvest Master's projects in vegetable storage and shelf-life extension, further strengthening the reputation of their laboratory as a research group in Zhejiang Province.

The research conducted in this project by HUC staff was awarded the First Prize for Research Achievement in 2004 by the Zhejiang Provincial Bureau of Education.

The project leader in HUC, Professor Shen Lianqin, was later appointed the president (equivalent to a vice-chancellor of an Australian university) of the Zhejiang University of Science and Technology (ZUST). Professor Shen established a food science and technology department and built a small postharvest laboratory. Two of the students from the project have since been employed by Professor Shen to conduct postharvest studies (vegetable postharvest research on modified-atmosphere packaging).

As a result of this project, both the HUC and ZUST now have active research groups in postharvest technology.

Capacity building is also reflected in the training of graduate students in both Australian and Chinese institutions.

Inter-institutional linkages have been enhanced through the execution of this project. Researchers from the participating organisations met regularly during the course of the project to exchange ideas and report on research progress. The contact between researchers has been maintained since the completion of the project. Links between QDPI and UA were also generated through the transfer of one of the project leaders, Dr Andreas Klieber, to UA.

The research teams have established close contact with vegetable growers, distributors and retailers and local government extension officers through seminars and meetings. The relationship has been fruitful and researchers from BVRC, HUC and ZU are continuing to work with the farmers, firms and officials in other research projects.

3 Project impacts

The project outputs discussed in the previous chapter are mainly new knowledge about extending the shelf life of leafy vegetables, while the project impacts are changes induced in the production, harvesting and postharvest handling practices inspired by the new knowledge through extension and application of the project outputs.

Project impacts are often categorised as being economic, environmental or social. Economic impacts are usually changes in profitability due to higher demand and/or bigger markets, lower costs, higher yields and/or better quality. Environmental impacts are effects on the natural system, such as reduced waste and pollution or improved environmental quality. Social impacts may include enhanced networking, empowerment of the most disadvantaged groups, recognition of gender contributions and the development of human and social capital. Environmental and social impacts may be quantified in monetary terms, but in many cases they do not have market values.

Some impacts have been realised but, because the project was completed as recently as 2002, some are still only potential. To quantify potential impacts, certain assumptions and projections must be made.

Project impact regions

China

The project was carried out at two locations in China: in Beijing in northern China and Zhejiang in southern China. In each place, the project team worked closely with a number of growers, distributors and agricultural technicians and extension officers. For these participants, the team has a clear picture about the application and adoption rates of the techniques and specific impacts. For others, the team has only a vague idea about the level of adoption and benefits.

In Beijing, two firms were directly involved in the trial and extension of the postharvest research results of the Beijing Vegetable Research Centre (BVRC). These two firms operate a full supply chain of vegetables from growing, harvesting, handling, distributing to retailing. Their supply accounts for about 1% of the Beijing vegetable market.

In Zhejiang, where there are few firms operating supply chains extending from growing to retailing, the situation is different. At this location, two teams worked simultaneously to extend the techniques to vegetable growers and distributors/retailers. A research team at the Hangzhou University of Commerce

(HUC) selected three counties—Huangyan, Kecheng and Longyou—in Zhejiang Province as trial regions. The team worked closely with local extension officers and/or vegetable technicians to apply the research findings. The other research team, at Zhejiang University (ZU), worked with major distributing firms supplying supermarkets in Hangzhou.

In addition to firms and regions that were directly involved in the project, other regions and firms have also benefited from the project in various ways. First, as reported in Table 3, researchers conducted a series of extension seminars and classes, and distributed extension materials, to disseminate the research findings. For example, researchers from HUC ran training classes for army logistics officers responsible for the supply of vegetables to soldiers in southeastern China. Second, the trial firms and regions have hosted visitors from other regions or provinces, which helps dissemination of the information. For example, one of the trial firms in Beijing has received more than 200 visitors since the completion of the project, some of them from as far away as Guizhou and Tibet.

Overall, there are three beneficiary groups of the project results, with different degrees of impact. The firms and areas that are directly involved in the project are the most affected. They are followed by groups in other regions in Beijing and Zhejiang. The least affected groups are in other provinces. The evaluation will focus on the first two groups.

Australia

Although the project was focused on overcoming vegetable postharvest problems in China, some findings of the project had impacts on the Asian vegetable sector in Australia as well.

Information on postharvest storage was presented to 38 non-English-speaking growers of Asian vegetables at a field day in Queensland in 2000. Single page descriptor sheets of postharvest handling series for seven Asian vegetables were produced in 2002 and 2003. The researchers also contributed articles in the *Access to Asian vegetables* newsletter. The modified-atmosphere packaging (MAP) research findings were supplied to a major Australian fresh-cut salad manufacturer. This led to the introduction into supermarkets across Australia of packaged mixes of Asian vegetables (O’Hare et al. 2002).

Economic impacts

Economic impacts are mainly longer shelf life and/or lower losses, which lead to higher profitability.

Beijing

In Beijing, three suites of postharvest handling technology developed by BVRC have been successful: forced-air pre-cooling (Gao et al. 2001), improved transit and packaging practices, and long-term storage technologies for oriental bunching onions.

Pre-cooling after harvest significantly extends the shelf life of vegetables and has become a standard procedure for supermarkets and export produce. Without pre-cooling, it is hard for growers to sell their produce to distributors or exporters. In addition to forced-air pre-cooling, cooling can be done using vacuum or a cold room. Table 4 compares the three methods.

Table 4. Comparison of different pre-cooling methods for fresh vegetables

Pre-cooling	Investment (RMB yuan per tonne capacity)	Time taken to lower temperature to 2°C (hours)	Moisture loss (%)
Forced-air pre-cooling	40,000–60,000	4.0	4–5
Vacuum pre-cooling	400,000–600,000	0.5	Low
Cold-room pre-cooling		20.0	High

Source: Li Wu, Zheng Shufeng, pers. comm., 22 November 2004.

Although the operating costs are similar, a significant advantage of forced air pre-cooling is its lower investment, which is only 10% of vacuum pre-cooling. This is particularly important for Chinese growers who normally grow only a small area of vegetables. Expensive equipment is simply not feasible for them.

Forced-air pre-cooling is also superior to cold-room pre-cooling because it is quicker, and thus incurs lower moisture losses.

The improved transit and packaging practices use stackable plastic baskets with some film wrapping. It was found that this simple method could reduce losses by 5–6% compared with traditional methods. It also reduces the transportation volume by one-third (Li Wu and Zheng Shufang, pers. comm., 22 November 2004).

Losses during long-term storage (from autumn to next summer) of oriental bunching onions were reduced through improved storage conditions. Traditional pit storage reported a loss rate of 82–83%, while the improved storage method developed reported a loss rate of 75% (Li Wu, pers. comm., 22 November 2004).

Zhejiang

In Zhejiang, HUC researchers made simple changes to the traditional handling procedure that significantly reduced postharvest losses. Rehydration and control of water loss led to a reduction in losses of 14.5% (Wang Xiangyang, pers comm., 24 November 2004).

Researchers from Zhejiang University applied improved handling procedures in the supply of pak choy to supermarkets. It was found that losses were reduced by 11–13% (Ying Tiejin, pers. comm., 25 November 2004).

A simple change was made to the postharvest handling of Chinese cabbage by HUC researchers, namely keeping 2–3 outer leaves of cabbage to reduce injury during transportation and storage. This simple change is found to be effective, reducing losses by 22%.

The effects on loss reduction of these improved methods used in Zhejiang Province are summarised in Table 5.

Table 5. Reduction in postharvest losses by application of improved handling methods in Zhejiang Province

Improved handling method	Loss in control sample (%)	Loss with improved method (%)
Controlled water loss and then rehydration – pak choy		
1st day (71.5% sold)	20.5	6.8
2nd day (remaining 28.5% sold)	32.5	16.5
Average	23.9	9.6
Improved postharvest handling for supermarkets – pak choy		
Staying in the field for 30 minutes after harvesting, open-air storage overnight, film wrapping and open-air sale next day	32.6	21.6
Staying in the field for 30 minutes after harvesting, cold-room storage overnight, film wrapping and refrigerated sale next day	32.6	19.6
Keep 2–3 outer leaves of Chinese cabbage		
2nd day	28.5	6.2
3rd day	28.6	6.4
Average (0.65:0.35)	28.5	6.3

Source: Wang Xiangyang, pers. comm., 24 November 2004 and Ying Tiejin, pers. comm., 25 November 2004.

Australia

In Australia, MAP and stabilising temperature have been found to double shelf life in pak choy and other leafy Asian brassicas (Table 6). Extending shelf life means that Asian vegetables such as pak choy can be included in fresh-cut salad mixes, adding both visual appeal and flavour to salads (O'Hare et al. 2000; 2001).

Table 6. Change in shelf life (days) of leafy Asian brassicas with application of modified-atmosphere packaging in Australia[a]

	Control	2% O_2	5% CO_2	2% O_2 + 5% CO_2
Pak choy	8.5 (a)*	11.5 (b)	14.0 (bc)	18.0 (c)
Tatsoi	10.5 (a)	15.5 (b)	17.0 (bc)	19.5 (c)
Choy sum	10.0 (a)	14.5 (b)	14.5 (b)	20.5 (c)
Chinese mustard	7.5 (a)	10.0 (a)	13.0 (b)	19.0 (c)
Mizuna	15.0 (a)	16.6 (a)	16.5 (a)	21.0 (b)
Mibuna	18.0 (a)	30.5 (b)	20.5 (a)	18.5 (a)

[a] Letters in brackets denote the significance of the difference in shelf life: figures (within a row) followed by the same letter are not significantly different (p<0.05).
Source: Table 1 in O'Hare et al. (2000).

Environmental impacts

An important environmental benefit from the aforementioned reductions in losses would be a concomitant reduction in urban rubbish.

Some of the methods reduce the transportation volume by leaving some of the residue of handling activities in the field. This would help improve the organic structure of the soil. Another second-round effect would be a reduction in traffic jams and air pollution, problems which have become serious in most Chinese cities.

Social impacts

As discussed in the previous chapter, the most significant social outcome has been in capacity building and human-capital accumulation. The networking among researchers, government officials, growers and distributors is also notable.

However, it is hard to quantify these impacts in monetary terms. The following are some of the difficulties:

- Most social impacts usually do not have a market value. For example, enhanced networking is valuable, but how much is it worth?
- Putting a monetary value on specific social impacts may also involve ethical issues, especially when valuation involves people. For example, how to value a PhD or Masters graduate? Certainly, the labour market may provide some information, but will it reveal the true value of the graduate? More interestingly, which labour market information should we use to estimate the value of a foreign student receiving education in Australia?
- Some of the impacts are potential and they tend to work jointly with other factors. For example, how much does a specific research project contribute to someone's knowledge base?

In addition, some of the social impacts may already be reflected in the economic benefits. For example, accumulation of knowledge is an important part of human capital, and the benefits of applying the knowledge have been addressed in the economic part.

Finally, Beijing and Zhejiang are among the most developed regions in China and already have high levels of social development. Therefore, other social impacts, such as empowerment of women through increased income, improved health due to increased vegetable consumption by poorer farmers, higher levels of schooling reached because families can afford to send their children longer, are likely to be insignificant.

4 Economic analysis of the project

Evaluation methodology

Figure 4 illustrates the approach taken to evaluate the project. Project benefits are calculated by comparing the impacts from the improved methods developed by the project with the situation if the project had not been undertaken. The benefits are net benefits per unit of vegetable product of applying improved methods, after deducting the additional costs of applying these methods.

Annual benefits are then generated based on this ‘unit net benefit’ by applying projections of future production and adoption profiles. The evaluation period is 30 years after the completion of the project.

The project budget is used to calculate the annual net benefit of the project, and finally the net present value (NPV) and benefit–cost ratio (BCR) are calculated at particular discount rates.

Some points of the evaluation approach are worth emphasising. These include the structure of the vegetable markets, the selection of an appropriate baseline and the exchange rate adopted.

Market structure

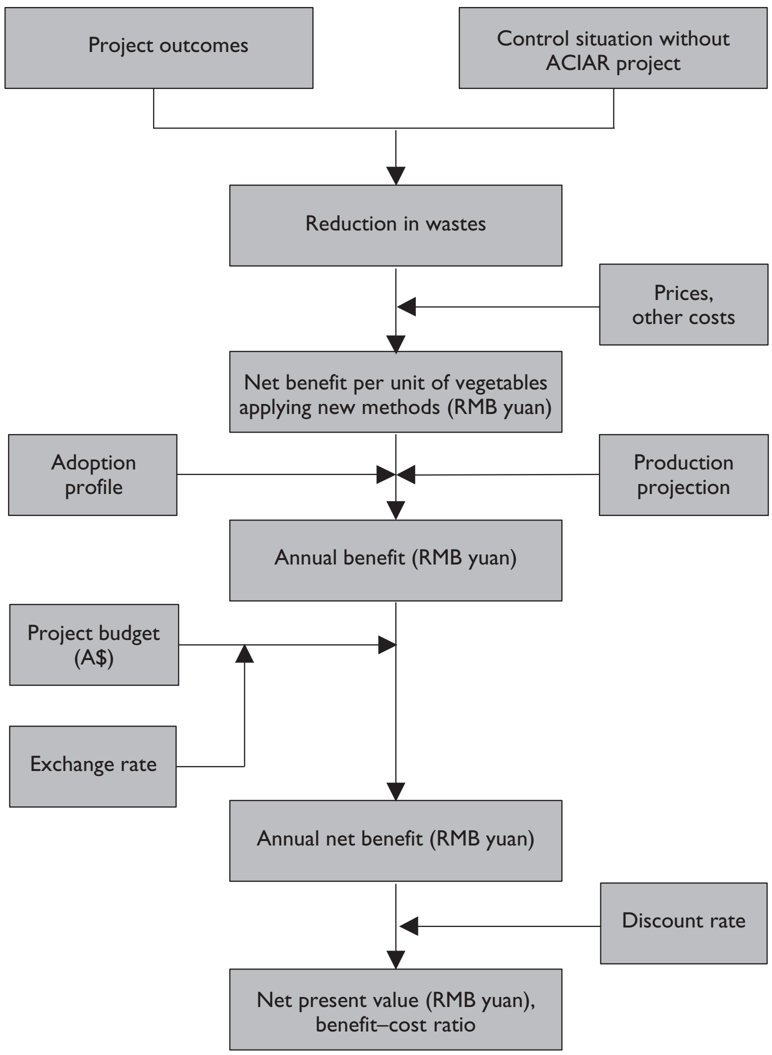
First, there is no significant distortion observed in the vegetable market in China. There may be some natural monopoly for some special vegetables, but the market is fairly competitive for the four types of vegetables we are concerned with. The market was once dominated by state-owned distribution firms, but the situation has long since changed. Vegetable distribution has been fully liberalised and virtually anyone can engage in these activities.

Second, the evaluation is carried out in a partial-equilibrium setting. It is assumed that vegetable prices are not affected by changes in supply resulting from the research-induced reduction in losses. This is because products affected by the research account for only a very small share of the market. Hence, the benefits are measured as the change in producer profits. Changes in consumer welfare are not considered.

The baseline

The benefit of the research project is evaluated against a baseline, which is a scenario assuming that the ACIAR-funded project did not take place. An appropriate baseline is the key to the evaluation result.

Figure 4. Approach to the evaluation of ACIAR project PHT/1994/016 on extending the shelf life of leafy vegetables



To determine the baseline, the Chinese researchers were asked what they thought would have happened in the absence of the ACIAR-funded project. Researchers in Beijing and Zhejiang responded differently to this question.

Researchers in Beijing believe that the Chinese Government would have funded the postharvest research even if the ACIAR-funded project had not gone ahead. This belief is based on the fact that, historically, postharvest handling, especially storage, has been a focus of vegetable research in Beijing and other northern Chinese cities. This is because most species of vegetables cannot be grown in the winter due to unfavourable weather. In addition, along with higher income and improved logistics, the vegetable distribution system has changed significantly in Beijing. The scattered, roadside vegetable stalls that were once dominant have been replaced by fresh-food markets, community vegetable markets (similar to the 'fruit barns' in Australia) and supermarkets. The pace of this transformation increased as a result of Beijing being nominated as the host city for the 2008 Olympic Games. The Beijing Municipal Government plans that, by 2008, 70–80% of the city's vegetables will be marketed through supermarkets and community vegetable markets. Therefore, the researchers believe that the Chinese Government would have funded similar research projects after July 2001, when it was announced that the 2008 Olympic Games would be in Beijing. Hence, the delay in starting a comprehensive postharvest study such as the one being examined here would have been 3 years at the most (Li Wu and Zheng Shufang, pers. comm., 22 November 2004).

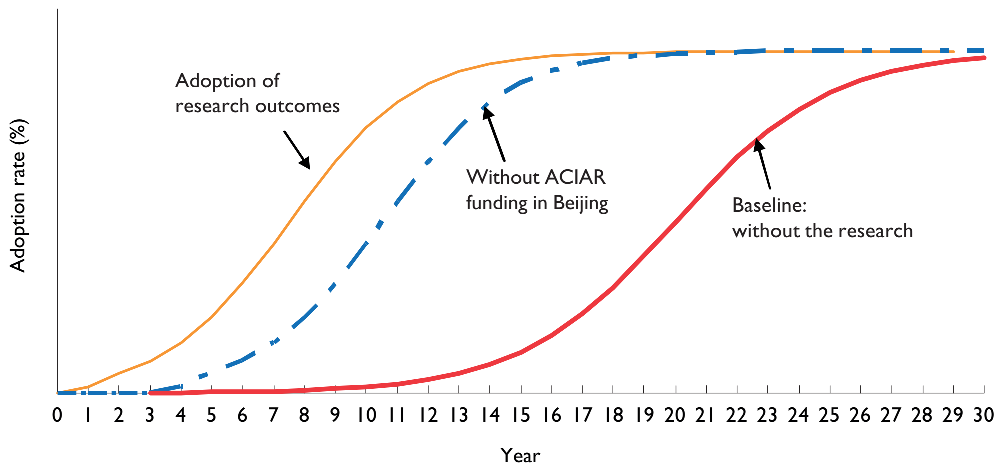
In contrast, Dr Wang Xiangyang from HUC thought that, without ACIAR funding, postharvest research on leafy green vegetables would not have been undertaken in Zhejiang. This is because vegetables can be grown and supplied in the province almost all year round. Hence, little attention has been paid to postharvest processing and storage. Two additional reasons why postharvest handling research was not given priority in government are that farmers in Zhejiang are better off than those in other provinces and the staple vegetables grown there are regarded as low value added. For these reasons, postharvest vegetable laboratories were not previously set up in Zhejiang. Government officials in Zhejiang in charge of research grants, when they reviewed the project outcomes, were surprised that the ACIAR-funded project could generate large benefits (Wang Xiangyang, pers. comm., 24 November 2004).

In line with factors in the above discussion, the baselines can be determined for Beijing (as illustrated in Figure 5) and Zhejiang.

The upper solid line in Figure 5 depicts the projected adoption profile of the research outcomes achieved by the project. If ACIAR had not funded the research project, the Chinese and/or Beijing governments would fund it in Beijing 3 years later. The dotted line depicts a scenario in Beijing in which 'without ACIAR funding' similar results would be produced by projects funded by the Chinese governments, with a 3-year delay. This is the baseline for evaluating the project impacts in Beijing.

The benefit of the research in Zhejiang, on the other hand, is not the difference between the adoption profile and the horizontal axis, which tends to over-estimate the benefit. Even if there are no projects like the one under evaluation, there could still be some 'autonomous' improvements in the technology and gradual adoption of improved techniques resulting mainly from 'learning by doing' and spill-overs. Therefore, the correct baseline should be the case of autonomous improvement without the research—the lower solid line in Figure 5.

Figure 5. Selection of the baseline—'without ACIAR funding' versus 'without the research'—for evaluation of ACIAR project PHT/1994/016



Exchange rate

The evaluation uses the market exchange rate to convert the benefits and costs in the Chinese currency, RMB yuan, into Australian dollars. Because the yuan is pegged to the US dollar—currently at 8.28 RMB yuan/US$—it is often argued that the market exchange rate does not reflect the true value of the Chinese currency. There have been ongoing pressures on the Chinese Government to adopt a more flexible exchange regime, more specifically, to let the yuan appreciate. A survey of 33 prominent analysts found that supporters for the view that the yuan is undervalued outnumbered the doubters by more than two to one (Anon. 2003). However, it is extremely difficult to estimate an 'equilibrium' exchange rate and current methodologies give a wide range of estimates.

One methodology is a purchasing power parity (PPP) calculation of the equilibrium RMB exchange rate. Ren and Chen (1995) produced an estimated

PPP exchange rate of between 0.87 and 1.18 RMB yuan/US$ based on their collection of matching price data in China and the United States for 1986. This compares with an estimate of 0.99 for 1986 in the World Development Indicators. Using the data from the 2003 edition of the World Bank's World Development Indicators, Bosworth (2004) reported a PPP estimation of the equilibrium RMB exchange rate of roughly 2 RMB yuan/US$. These estimates are in the category of absolute PPP calculation; that is, they make direct comparison of prices of a bundle of 'identical' goods in two countries.

However, for a number of reasons, absolute PPP does not hold across nations with different levels of development. The most important reasons are the existence of non-tradable goods and services and of significant transactions costs—transport, trade barriers, taxes and information costs. Bosworth (2004) estimated an exchange rate of about 5.8 RMB yuan/US$, after correcting for cross-country per-capita income differences. In contrast, measures of relative PPP based on cumulative cross-country differences in inflation rates from a base period when the balance of payments and real exchange rate were assumed to be in balance, typically show that the RMB yuan is roughly at the right level. Nevertheless, selecting a good 'base' period for relative PPP calculations is also problematic for China; for example, whereas China's current account was close to equilibrium in 1994, its capital account was not.

The major alternative to PPP-based exchange-rate norms is to derive an estimate of an exchange rate that would be consistent with macroeconomic balance. Using this framework, Bosworth (2004) found that the Chinese currency is not fundamentally undervalued.

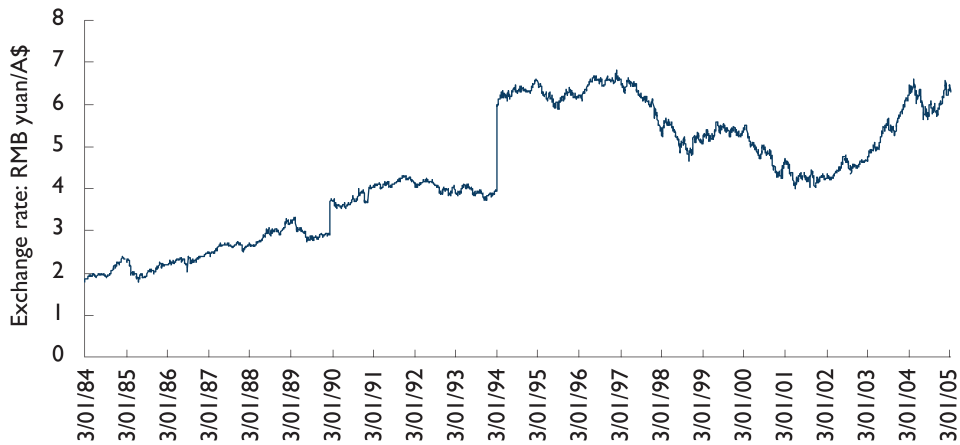
It is even more difficult to predict future exchange rates. Historical data provide little guidance. This is especially true for the Chinese case. Figure 6 shows the daily Australian dollar–RMB yuan exchange rate since 3 January 1984, as plotted by the Reserve Bank of Australia (RBA 2005). The exchange rates shows significant fluctuations.

Before 1994, there was gradual depreciation of the RMB yuan against the Australian dollar; from A$0.50/yuan to A$0.25/yuan in 10 years. This depreciation was in line with broader economic reform in China. Many economists regarded the depreciation as taking the distorted exchange regime in the right direction. Since January 1994 when a sharp depreciation the yuan occurred, the currency has been pegged to the US dollar at about 8.28 RMB yuan/US$, and the fluctuation in the exchange rate of Australian dollar to the RMB yuan is therefore mainly the result of movement of the Australian dollar against the US dollar.

The future of the exchange rate is thus contingent on two factors: when and if the current pegging regime is changed, and how long the Australian dollar maintains its current relative strength. Unfortunately, no one can be sure of the answer to either question.

Although it seems certain that a more flexible exchange regime will emerge in China in 30 years, there is no sign that the Chinese Government will change the current pegging system in the near future. Those speculating on the appreciation of the yuan over the past 2 years, have been repeatedly disappointed. Furthermore, as discussed above, there will be no significant appreciation of the yuan even if a floating RMB system is adopted at some time in the future.

Figure 6. Historical Australian dollar–RMB yuan exchange rates[a]



[a] Daily rate at 4 pm.
Data source: Reserve Bank of Australia (2005).

Figure 7. Historical Australian dollar–US dollar exchange rate[a]

[a] Daily rate at 4 pm.
Data source: Reserve Bank of Australia (2005).

The long-term trend for the Australian dollar is also not clear. Although at the time of this assessment in late 2004 it was at the highest level against the US dollar for 7 years, and the record high trade deficit was raising pressure for its depreciation, to some it had just merely recovered to its 1996 level, and was still 20% below its value in March 1984 (Figure 7).

Therefore, the average of the daily exchange rate in the past 6 months, which is just above 6 yuan/A$, is used in the evaluation to convert future benefits and costs in RMB yuan to Australian dollars. The rate is below the current level of 6.3 yuan/A$, and above the 10-year average of 5.5 yuan/A$ since the RMB yuan was pegged to the US dollar.

Another reason for adopting a constant future exchange rate is that it will minimise the discrepancy between the results in RMB yuan and those in Australian dollars.

To summarise, this evaluation uses the market exchange rate to convert Chinese benefits and costs to Australian dollars. In particular, historical annual averages of daily exchange rates are used for the period between 1998–99 and 2004–05, and the current average extends to the end of the evaluation period (Table 7). In addition, a full set of cost and benefit estimates is reported in the Chinese currency in parallel with the estimates in Australian dollars. Readers who have doubts about the exchange rates adopted may directly refer to those estimates.

Table 7. Exchange rates (A$ to RMB yuan) used in the evaluation of project benefits

Year	RMB yuan per Australian dollar[a]
1998–99	5.1911
1999–00	5.2070
2000–01	4.4546
2001–02	4.3341
2002–03	4.8354
2003–04	5.8995
2004–05	6.0777
After 2005	6.0777

[a] Annual average of daily exchange rate for the period from 1998–99 to 2003–04; 2004–05 exchange rate is the average of daily rate between 1 July 2004 and 11 January 2005

Source: Author's calculation based on RBA (2005).

Project budget

The total budget of the project was a little over A$3 million (RMB yuan 14.9 million) over a 4-year period. About 29% of the budget was funded by ACIAR. The remaining 71% was contributed by the commissioned and collaborating organisations. Just over 20% of the ACIAR funds were sent to China (Table 8).

Table 8. ACIAR project PHT/1994/016 budget (A$)

	Year 1 01/07/98–30/06/99	Year 2 01/07/99–30/06/00	Year 3 01/07/00–30/06/01	Sub-total of first phase	Year 4 01/07/01–30/06/02	Total
ACIAR funds	249,968	242,131	251,886	743,985	150,000	893,985
Other 'in-kind' contributions	587,547	594,547	600,047	1,782,141	382,533	2,164,674
Total	837,515	836,678	851,933	2,526,126	532,533	3,058,659
Total in RMB yuan	4,347,625	4,356,593	3,795,040	12,499,257	2,372,233	14,871,490

Source: ACIAR project documents.

'Unit net benefits'

Beijing

Forced-air pre-cooling

As mentioned in the previous chapter, forced-air pre-cooling has similar operating costs to vacuum pre-cooling, but the investment required is only 10% of that needed for vacuum pre-cooling. The benefit of forced-air pre-cooling is therefore calculated as the saving in interest payments and depreciation. Assuming an interest rate of 10% and depreciation over 10 years, the annual interest payments and depreciation of forced-air and vacuum pre-cooling, for a 1-tonne capacity unit, are, respectively, 8000–12,000 yuan and 80,000–120,000 yuan. Because vacuum pre-cooling takes only one-eighth of the time of forced-air pre-cooling to achieve the required temperature (30 minutes versus 4 hours), vacuum pre-cooling equipment of 1-tonne capacity can treat 13,140 tonnes of commodity per year, whereas a forced-air pre-cooling unit of the same capacity can treat only 1642.5 tonnes annually. As a result, forced-air pre-cooling saves 1.22–1.83 yuan, or A$0.20–0.30 (at the exchange rate of 6.0777 yuan/A$) per tonne of vegetables treated (Table 9).

Table 9. Benefit of forced-air pre-cooling over vacuum pre-cooling of vegetables

	Unit	Vacuum pre-cooling	Forced-air pre-cooling
Investment	yuan	400,000–600,000	40,000–60,000
Annual interest payment @ 10%	yuan	40,000–60,000	4000–6000
Depreciation over 10 years	yuan	40,000–60,000	4000–6000
Annual treatment of 1-tonne-capacity unit operating 18 hours per day, 365 days per year	tonnes	13,140	1642.5
Annual interest payment and depreciation per tonne of treatment	yuan/tonne	6.09–9.13	4.87–7.39
Saving in interest payment	yuan/tonne A$/tonne		1.22–1.83 0.20–0.30

Source: Author's estimates based on information from Table 4 and assumptions explained in the text.

Improved packaging and transport procedures

The improved packaging and transport procedures entail replacing plastic bags with stackable plastic baskets, proper film wrapping and reducing the frequency of changing containers. This technique has been applied in various vegetable species, including cabbage, broccoli, spinach, lettuce, celery and pak choy. Table 10 gives estimates of the benefits of this technique.

Table 10. Benefits of improved packaging and transport procedures for fresh vegetables

Item	Unit	Cabbage	Broccoli	Spinach	Lettuce	Celery	Pak choy
Price[a]	yuan/tonne	548.74	1426.25	1524.00	1176.67	525.17	1282.50
Value of reducing waste by 6%	yuan/tonne	32.92	85.58	91.44	70.60	31.51	76.95
Additional plastic basket cost	yuan/tonne	2.97	3.96	4.75	4.75	4.75	4.75
Additional plastic film cost	yuan/tonne	2.50	3.33	4.00	4.00	4.00	4.00
Additional labour cost	yuan/tonne	5.00	5.00	5.00	5.00	5.00	5.00
Additional transportation cost	yuan/tonne	–10.00	–10.00	–10.00	–10.00	–10.00	–10.00
Benefits to growers/distributors	yuan/tonne	22.45	73.28	77.69	56.85	17.76	63.20
Environmental benefits — reduction in urban garbage disposal costs @ 103.9 yuan/tonne[b]	yuan/tonne	6.21	6.21	6.21	6.21	6.21	6.21
Unit net benefit	**yuan/tonne** **A$/tonne**	**28.66** **4.72**	**79.49** **13.08**	**83.90** **13.80**	**63.06** **10.38**	**23.97** **3.94**	**69.41** **11.42**

[a] Average price in Beijing vegetable wholesale markets.
[b] The disposal costs are 1999 estimates as given in Zhang (1999).
Source: Author's estimates based on discussions with Li Wu and Zheng Shufang on 22 November 2004.

Depending on the vegetable species, the value of reduced waste ranges from 31.5 to 91.4 yuan per tonne. After taking account of the additional costs of baskets, plastic film and labour, and savings in transportation cost, the net benefit gained by growers and distributors is between 17.8 and 77.7 yuan per tonne. In addition, an environmental benefit valued at 6.21 yuan per tonne of vegetable is gained by society due to the reduction in the cost of urban garbage disposal. Therefore the unit net benefit ranges from 24 to 83.9 yuan (A$3.95–13.80) per tonne.

The following assumptions are made in estimating the net benefits:

- vegetable prices used are the average prices in Beijing vegetable wholesale markets
- waste is reduced by 6% using the new approach
- transport volume is down by one-third with the new approach
- labour cost increases by 10% with the new approach

- a stackable plastic basket with a capacity of 25–40 kg depending on the vegetable species costs 25 yuan—the life of the basket is 5 years, and each year about 40% of baskets go missing—the turnover rate of a basket is 4 days
- film cost is about 0.1 yuan per basket
- environmental benefit is measured by the saved garbage disposal expenses which were estimated at 103.9 yuan per tonne of residential garbage. (Zhang 1999).

It should be pointed out that the environmental cost differs from the garbage fee charged to urban residents. The fee, currently set at 3 yuan per month per household for those with official Beijing residential status or 2 yuan per month for others, does not cover the full cost of garbage disposal. In Hangzhou, the fee collected accounts for only 5% of the actual cost of disposal (Mao 2004).

Improved storage of oriental bunching onions

When oriental bunching onions are harvested in autumn, the retail price is between 0.8 and 1 yuan per kilogram. The price in spring is between 1.4 and 1.6 yuan/kg. If they are stored until next summer, they can be sold at 5.4–5.6 yuan/kg. However, huge losses occur during the long storage, with usually only 17–18% being left for sale at the end of storage. With optimally controlled temperature and humidity, the rate of loss can be reduced, leaving up to 25% saleable commodity after storage. After taking account of the storage cost, there is a profit margin between 0.4 and 0.6 yuan/kg (Li Wu, pers. comm., 22 November 2004). Therefore, the improved storage technology has a benefit of 32–48 yuan, or A$5.27–7.90, per tonne of produce.[4]

In addition, the reduction of 80 kg in waste helps reduce the cost of urban garbage disposal. The disposal cost is 103.90 yuan per tonne (Zhang 1999), giving an environmental benefit of reduced waste of 8.31 yuan (A$1.37) per tonne. Therefore, the unit net benefit is 40.31–56.31 yuan/tonne (A$6.64–9.27/tonne).

Zhejiang

Controlled water loss and rehydration

It is estimated that the unit net benefit of controlled water loss and rehydration is 141.06 yuan (A$9.19) per tonne of pak choy produced (Table 11). Most of the benefits (126.70 yuan or A$8.26) go to growers in the form of reduction in waste. Associated with the reduction in vegetable waste, urban residential garbage

[4] The reduction in losses is 80 kg/tonne of produce stored and the benefit is thus 3248 yuan/tonne when the price is 40.6 yuan/kg.

disposal costs fall by 14.36 yuan (A$0.94) per tonne of vegetable, which is a benefit to society. The estimation is based on the following key assumptions:

- pak choy price is 900 yuan/tonne
- pak choy is sold over 2 days, with 71.5% of a batch sold or wasted on the first day
- water costs 2.5 yuan per tonne of vegetable treated
- there are no additional labour costs
- environmental cost in the form of urban residential garbage is 100 yuan/tonne (Mao 2004; Yu 2004).

Table 11. Benefit of controlled water loss and rehydration in postharvest handling of pak choy

	Unit	Traditional treatment	Controlled water loss and rehydration	Change
Pak choy price	yuan/tonne	900	900	
1st day rate of loss	%	20.5	6.8	
1st day loss	tonne	0.147	0.049	–0.098
1st day sale	tonne	0.568	0.666	0.098
2nd day rate of loss	%	32.5	16.5	
2nd day loss	tonne	0.093	0.047	–0.046
2nd day sale	tonne	0.192	0.238	0.046
Total sale	tonne	0.761	0.904	0.143
Total sale revenue	yuan	684.72	813.92	129.20
Water cost	yuan		2.50	2.50
Benefits to growers	yuan		126.70	
Environmental cost @ 100 yuan/tonne[a]	yuan	23.92	9.57	–14.36
Environmental benefits to the society	yuan		14.36	
Unit net benefit	**yuan/tonne** **A$/tonne**		**141.06** **23.21**	

[a] According to Yu (2004) and Mao (2004), annual residential garbage in Hangzhou is about 1 million tonnes, while the disposal cost is 99 million yuan.

Source: Author's estimates based on Wang (2003a), Mao (2004) and Yu (2004).

Improved postharvest handling of pak choy for supermarkets

The net benefit of the improved postharvest handling procedure of pak choy for supermarkets is estimated to be between 295.05 and 392.31 yuan/tonne (A$48.55–64.55/tonne) (Table 12). About 282.07 to 381.34 yuan (A$46.41–62.74) goes to distributors and retailers, while the remaining benefit is environmental and accrues to society as a whole.

Table 12. Benefit of improved postharvest handling of pak choy for supermarkets

	Unit	Traditional method	New method one[a]	New method two[b]
Raw vegetable	kg	1000.00	1000.00	1000.00
Cleaned vegetable	kg	674.30	784.00	804.10
Revenue from selling cleaned vegetable @4.2 yuan/kg	yuan	832.06	3292.80	3377.22
Cost of purchasing raw vegetable @1.92 yuan/kg	yuan	1920.00	1920.00	1920.00
Transportation cost	yuan	30.00	30.00	80.00
Labour cost	yuan	144.00	192.00	192.00
Wrapping cost	yuan		31.40	32.20
Electricity cost	yuan			78.10
Equipment depreciation	yuan			54.79
Profit	yuan	738.06	1119.40	1020.13
Benefits to distributors and retailers	yuan		381.34	282.07
Environmental cost @ 0.10 yuan/kg[c]	yuan	32.57	21.60	19.59
Environmental benefits to the society	yuan		10.97	12.98
Unit net benefit	**yuan/tonne** **A$/tonne**		**392.31** **64.55**	**295.05** **48.55**

[a] Entails holding in the field for 30 minutes after harvest, transporting with normal trucks, storage at ambient temperature, wrapping with plastic bags and sale at ambient temperature in the supermarket.
[b] Similar to New method one, except transport is in refrigerated vans, storage is in cool rooms overnight, and sale is from supermarket refrigerated cabinets.
[c] According to Yu (2004) and Mao (2004), annual residential garbage in Hangzhou is about 1 million tonnes, and the disposal cost is 99 million yuan.
Source: Author's estimates based on Ying (2003), Mao (2004) and Yu (2004).

Keeping 2–3 outer leaves on Chinese cabbage

Table 13 reports the estimated benefits of keeping 2–3 leaves outer leaves on Chinese cabbage during transport. This simple approach yields a benefit of 130.24 yuan (A$21.43) per tonne of Chinese cabbage sold. An interesting point is that the urban garbage disposal cost is actually lower when the outer leaves are kept. Although a greater mass of commodity is transported to cities, the reduction in wastage is much larger.

It is difficult to separate the gains to growers, distributors and retailers. Wang (2003b) argues that growers gain from the new approach by 17.5 yuan per tonne of Chinese cabbage. Even though cabbages with trimmed heads receive a higher price than those which do not have their outer leaves trimmed (500 yuan/tonne versus 450 yuan/tonne), the gain in price is not enough to compensate for the loss in weight (865 kg versus 1 tonne). However, it is hard to understand why growers did not adopt the more profitable approach in the first place, given that it requires no additional effort. Higher transport costs cannot explain this because the gains to growers are higher than the additional transport costs.

Table 13. Benefit of keeping 2–3 outer leaves on Chinese cabbage during transport

	Unit	Traditional handling	Keeping outer leaves	Change
Weight of Chinese cabbage	kg	1000.00	1000.00 (1156.07 kg transported to cities)	
Wasted	kg	285.35	62.00	–223.35
Sold	kg	714.65	938.00	223.35
Other	kg		156.07	156.07
Revenues @ 0.60 yuan/kg	yuan	428.79	562.80	134.01
Transportation cost	yuan	33.00	37.50	4.50
Additional labour cost (loading etc.)	yuan		6.00	6.00
Environmental cost				
Total urban garbage	kg	285.35	218.07	–67.28
Cost @ 0.10 yuan/kg[a]	yuan	28.54	21.81	–6.73
Unit net benefit	**yuan/tonne**		**130.24**	
	A$/tonne		**21.43**	

[a] According to Yu (2004) and Mao (2004), annual residential garbage in Hangzhou is about 1 million tonnes, and the disposal cost is 99 million yuan.

Source: based on Wang (2003b) with some adjustment by the author, Yu (2004) and Mao (2004).

One explanation is as follows. To encourage growers to adopt the new method, distributors and/or retailers are willing to pass on some of their gains to growers. If so, growers gain 23.5 yuan/tonne (17.5 yuan rise in sales revenue plus 6 yuan of labour saving in picking outer leaves), while distributors and retailers gain 100 yuan/tonne, and society as a whole gains 6.73 yuan/tonne of environmental benefits.

Australia

As shown in Table 6, modified atmosphere packaging (MAP) doubles the shelf life of some leafy Asian vegetables. Longer shelf life means lower losses. MAP is an expensive technology, however, and is justified only for the fresh-cut salads for which a higher price can be charged.[5] Air Liquide Group (2004), for example, reports that the packaging materials alone (gases and films) account for 11% of the total cost of the product.

We understand that mixes of baby Asian salad vegetables were not available, and that Asian leafy brassicas were a constituent of other lettuce-based salad mixes, before the MAP research findings were supplied to a major Australian fresh-cut salad manufacturer, and that the manufacturer had already applied some MAP technologies in producing fresh-cut salads (Tim O'Hare, pers. comm., 13 April 2005). It is therefore necessary to distinguish between the new mixes of baby

[5] For example, processed pak choy returns A$13.00/kg, while intact produces return only $1.50/kg for wholesale and $3.00/kg for retail (PHT/1994/016 proposal, page 18).

Asian salad vegetables and the older products (other fresh-cut salads) in estimating the net benefits of applying the MAP technology from the project.[6]

For the older products, the research has provided improved MAP technologies. Because there has already been investment in equipment and application of gases and films, there might be no significant additional cost to apply the new MAP technologies. However, for that to be so, one would need to assume that the shelf life of the older products was limited by their Asian leafy constituents, and this was not necessarily the case. The manufacturers could, for example, simply remove the Asian leafy vegetables to extend the shelf life of the mix.

For the new products, the benefit of the MAP research should be evaluated against a hypothetical scenario in which the new products are produced and marketed without MAP technology. In general, the additional cost of applying the MAP research findings would include gases, packaging films and equipment-related costs. In this case, as the manufacturer has already purchased MAP equipment for the older products, it could be assumed that existing equipment would be used efficiently to make the new products and there would be no extra depreciation costs. However, other equipment-related variable costs, such as electricity and manpower, must be considered, together with extra packaging costs, such as gases and new types of films.

According to the project PHT/1994/016 research proposal, losses of Australian Asian vegetables are of the order of 10%. Considering that the rate of losses is higher for the fresh-cut salads, doubling shelf life would reduce losses by 10% of total produce. With this assumption, the maximum net benefit of applying the new MAP technology to older products would be 10% of the final produce value — assuming no extra cost of applying new technology. However, as the shelf life of the product was not necessarily limited by the Asian leafy constituents, which account for about 10% of total produce, we assume that there is a 10% chance of achieving the maximum benefit; that is, on average, the unit net benefit is 1% of the produce value for the older products.

On the other hand, given the fact that gases and films account for 1 and 10% of the final produce value (Air Liquide Group 2004), it is assumed that the extra costs of applying the MAP technology to the new mixes of baby Asian salad vegetables (costs of gases, extra cost of new films, electricity and so on) are 9% of final produce value. Reducing losses by 10% would imply a unit net benefit of 1% of the produce value.

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[6] MAP research results were supplied to a major Australian fresh-cut salad manufacturer. Since then, mixes of baby Asian salad vegetables have been released across Australia. Asian leafy brassicas also are a constituent in other lettuce-based salad mixes, but this was already the case before the research results were released, according to the 2001–2002 annual report of project PHT/1994/016.

We conclude then that the expected unit net benefit with both the older and new salad mixes is about 1% of the produce value.

Production projections

Vegetable production is projected on the basis of past trends. It is assumed that the growth rate will decline over time (Table 14). Figure 8 shows the resultant projection of total vegetable production in Beijing and Zhejiang.

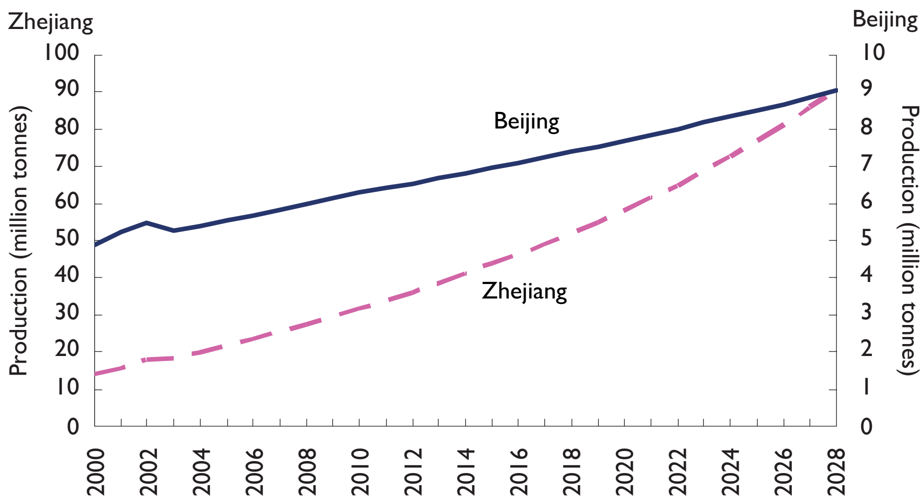
Table 14. Projected annual growth rates (%) in vegetable production in China

Period	China	Beijing	Zhejiang
2000–2005[a]	8.42	2.54	9.77
2006–2010	6.42	2.54	7.77
2011–2015	5.42	2.04	6.77
2015–	4.42	2.04	5.77

[a] These are the actual growth rates from 2000 to 2003.
Source: Ministry of Agriculture, Department of Market and Economic Information (2004).

Predictions of future production of specific vegetable species follows the same methodology when historical data are available. When the data are not available, the general trend in vegetable production in the particular region is used. These projections are shown in Figures 9–16 together with profiles of the adoption of improved postharvest techniques and baseline for benefit estimation.

Figure 8. Projections of vegetable production in Beijing and Zhejiang



Adoption profiles

The evaluation period is 30 years, starting from 1998 when the research project began. However, the new findings of the project were not applied until 2001. In this section, unless otherwise specified, information about current adoption rate was gathered from Chinese researchers, while the future adoption profiles are assumed based on discussions with them during the field trip.

Forced-air pre-cooling

Currently, the technology has been widely applied in the handling of lettuce, spinach, broccoli, pak choy etc. The adoption rate is estimated to be 10% in the whole Beijing market. It is assumed that the rate will reach 40% in the evaluation period (Figure 9).

All export vegetables need some form of pre-cooling. Currently 10% of the vegetables are cooled using forced-air pre-cooling. It is assumed that the rate will increase to 40% (Figure 10).

Figure 9. Production of lettuce and other vegetables suitable for forced-air pre-cooling and adoption rate of the technology in Beijing

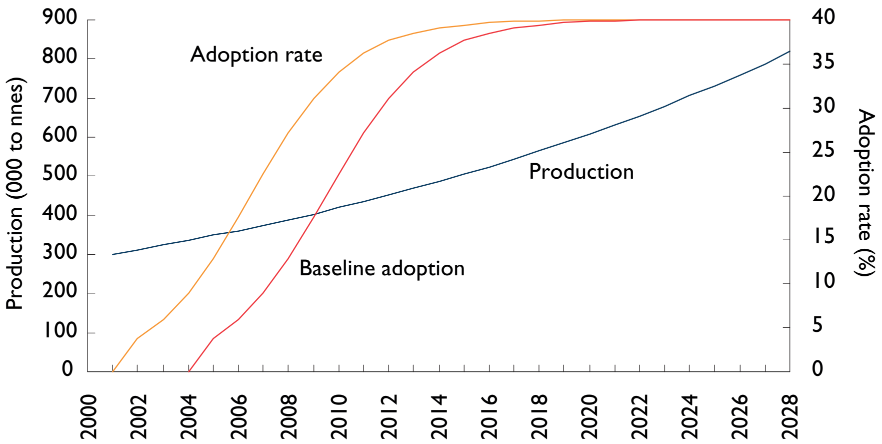
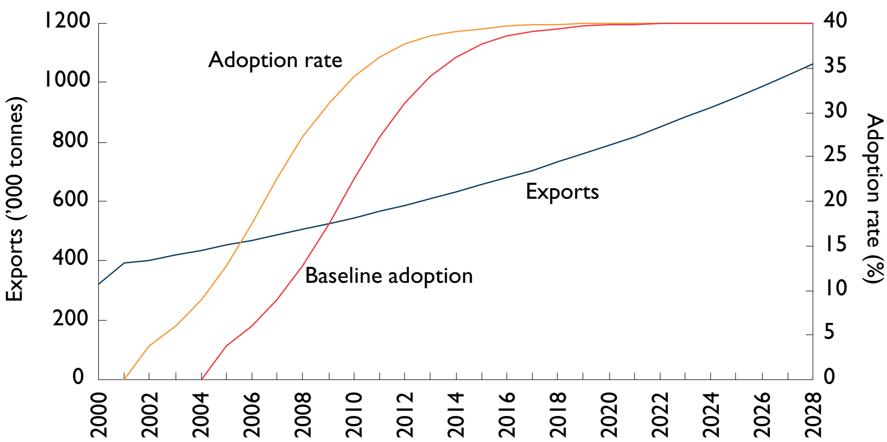


Figure 10. Projection of vegetable exports and adoption of forced-air pre-cooling in Beijing



Improved packaging and transit technology

This technology has also been widely applied in various vegetable species. The adoption rate is currently about 20% in the whole Beijing market.

Because of the Olympic Games in 2008, the Beijing government has set an agenda to develop fresh-food supermarkets and to promote clean vegetables. It is therefore predicted that the adoption rate will reach 80% by 2008 (Figure 11).

Improved long-term storage of oriental bunching onions

Currently 2500 of 150,000 tonnes total production of oriental bunching onions are stored with the improved methodology, implying an adoption rate of 1.67%. As supply can be sourced from other provinces during spring and summer, less attention will be paid to longer-term storage. It is therefore assumed that the rate will reach 10% in the evaluation period (Figure 12).

Figure 11. Production of vegetables suitable for improved packaging and transit technology and the adoption profile in Beijing

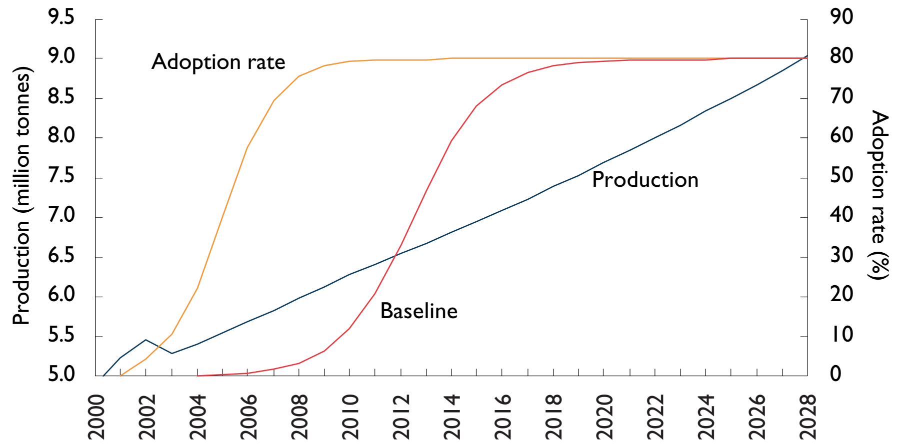
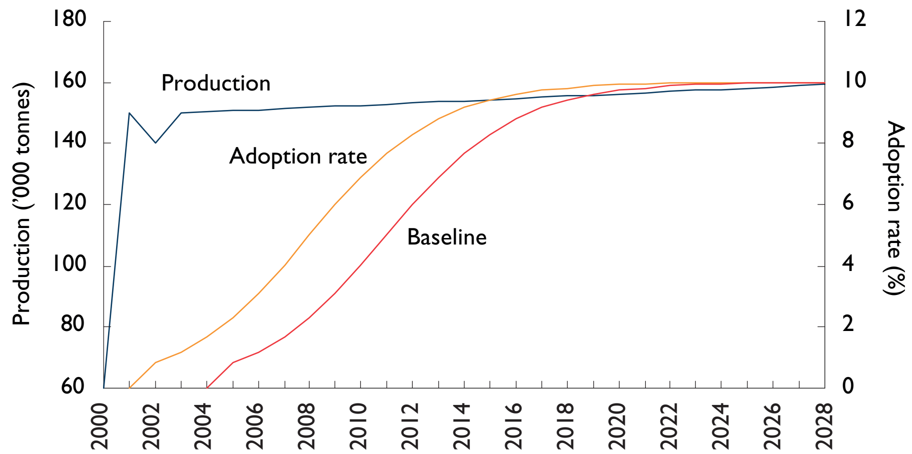


Figure 12. Production of oriental bunching onions and adoption of improved storage technology in Beijing



Improved handling of pak choy in Zhejiang

In trial regions—Huangyan, Kecheng and Longyou in Zhejiang Province—the current adoption rate is 70–80% (reports certified by Huangyan, Kecheng and Longyou agricultural extension stations). It is expected that the rate will reach 90% in the evaluation period (Figure 13).

In other parts of Zhejiang Province, the current adoption rate is less than 1%, and it is assumed that the rate will reach 10% in the evaluation period (Figure 14).

Improved handling of pak choy for supermarkets

In Hangzhou, the capital city of Zhejiang Province, currently about half of the supermarkets have adopted the improved technology, applying it to about 10% of the total supply of pak choy.

Figure 13. Pak choy production and adoption rate of improved handling technology in trial regions of Zhejiang Province

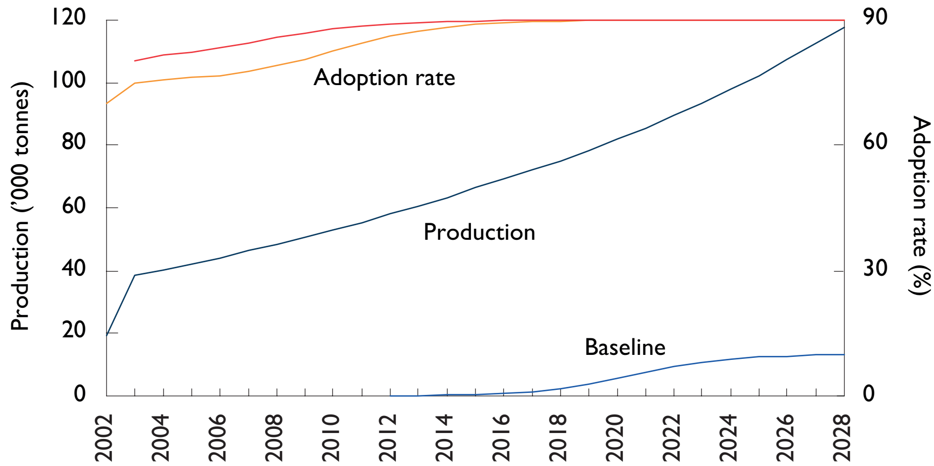
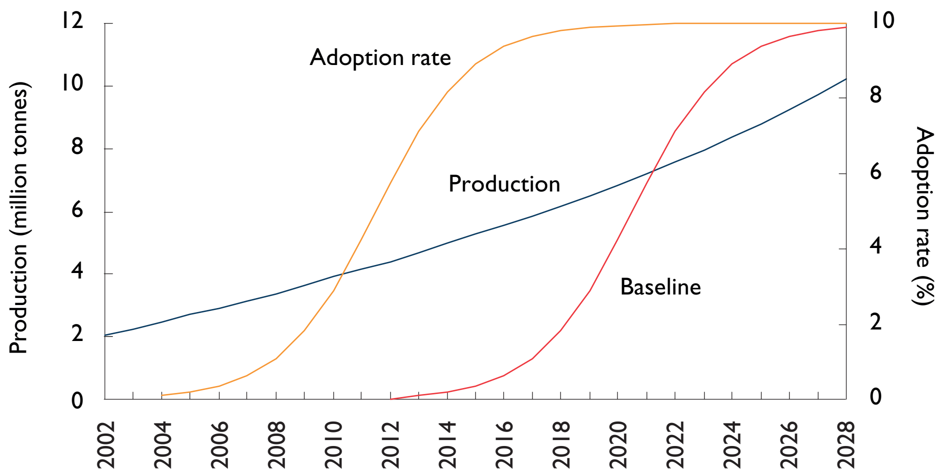


Figure 14. Pak choy production and adoption rate of improved handling technology in non-trial regions of Zhejiang Province



However, after an initial boom, most fresh-food supermarkets in Hangzhou later began to find it difficult to make a profit, and some ceased business. Because of this setback, it is uncertain how the supermarket business will develop in the future.

More importantly, some of the benefits have already been included in the benefits of improved handling system for growers and distributors. In order to avoid double counting, the benefit of this technology is not disaggregated.

Keeping the outer leaves of Chinese cabbage

In trial regions—Huangyan, Kecheng and Longyou in Zhejiang Province—the current adoption rate is 80% (reports certified by Huangyan, Kecheng and Longyou agricultural extension stations). It is assumed that the rate will reach 90% in these regions during the evaluation period (Figure 15).

In other parts of Zhejiang Province, the current adoption rate is less than 1%, and it is assumed that the rate will reach 10% in the evaluation period (Figure 16).

Modified-atmosphere packaging in Australia

The market for fresh-cut produce is new and growing rapidly in Australia. The value of sales of fresh-cut products was only $5 million in 1995, amounting less than 0.1% of retail sales (Fox 1995). The market's value grew to A$40 million in 2000–01, A$48 million in 2001–02 and A$123 million in 2003–04. It has been growing at a rate of over 25% per annum in recent years.

The firm applying the modified-atmosphere packaging (MAP) technology is a leader in the industry and currently holds 65% of the Australian market. It is expected that this year's sales will be A$80 million (Harvest FreshCuts/Vegco 2003). The current adoption rate of MAP technology is 65%. This level of adoption will remain constant because other firms are much smaller so it is not economically feasible for them to apply the MAP technology.

There is no discrete indicator of the share of Asian leafy vegetables in the fresh-cut produce market. Lettuce is the largest single component of the market, accounting for 25% of all fresh-cut vegetables. It seems reasonable to assume that Asian leafy vegetables as a whole would account for 10–20% of the fresh-cut produce, valued at A$12–25 million nationwide (or around A$8–16 million for the company) in 2003–04.

The assumptions about sales of fresh-cut leafy Asian vegetables, adoption profiles of MAP technology and the baseline are shown in Figure 17.

Figure 15. Chinese cabbage production in trial regions of Zhejiang Province and adoption rate of retaining the outer leaves during transport

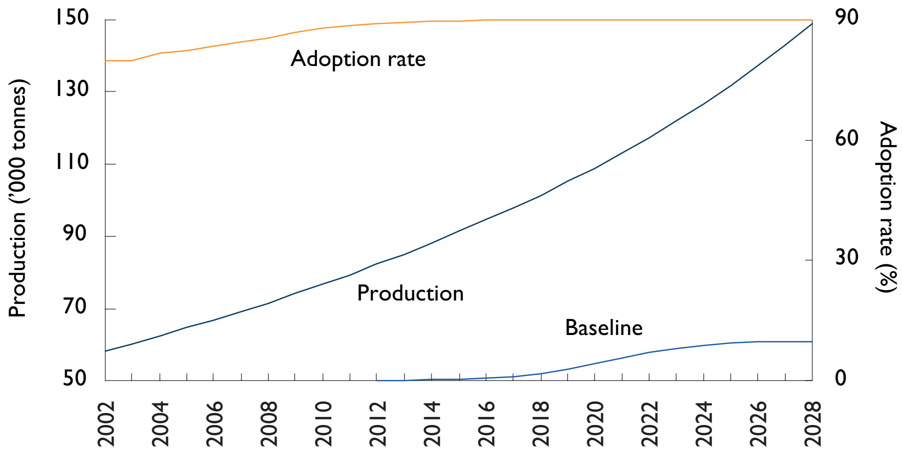


Figure 16. Chinese cabbage production in non-project regions of Zhejiang Province and adoption rate of keeping the outer leaves during transport

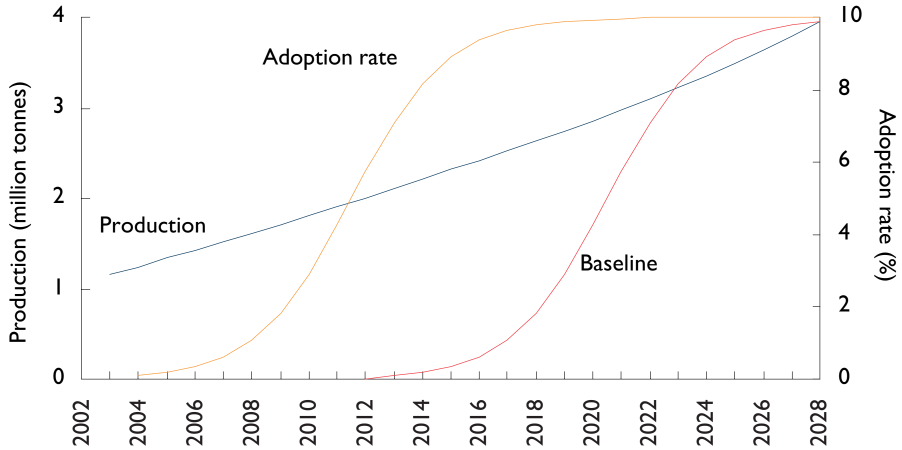
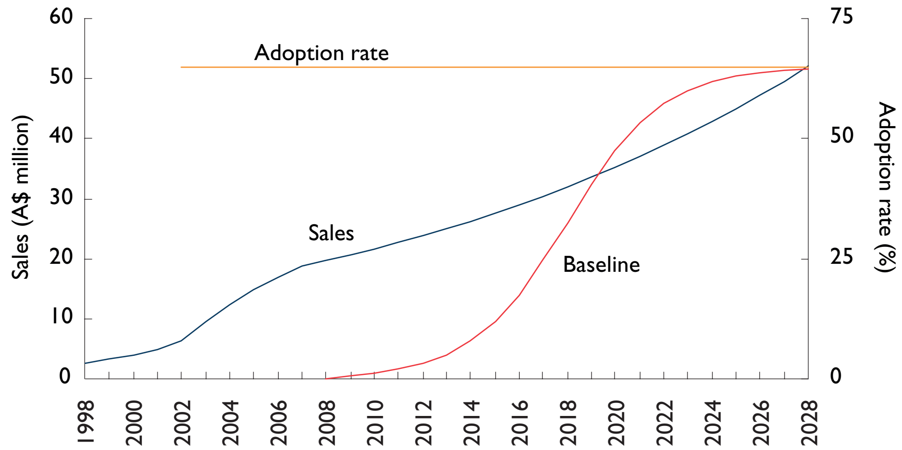


Figure 17. Sales of fresh-cut leafy Asian vegetables and adoption profile for modified-atmosphere packaging technology in Australia



Results

Benefits to China and Australia

Table 15 presents estimates of the present value of benefits, together with notes about the key assumptions made in calculating the results. Table 16 gives annual benefit flows in Beijing, Zhejiang and Australia.

Table 15. Present value of benefits in Beijing and Zhejiang from the adoption of new postharvest handling techniques for leafy vegetables

Technologies	Application	Key assumptions	@ 5% discount rate (2004 A$ million)	@ 5% discount rate (2004 RMB yuan million)
Beijing				
Forced-air pre-cooling	Exports; lettuce etc.	Currently 10% adoption, eventually 40%	0.22	1.31
Improved packaging and transit	Lettuce, cabbage, celery, spinach, broccoli, pak choy etc.	Currently 20%, 80% by 2008	41.06	248.84
Improved long-term storage of oriental bunching onions	Oriental bunching onion	Currently 1.67%, eventually 10%	0.27	1.61
Zhejiang				
Controlled water loss and rehydration	Pak choy	In trial regions, currently 70–80% and 90% eventually; in other regions, currently 1% and eventually 10%	83.67	507.86
Improved handling of pak choy for supermarkets	Pak choy	Not disaggregated, as some of the benefits are included in the above calculation. Also the development of fresh-food supermarkets had a setback recently and their future is uncertain.		
Keeping outer leaves of Chinese cabbage during transport	Chinese cabbage	In trial regions, currently 80% and 90% eventually; in other regions, currently 1% and eventually 10%	28.44	171.79
Australia				
Modified-atmosphere packaging technology application to fresh-cut leafy Asian vegetables	Leafy Asian vegetables	Current and future adoption rate 65%; 5–20% annual growth in sales	1.59	9.58
Total			155.24	940.99

In China, the estimates are restricted to Zhejiang and Beijing, without taking consideration of benefits elsewhere. Although there are some signs of information dissemination through visits and business links as discussed in chapter 2, it seems that the adoption in other provinces is insignificant and the future profile is uncertain.

One factor restricting the adoption in other provinces is the type of methodologies recommended. Some of them are specific to the trial regions, and adoption in other places would need additional effort in research and adaptation.

Table 16. Annual benefits from the adoption of new technologies for handling leafy vegetables in China and Australia

Year	Beijing (A$ '000)	Zhejiang (A$ '000)	Australia (A$ '000)
2002	443.56	1069.52	41.00
2003	826.78	1289.80	61.00
2004	1733.89	1402.97	80.00
2005	3168.71	1550.35	96.00
2006	4661.00	1762.31	110.40
2007	5709.82	2108.91	121.44
2008	6237.01	2683.79	127.51
2009	6356.81	3618.94	132.42
2010	6116.00	5052.01	138.05
2011	5455.80	6959.06	143.28
2012	4419.27	9230.89	147.64
2013	3183.46	11,434.93	150.40
2014	2041.61	13,478.04	150.51
2015	1193.66	15,121.47	146.69
2016	656.58	16,147.17	137.73
2017	348.76	16,614.30	123.13
2018	181.98	16,406.23	103.85
2019	94.22	15,394.75	82.34
2020	48.69	13,585.64	61.59
2021	25.20	11,260.68	43.86
2022	13.09	8909.41	30.09
2023	6.84	6953.53	20.11
2024	3.61	5559.56	13.20
2025	1.92	4680.81	8.57
2026	1.03	4187.24	5.52
2027	0.56	3952.35	3.54
2028	0.31	3882.20	2.26
Present value (@ 5% discount rate)	41,548.44	112,108.26	1587.92

A more important factor is that the extension involves millions of small growers. As demonstrated in the trial regions, it is effective to use local government extension networks. However, because the collaborating Chinese organisations are 'local' institutions—BVRC is under the jurisdiction of Beijing municipality government while HUC is under the Zhejiang provincial government—it is beyond their capacity to undertake nationwide extension activity. Currently, there is no sign that the central government and/or governments in other provinces are keen to adopt the methodologies.

Nevertheless, the estimation has shown significant benefits in China even without considering adoption in other provinces. With a discount rate of 5%, the present value of benefits over a period from 1998 to 2028 is 931.41 million yuan, or A$153.66 million.

Over the same period, the application of MAP technology on fresh-cut leafy vegetables in Australia yields a present value of benefit of A$1.59 million, or 9.58 million yuan at a 5% discount rate.[7]

Extension costs

In addition to project budgets, future extension costs should also be considered, because higher adoption rates will not be achieved automatically. A pro-rata approach is employed to work out the extension costs in the future. First, the extension costs associated with the current level of adoption are estimated. They include the funds transferred to collaborating local extension stations (15,000 yuan per trial region) and the costs of conducting seminars (30 yuan per participant per day including lost income and additional costs of travelling, meals etc.) An extension cost per tonne of vegetable produce in which the new technology is adopted is then calculated. This is about 1.48 yuan/tonne. Finally, this rate is applied to any additional adoption to get the extension rate. The present value of the extension cost is 0.21 million yuan, or A$35,300, at a 5% discount rate.

Table 17. Present value of costs and benefits of ACIAR project PHT/1994/016

	@ 5% discount rate (A$ '000)	@ 5% discount rate (RMB yuan '000)
Research costs	3,842.2	18,671.2
ACIAR funds	1,123.8	5,464.5
Contributions	2,718.4	13,206.7
Extension costs	35.3	214.6
Total costs	3,877.5	18,885.8
Benefits	155,244.6	940,993.2
Zhejiang	112,108.3	679,653.4
Beijing	41,548.4	251,756.5
Australia	1,587.9	9,583.3
Net benefit to 2028	151,367.1	922,107.4
Net benefit to 2004	3.9	25.1
Benefit–cost ratio	40.0	49.8
Internal rate of return (%)	52.8	56.5

[7] It should be noted that this estimation of the Australian benefit is a conservative one. From the discussion in the 'Unit net benefit' section, the Australian benefits could be higher in the following ways: the MAP technology from the research may be applicable to all fresh-cut salad products in Australia, or the proportion of fresh-cut salads whose shelf life was limited by Asian leafy constituents may be higher, and the adoption rate may be higher.

Final evaluation results

The final result of the evaluation of the project is summarised in Table 17. It can be seen that the ACIAR-funded project will bring about large benefits, over 99% of which go to the Chinese vegetable growers, distributors, and the society as a whole. Only 2 years after its completion, the benefits of the project have more than covered its costs. At a 5% discount rate, the net present value is 151.37 million 2004 Australian dollars, or 922.11 million 2004 RMB yuan, over a period of 30 years from 1998 to 2028. The internal rate of return, the rate at which the present value of benefits equals the present value of costs, is as high as 52.8% if the benefits and costs are measured in Australian dollars, or 56.5% if measured in RMB yuan. The benefit–cost ratio is 40.0 if both benefits and costs are measured in Australian dollars, or 49.8 if measured in RMB yuan. The difference arises from the fact that the Australian dollar depreciated during the project period when most of the expenses were incurred.

Impact on farmers' incomes

Reduction in poverty is usually an important component of evaluating an aid project. However, as discussed before, Beijing and Zhejiang are among the most developed regions in China. Farmers in these two regions are richer than those in central and western provinces. In addition, it is a common phenomenon in China that vegetable growers are in a better financial position than grain growers. Therefore, generally speaking, poverty is not an issue for vegetable growers in these two regions.

Nevertheless, a significant increase in incomes has been observed for those adopting the technologies developed in the project. In the trial regions of Zhejiang Province, for those vegetable growers who attended the extension seminars, the average increase in income is between 625 and 1282 yuan per person per annum, being equivalent to 14–29% of rural household annual per-capita income in Zhejiang Province. In Beijing, in addition to higher income from growing vegetables with new technology, farmers also benefit from employment opportunities in vegetable distribution firms.

Conclusion

The ACIAR-funded project, ‘Shelf-life extension of leafy vegetables’, achieved the following objectives:

- assessment of the existing Chinese handling systems and quantification of existing handling problems for Chinese cabbage, pak choy, broccoli and oriental bunching onions
- optimisation of environmental conditions to extend shelf life
- identification of inherent physiological factors limiting shelf life.

During the course of the research from July 1998 to December 2002, a number of practical and economically feasible methods of postharvest handling were investigated and applied in Beijing and Zhejiang. Most notably, the following techniques have been widely adopted:

- forced-air pre-cooling
- an improved packaging and transport method with stackable baskets, film wrapping and minimal change over
- an improved long-term storage technique for oriental bunching onions
- a controlled water loss and rehydration technique
- an improved handling procedure for pak choy destined for supermarkets
- retention of outer leaves of Chinese vegetables during transport.

Applying these techniques will produce significant benefits to vegetable growers, distributors and retailers in Zhejiang and Beijing. It is estimated that, over the period between 1998 and 2028, the net present value of adoption of these techniques in these two provinces will be RMB yuan 912.5 million (A$149.8 million) at a 5% of discount rate. In addition, there will be A$1.59 million of NPV to Australia. The benefit–cost ratio is 40 and the internal rate of return 52.8% if both benefits and costs are measured in Australian dollars.

Clearly, the project is economically successful.

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