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Final report

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prepared by	Jenny Ekman
co-authors/ contributors/ collaborators	AHR - Adam Goldwater UPMindanao - Emma Ruth V. Bayogan, Leizel B. Secretaria, Angelyn T. Lacap, Christine Diana S. Lubaton, Viena G. Monterde VSU – Marilou M. Benitez, Aljay D. Valida, Eutiquio E. Sudaria, Analita S. Salabao, Fatima Rose C. Rivera, Michael Adonis M. Sudaria and Ericjhon P. Hinayon UQ – Daryl Joyce, Anh San Tram, Khamla Mott, Melinda Perkins, Bhesh Bhandari
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Contents

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- The University of Queensland (UQ)
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- Visayas State University (VSU)
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- Southern Philippine Fresh Fruits Corporation (SPFFC)

2 Executive summary

In the Philippines, consumption of fruit and vegetables is generally low, and considerable postharvest losses of fruit and vegetables not only reduce returns to growers, but also contribute to high prices. This project aimed to reduce losses and maintain quality of fruit and vegetables after harvest, thereby increasing farmer incomes and encouraging increased purchase by consumers.

Developing postharvest research capacity at The University of the Philippines Mindanao (UPMin), and Visayas State University (VSU) was another key aim of the project. Postharvest laboratories were developed at both universities, and researchers were trained in the use of equipment and in conducting postharvest research.

Major causes of postharvest losses in vegetable supply chains were due to mechanical damage from poor handling and non-rigid packaging during transport; and high temperatures. Postharvest mango losses were predominately due to bruising of fruit when harvesting, and above optimum ripening temperatures reducing shelf-life.

A range of simple and cheap interventions were tested. On mango, alternative preharvest bagging materials, improved fruit handling and desapping at harvest, and improved ripening practices were tested. On vegetables, new packaging and crates for transport; postharvest sanitisers and hot water treatments; evaporative coolers for storage; ethylene scrubbing or blocking compounds; and modified atmosphere packaging were tested. Opportunities for value added vegetable and jackfruit products were investigated.

An Australian component on mangoes made significant progress in understanding the causes of the skin disorders: under skin browning, lenticel discolouration and resin canal disorder. Susceptibility of ‘Honey Gold’ mangoes to under skin browning was reduced when harvesting at night; a practice now widely adopted by growers in Australia. Further work is required on lenticel discolouration and resin canal disorder.

The potential efficacy of Ripestuff™ as a safe source of ethylene for in-transit ripening of mango fruit was demonstrated in Australia. Its promise as an alternative to dangerous calcium carbide was introduced in the Philippines. Collaborative research undertaken at UPMin and UQ provided better understanding of ethylene release from Ripestuff™ in a Philippines wet market context. This knowledge was used to develop prototype Ripestuff™ delivery systems capable of ripening mango and other fruit at a rate comparable to that with calcium carbide. This will allow future commercial use in the Philippines and other Asia-Pacific countries.

Results were presented at numerous conferences, and 21 papers were published in refereed journals. Best practice and grading guides were developed for mango and vegetable crops, and presented in training to more than 1460 Filipino growers and supply chain stakeholders. Uptake of guidelines will ultimately help reduce postharvest losses and better maintain quality, increasing income to growers and supply chain members; and providing consumers with better quality fruit and vegetables at more affordable prices.

The postharvest expertise and materials developed in this project should continue to be utilised in future ACIAR projects, particularly the new GAP project: HORT2016-188. While improvements in postharvest management have been achieved in this project, increasing the use of small-scale refrigeration in the Philippines could provide the single largest reduction in postharvest losses. Further development of value-added products, alongside

the private sector in the Philippines would support efforts to incorporate more fruit and vegetables into the Filipino diet.

2.1 List of abbreviations

1-MCP	1-Methylcylcopropene
ACIAR	Australian Centre for International Agricultural Research
AHR	Applied Horticultural Research
DAF	Department of Agriculture Queensland
DAFI	Days after flower induction
HWT	Hot water treatment
ICM	Integrated crop management
LD	Lenticel discolouration
MAP	Modified atmosphere packaging
RCD	Resin canal disorder
SER	Stem-end rot
SPFFC	Southern Philippine Fresh Fruits Corporation
TA	Titratable acidity
TRS	Table ripe stage
TSS	Total soluble solids
UPMin	University of the Philippines Mindanao
UQ	University of Queensland
USB	Under skin browning
VC	Value chain
VSU	Visayas State University

3 Background

The Philippines has the lowest vegetable consumption value in Asia, averaging less than 30 kg per person annually. This is less than a quarter of the 146 kg annual intake recommended by the World Health Organisation. Low consumption of vegetables is believed to be a major factor in increasing rates of obesity (presently 27% of adults), hypertension (25% of adults), and diabetes (7.5%) (FNRI, 2008). It also limits farmer incomes, which may be as little as PHP 78,000 annually (AUD 1,733) (Potutan et al., 1998).

While there remains a cultural preference for meat and rice, price and availability is also a major barrier to increasing consumption. According to the Philippines Bureau of Agricultural Statistics (BAS, 2010), there is a strong relationship between income and the amount of fruit and vegetables consumed (Figure 1).

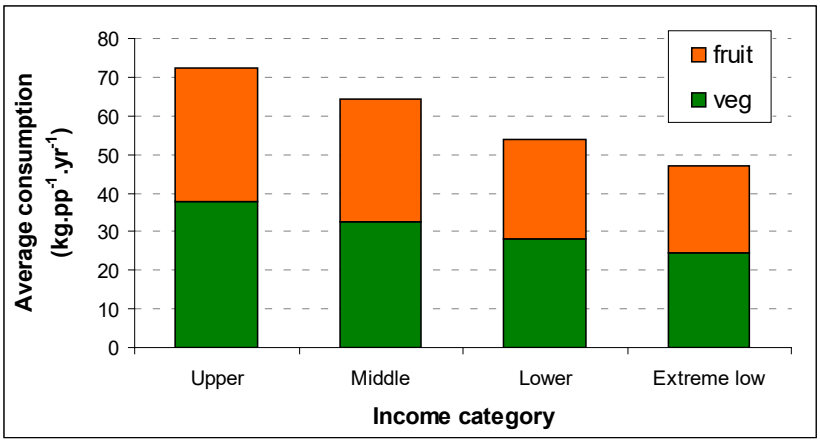


Figure 1. Average consumption of fruit and vegetables in the Philippines by income grouping. Data from the Philippines Bureau of Agricultural Statistics, 2008-2009.

It is believed that 45 million Filipinos live on less than $2 per day (ACIAR, 2012). As a result, most consumers are highly price sensitive. Fresh produce is expensive compared to other foods. For example, rice may be PHP 30/kg and dried fish PHP 60/kg, but potatoes are PHP 60-100/kg while a lettuce can be up to PHP 300/kg. When considered as cost per calorie, the difference is even greater. Whereas most Australians spend less than 15% of their income on food, Filipinos are likely to spend >50% (Table 1). High prices limit sales and consumption, reducing opportunities for small farmers.

Table 1. Comparison of income, food costs and per capita vegetable consumption Australia (AU) and the Philippines (PH).

	Australia	Philippines	Multiplier (AU:PH)
Average income	$76,000.00	$5,000.00	x 15
Price of rice	$2.50/kg	$0.70/kg	x 4
Price of buk choy	$4.20/kg	$1.70/kg	x 2½
Price of potatoes	$2.00/kg	$1.42/kg	x 1½
Price of banana	$2.50/kg	$0.60/kg	x 4
Annual vegetable consumption	100-150 kg	20-40 kg	x 4

Waste in supply chains reduces returns to growers and is a major contributor to these high prices. Data from the Philippine's Bureau of Agricultural Statistics indicate that consumption of fruit generally ranges from 20–30 kg per person annually for all regions (2008-2009). However, the same source also estimates that based on production, known waste, and export data, 82 kg per person is available to consume (2009 data). This suggests over 60% is lost. While this may appear high, this is consistent with the FAO Report on Global Food Wastes, which estimated that approximately 52% of fruit and vegetables grown in Southeast Asia are wasted. Around 27% of this waste occurs during postharvest handling and processing (Gustavsson et al., 2011).

Despite the importance of waste in determining grower incomes and consumption, only very limited studies have been conducted. Pantastico (1979) suggested that postharvest losses of fruits and vegetables in the Philippines are 28% and 42%, respectively. Although this study is relatively old, it seems possible little has improved as other estimates range from 40% up to 60% (Yaptenco et al., 2001; Estigoy, 2006). Although 15% to 20% of cabbages which are "rejected" are still sold, these may fetch less than the cost of production (Sarmiento et al., 2013).

In the case of fruits, lack of refrigeration, inappropriate handling practices, tropical conditions, and inefficient supply chains can all increase waste. Losses of bananas transported from Mindanao to Manila in Luzon were 30% to 40% (Lizada, 1993), while postharvest waste of mangoes ranged similarly up to 40% (Esguerra, 2012; Paz et al., 2009). Over 30% of calamansi was lost between Sibugay and Manila due to physical damage, disease, ripening, and physiological disorders, such as oleocellosis (Paz et al., 2009).

Vegetables may suffer even greater losses. For example, losses of 22% to 98% have been reported for onions (Mangaoang, 1982, Lizada, 1990). In various studies, cabbage transported from Benguet to Manila suffered 15% to 29% waste, the higher values being recorded during hot to wet conditions (Manto, 1980, Paz et al., 2009). Yaptenco et al. (2001) estimated losses of other vegetables through the same supply channel as around 22%.

Moreover, the long and complex supply chains in the Philippines contribute greatly to the increase of postharvest losses because products are handled many times before they reach the consumer. From the farm, they may be placed into sacks or crates, carried by another farmer back to the village, sorted by a local trader and transferred into another basket, crate or sack and transported to larger town by small truck, bicycle or jeepney before it reaches the retail store or supermarket.

Research has demonstrated that relatively simple interventions can significantly reduce postharvest losses. For example, a project by the Department of Science and Technology (DOST, 2008) found that preparing, sorting and packing on-farm instead of the traditional all in "buhos" system decreased handling four-fold, reducing handling and transport losses from 38% to 16% for cabbage and from 36% to 2% for carrots. The same project also found that packing cabbages in crates instead of bags reduced rots and physical damage by 17%.

Similarly, a University of the Philippines Los Baños (UPLB) project showed that packing at a central assembly area near the farm, using plastic crates instead of sacks and transporting by refrigerated truck reduced losses of cabbage from 29% to 4%. This reduced direct financial losses from PHP 173,000 to PHP 12,200 for a single shipment

(Serrano et al., 2009). Estigoy (2006) found that the reduction in losses and improvement in quality achieved by precooling produce before shipment to Manila made such technology feasible. Such interventions need to be verified with a range of vegetables and full analysis of benefits and costs, particularly if they are to be adopted in the Southern Philippines.

Given the high levels of damage observed in markets and retail stores in the Philippines, it is probable that simple and cheap measures could have very significant benefits in terms of reduced losses and increased quality. So long as the benefits demonstrably exceed costs, change should be possible. But the best-bet systems need to be determined, costed, demonstrated and accepted before change will occur.

This project was developed in response to the key priorities of the Philippine government as they relate to fruit and vegetable production and consumption. It also addressed an ACIAR program priority theme of increasing market competitiveness of Philippine horticultural products and was aligned with the Philippines Council for Agricultural, Aquatic and Natural Resources Research and Development (PCAARRD) 5-year plan for poverty reduction and food security for regions 8, 10 and 11 and sustainable development for regions 7, 10 and 11, which aimed to reduce postharvest losses for vegetables below 20% by

1) Improving postharvest handling systems and facilities,
2) Improving production and marketing efficiencies (supply chain management), and
3) Improving knowledge.

The project was developed as part of an integrated ACIAR program of research and development for fruit and vegetables in the Philippines (Figure 2). Complementary projects included Integrated Crop Management (ICM) of Vegetables, Jackfruit, Mangoes, and Value Chains. These projects all shared a common goal of improving food security and livelihoods for smallholder farmers.

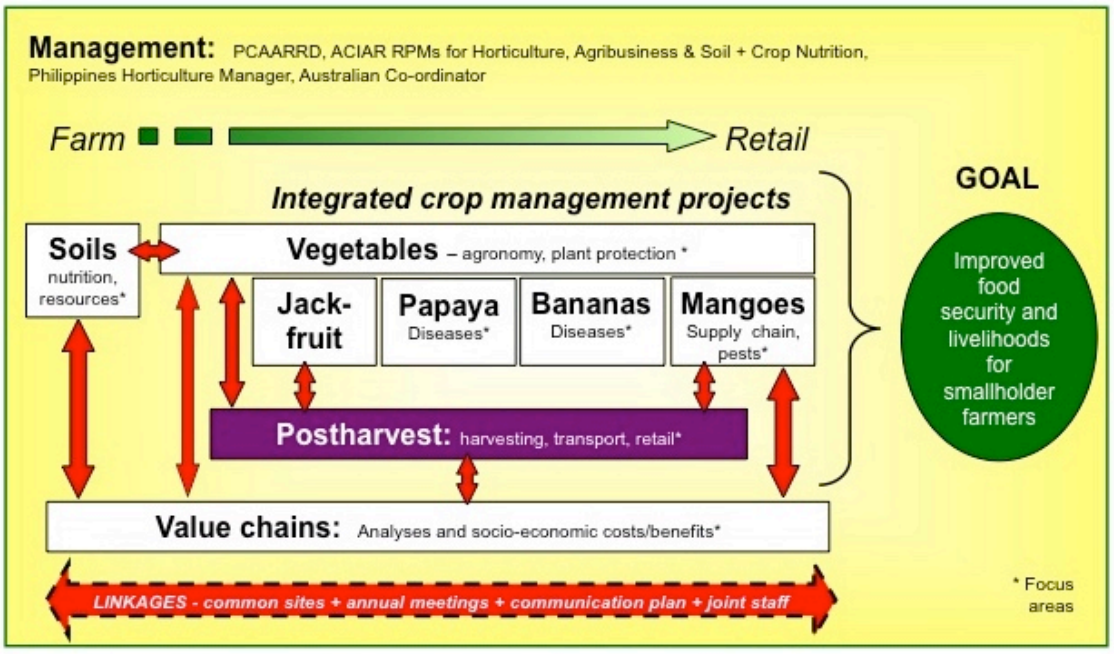


Figure 2. Structure of ACIAR Southern Philippines research program. Postharvest was strongly linked with Value Chains and ICM of vegetables, but also connected with projects on mangoes and tropical fruits

4 Objectives

The aim of this project was to reduce losses in product volume and maintain quality of fruit and vegetables after harvest, thereby increasing farmer incomes and encouraging increased purchase by consumers.

The project also aimed to develop physical facilities and research skills for postharvest advancement in the Southern Philippines. It therefore had four specific objectives;

Objective 1 - Determine where and why postharvest loss occurs in supply chains for selected fruit and vegetables

- Identify typical supply chains for target vegetable crops from each region in both the Philippines and Australia
- Develop methods for grading and evaluating fruit and vegetable crops and ensure all project participants use the same methodology
- Conduct preliminary supply chain studies of Philippines vegetables and Samal Island mangoes
- Repeat the supply chain studies using vegetables grown using 'improved' methods developed through the ICM project
- Identify major causes of loss including biotic (e.g. disease) and abiotic (e.g. bruising) disorders, and prioritise these for intervention strategies
- Examine pre and postharvest causes of under-skin browning in Australian mangoes

Objective 2- Reduce losses and improve quality of fruit and vegetables through development of effective postharvest intervention strategies

- Using a participatory action approach, test the efficacy of intervention strategies on supply chain losses for Samal Island mangoes and key vegetable crops
- Compare saleable volumes and returns for products grown using the treatments being tested in other ACIAR Philippine projects
- Test the extent to which pre-harvest conditions affect postharvest quality and USB of Australian mangoes. Develop intervention strategies in handling and maturity management to reduce this disorder.
- Optimise harvest and postharvest practices for mangoes using a commercial packhouse operation as a test case
- Develop best practice guidelines and training materials for key vegetable crops
- Conduct training workshops with supply chain partners on key findings (outputs and outcomes) from the trials
- Conduct trials on replacements for calcium carbide, a potentially carcinogenic, contaminating and explosive product currently used to ripen mangoes. Products to be tested include the Ripestuff™, a form of encapsulated ethylene. A method of applying this will be developed which is consistent with normal supply chains and their limitations.

Objective 3 - Develop active, profitable and sustainable linkages between farmers and retailers

- In conjunction with other Philippine projects (VC, ICM vegetables) and commercial collaborators, determine whether there are opportunities for value added vegetable or mango products. Prioritise these for further development
- In conjunction with other Philippine projects (VC, ICM vegetables) and commercial collaborators, determine which postharvest management strategies will best match outturn quality and price to consumer requirements
- Using the new and existing postharvest technologies, identify new value added products, develop prototypes and test storage and shelf life qualities of these prototypes

Objective 4 - Build postharvest research capacity in the Southern Philippines

- Facilitate participation by senior project researchers in International conferences, including presentation of project results to international audiences
- Provide basic postharvest equipment to UP Min and VSU to facilitate involvement in supply chain studies (Year 1) and conduct workshops to ensure all staff are familiar with equipment use and employing equivalent methodologies
- Construct and equip a postharvest research laboratory (including cool rooms) at UPMin, Davao City (Year 2)
- Workshops conducted on optimal postharvest management techniques with all supply chain participants for vegetables and mangoes including research staff, farmers, wholesalers and retailers
- Submit papers on project results to refereed journals

5 Methodology

Activities in the Philippines were conducted in three (overlapping) stages:

Stage 1: Technical equipment and training were provided to staff involved in the Visayas State University (VSU) and University of the Philippines Mindanao (UPMin). Postharvest research facilities in UPMin were built and/or renovated including the installation of four cold rooms and renovation of a container van as a postharvest laboratory. Training were provided in equipment use, experimental design and analyses, basic photography, and creating IEC materials.

Stage 2: Map supply chains of specific fruit and vegetables in the Philippines and Australia. Current postharvest practices in specific fruit and vegetables in each country were evaluated. Postharvest losses in supply chains were determined and critical points for intervention strategies were identified.

Stage 3. Develop and test intervention strategies on supply chain losses and quality. Postharvest quality was examined in laboratory storage trials and within supply chains for products handled with or without improvements in postharvest management. A large number of different treatments were tested, but can be generally categorised as:

- Pre-harvest practices such as plant grafting and application of mulch
- Better packing methods to reduce transport damage
- Use of different types of plastic packaging to modify the atmosphere around the product
- Improved temperature management through refrigeration or evaporative cooling
- Postharvest application of novel compounds, including fumigants, organic fungicides, fruit coatings etc.
- Hot water treatments (HWT) to control disease and browning reactions
- Reduction in ripening time and changes to ripening agents for mangoes

Vegetable crops and mango were chosen to be consistent with those considered high priority crop in the Philippines by PCCAARD. The crops examined included;

	Vegetables	***Fruit***
UPMin	sweet pepper, tomato, eggplant, Chinese cabbage	'Carabao' mango mangosteen, santol, rambutan (student projects)
VSU	cabbage, eggplant, tomato ampalaya	Jackfruit
Australia	mango	

Objective 1 – To determine where and why postharvest loss occurs in supply chains for selected fruits and vegetables

Vegetables

The major supply chains of six vegetables (sweet pepper, eggplant, tomato, bitter gourd, cabbage and Chinese cabbage) were mapped and evaluated. Supply chain maps were constructed through surveys and interviews conducted in Leyte, and Mindanao, including Kapatagan, Digos City; and Davao City in Southern Mindanao and Bukidnon and Cagayan de Oro City in Northern Mindanao. The survey participants included farmers, traders, wholesalers and retailers. In Mindanao, a total of 43 farmers and 25 traders were interviewed. In Leyte 6 farmers, 11 traders and 11 retailers were interviewed.

Supply chains were assessed by tracking specific batches of product from harvest to retail. Each supply chain was monitored at least twice per product.

The UPMin team monitored supply chains during July, September and November 2014, with results validated in March 2015. Assessors travelled with the product, monitoring it from harvest until it reached the retail market. Data loggers were included with the produce in each shipment to record temperatures and relative humidity along the chain. Marked samples were used to monitor weight loss. At each “control point” within the chain (e.g., after harvest, on arrival at wholesale, after repacking, at retail) samples were purchased for testing and analysis.

Additional studies were conducted examining certain issues in more detail. For example, differences in damage to eggplant and cabbage in the top, middle and bottom of sacks, and injury to tomatoes in those at the edge of wooden crates compared to in the centre. This helped further clarify the sources of injury.

The VSU team coordinated with the Value Chain project team to monitor quality of tomatoes harvested in Cabintan by CALCOA (Cabintan Livelihood Community Organisation) from farm to retail in Cebu City. The VSU team also examined local supply chains for vegetables, and surveyed growers and retailers about postharvest losses.

To standardise quality assessments, each of the research teams developed quality assessment guides for their target products. These included both objective (brix, weight loss, firmness etc.) and subjective (presence of rots, cuts, bruises, colour, wilting and overall acceptability) measurements. Each product was then assessed using the quality guides, using parameters such as colour, firmness, water loss, sugar content, acidity, severity of rots, cuts and bruises, and overall acceptability. Handling practices were evaluated, and the critical point of losses were identified.

Mango

For ‘Carabao’ mango, a supply chain for fruit produced in the Island Garden City of Samal, in Davao del Norte, Mindanao and in some areas of Davao del Sur, Mindanao was mapped. A mango packhouse and export operation owned by the Southern Philippine Fresh Fruits Corporation (SPFFC) was visited. Its operations and handling system of mango were observed. Supply chain temperatures were recorded, and the reject bin was analysed to identify quality defects.

In Australia, unsightly mango fruit skin and flesh physiological disorders/ defects that express anywhere from harvest through treatment, handling and marketing to

consumption are a constant, although variable, problem for supply chain stakeholders. For the most part, exact causes of disorders are not known, much less reliably effective controls. Among many disorders of Australian mangoes, LD, RCD and USB are particularly problematic.

These three disorders were characterised anatomically and biochemically at the tissue level. Based on compelling biochemical evidence and considering the relative magnitude of the problem, management/ control of USB became the primary focus.

Objective 2- To reduce losses and improve quality through development of effective postharvest intervention strategies

Based on losses identified through objective 1, a range of intervention studies and postharvest trials were conducted in vegetables, mango and (as student projects) a range of other crops (santol, mangosteen, rambutan, bitter gourd, potato and chayote).

Vegetables

Postharvest intervention studies focussed on areas in the supply chain where major losses were identified from objective 1, including transport and storage. As most supply chains operate without refrigeration, the focus was on packaging to minimise physical damage and treatments to extend shelf-life at ambient temperature. Where possible, interventions were tested in commercial supply chains, or otherwise under simulated conditions in the lab. Intervention strategies tested by UPMin and/or VSU included:

- *Pre-harvest* – Effect of protected cropping, and organic mulches on postharvest quality of tomato. Effect of grafting on postharvest quality of bitter gourd.
- *Harvest* – Effect of washing agents on tomato shelf life. Effect of harvest maturity on postharvest quality of tomato at retail.
- *Transport* –Effect of rigid containers such as plastic crates or styrofoam boxes, versus traditional loose sacks and rattan baskets on physical damage. Reduction in transport damage using natural liners (leaves) inside containers.
- *Storage* – Evaporative coolers were evaluated as potentially affordable alternatives to conventional refrigeration systems for storing vegetables. These were setup at both UPMin and VSU.
- *Storage temperatures* – Quantifying the benefits of refrigeration.
- *Packaging* – Packaging such as polyethylene bags, clamshells, plastic trays with cling wrap, with or without potassium permanganate was assessed for sweet pepper, eggplant, and tomato in the lab.
- *MAP* - assessed for a number of vegetable crops at ambient temperature or under refrigeration.
- *Other postharvest treatments* – numerous treatments to delay ripening, or prevent decay were trialled, including chitosan on pepper; 1-methylcyclopropene (1-MCP) on pepper, tomato and eggplant; salicylic acid and hot water spray/dip on pepper and tomato; alum (aluminium potassium sulphate), newspaper, guava and mangosteen extracts on cabbage.

At UPMin, ten undergraduate student projects studied other vegetable and fruit crops including mangosteen, santol, rambutan, potato, bitter gourd, chayote. Effects of the

following treatments were considered on postharvest quality; 1-MCP, potassium permanganate, ripening agents, gibberellic acid and ethephon.

Mango

In the Philippines, mango intervention trials covered most of the supply chain, including preharvest treatments, maturity assessment, harvest and desapping methods, postharvest treatments and ripening methods:

- *Preharvest* – the effect of different fruit bagging materials on postharvest quality were evaluated in three mango orchards on Samal Island, Davao del Norte and Davao Oriental. Bags were applied to mangoes soon after fruit set, as per the standard commercial practice which uses newspaper. Bags were removed at harvest when quality was assessed.
- *Maturity assessment* – Physiochemical characteristics at various stages of harvest maturity using flotation in water or salt solution were evaluated.
- *Harvest timing* –The first intervention targeted a reduction in sap (latex) burn on the skin. Latex volume and quality as affected by harvest time and a delay in destemming, or pedicel location at destemming was investigated. Postharvest desapping treatments were also evaluated.
- *Harvest method* - The effect of harvest method, drop heights and maturity on bruise severity were evaluated over 5 field and lab trials. Bruising volume was measured, along with other quality parameters. Weight loss and quality were also evaluated for fruit exposed to sun for various times after harvest.
- *Hot water treatments* – the effect of HWTs on the progression of diseases such as anthracnose and SER were evaluated. Various length and temperature of treatments were evaluated in a hot-water bath in the laboratory.
- *SmartFresh™ (1-MCP)* - was evaluated as a tool to delay ripening of mango, and was applied at different maturity stages at harvest.
- *Ripening* – Variations to the most common ripening system used in the Philippines (calcium carbide in baskets) were investigated. The effect of location in the ripening basket, and duration and concentration of calcium carbide treatment on mango quality and time to reach table-ripe stage was investigated.
- *Ripening agents* - other potentially safer ripening agents were investigated including bioethylene sources such as *Gliricidia sepium* leaves, ‘Cardava’ banana, ripening mangoes, ethylene produced with a catalytic generator, methyl jasmonate, ethephon and Ripestuff™. Ripestuff™ is a powder which allows for the safe production of ethylene for ripening. Trials to develop an effective method of application were undertaken in collaboration with The University of Queensland (UQ). Ten experiments at UPMin, and seven experiments at UQ were conducted during the project variation / extension period. Knowledge exchange was facilitated by regular email and Skype teleconferences, as well as a training visit to UQ by UPMin researcher Angelyn Lacap.
- *Ripeness stage* - a mango ripeness level detector using three digital image processing algorithms was also investigated.

In Australia, intervention strategies targeted ripening practices and skin disorders:

- *In-transit ripening and prediction of outturn quality for mango* – Mangoes grown in tropical northern production areas of Australia for the domestic market may be transported by road and/ or rail for up to 4000 km to Southern ripening centres. Long transport duration represents relatively longer 'time in the system', during which fruit are progressively deteriorating. The prospect of using new and novel ethylene-releasing Ripestuff™ for ripening mangoes in-transit was investigated. Case study experiments were conducted using Ripestuff™ to release ethylene into transport containers. In parallel, simulation experiments were carried out to characterise how various different temperature, relative humidity (RH%), ethylene (C_2H_4) and carbon dioxide (CO_2) conditions that could be found in transport containers might interact to affect fruit outturn quality. Using outturn quality data, spreadsheet modelling of fruit ripening responses to various gas combinations (… such as to simulate in-transit conditions in truck containers …) was preliminarily investigated.
- *Causes of USB on 'Honey Gold' mango* – Reviews of the literature on the biology and technology of mango production quality were undertaken initially. Thereafter, microscopy (viz., light and electron) and biochemistry (e.g., HS-SPME-GC-MS) were applied to characterise symptoms. PhD student Anh Tram San was recruited into this work on disorders which was conducted collaboratively with industry (e.g., Piñata Farms) as well as collaborating Australian research providers (UQ, DAF). Susceptibility of 'Honey Gold' mango to USB was evaluated in fruit harvested at different times of the day, stored at ambient or 12ºC, and exposed to physical stress (vibration). USB symptoms under the microscope were compared to other mango skin disorders, including RCD, and LD. Approaches, methods and findings were shared with Philippines workers through reciprocal visits and workshops.

Objective 3 – To develop active, profitable and sustainable linkages between farmers and retailers

Trials were conducted to improve overall quality and shelf-life of value-added products including fresh-cut *chop suey* mix, fresh-cut *pinakbet* mix, and fresh-cut jackfruit. Preliminary surveys were done at wet public markets in Davao and Leyte to determine common preparation, handling, and storage practices of these commodities, and make comparisons with practices at supermarkets. Literature reviews were conducted to assess which intervention strategies could be adaptable to these commodities.

For chop suey mix (UPMin), intervention trials included hot water, and UV-C treatment at pre or post-cutting of fresh-cut chayote, carrots, sweet pepper and Chinese cabbage. In the case of pinakbet (VSU) trials examined HWT of eggplant, okra, string beans, ampalaya and squash. MAP was also tested on both chop suey and pinakbet mixes.

HWTs and MAP were trialled on minimally processed jackfruit, after slicing.

Objective 4 – To build research capacity in the Southern Philippines

Basic postharvest equipment was provided to the postharvest team at VSU, while a full postharvest research laboratory was setup at UPMin. This was guided by previous ACIAR

projects which constructed postharvest facilities in Pakistan and Cambodia. Specifications were developed in conjunction with Philippines collaborators.

Larger items such as cool rooms, refrigerated cabinets, laboratory furniture, air-conditioner, freezer, computers and cameras were sourced directly within the Philippines. The water bath and other specialised postharvest equipment including the modified atmosphere packaging (MAP) test units, ethylene analyser, data loggers, refractometers, colorimeters, spectrophotometer, mini-titrator and other items were purchased in Australia.

Training in the use of equipment was provided to local staff and graduate students at both universities. This also provided an opportunity to include training in general laboratory techniques, experimental design and statistical analysis. Training was primarily conducted by the UQ and AHR teams from Australia.

Once the laboratory was setup, and key staff and research assistants had been trained, undergraduate students were given the opportunity to undertake postharvest research. The project offered a series of seed grants to 3rd year and Honours students wishing to do a research project on a postharvest issue. This was highly effective in encouraging students to work in postharvest, who might otherwise have chosen quite a different area of study.

VSU and UPMin researchers were encouraged to publish findings from the research activities in refereed journals, present at international conferences, and conduct workshops with Filipino growers and supply chain stakeholders.

Key findings from objectives 1 and 2 were used to develop best practice guidelines and training materials for mango and key vegetable crops. General postharvest training was conducted with farmers, wholesalers, retailers and government employed extension technicians.

6 Achievements against activities and outputs/milestones

Objective 1: To determine where and why postharvest loss occurs in supply chains for selected fruit and vegetables

No.	Activity	Outputs/ milestones	Achievements
1.1.	Identify and appoint research assistants to map supply chains	Two full time staff appointed, one based in UPMin, one VSU	November 2013 – Aljay Valida hired February 2014 – Marian Salamanes was hired, March 2014- Angelyn T. Lacap was hired March 2015 – Leizel Secretaria was hired as a research assistant at UPMin, replacing Marian Salamanes. January 2016- Christine Diana S. Lubaton was hired replacing Angelyn Lacap. Angelyn Lacap resigned her position in UPMin to pursue a Master's degree in Thailand August 2017- Viena G. Monterde was hired March 2018- Angelyn Lacap was hired for the extension of the project on Ripestuff™ in mango
1.2.	Supply chains identified for target vegetable and fruit crops	Supply chains identified in • Davao region (2 x vegetables, 1 x mangoes), • Cagayan d'Oro (1 x vegetables) • Visayas (2 x vegetables)	Supply chains were mapped for: • Chinese cabbage, eggplant, sweet pepper and tomato in Davao del Sur • Chinese cabbage, eggplant, sweet pepper, tomato in Northern Mindanao • Vegetables generally in Bukidnon and Cagayan d'Oro • Tomato, cabbage, ampalaya and eggplant in Southern Leyte
1.3.	Grading and evaluation methods developed	• Small lab equipment items purchased • Training workshop conducted (10 staff) • Grading scales developed for key vegetable crops	UPMin developed grading guides for sweet pepper, tomato, eggplant, and Chinese cabbage VSU developed grading scales for tomato, cabbage, ampalaya and eggplant A large number of laboratory equipment items were purchased for UPMin and/or VSU. These included data loggers, gas analysers, benchtop titrators, colorimeters, spectrophotometer, penetrometers, digital refractometers, balances, pH meters, hot water baths, digital camera, pipettes, cool-bot, refrigerated cabinets, freezer, laptop computer and other office supplies as well as many other small laboratory items.
1.4.	Conduct preliminary supply chain study of Australian custard apples	Initial study of the Australian custard apple supply chain.	This activity was replaced by a study of microscopy and skin structure of mangoes.

No.	Activity	Outputs/ milestones	Achievements
1.5.	Supply chains for vegetables mapped and quality assessed at minimum 4 points in chain	Data generated on changes in quality, damage incidence and weight for a range of fresh vegetables including ampalaya, capsicum, tomato and eggplant	UPMin recorded losses at harvest, after transport, at wholesale and at retail. Total losses averaged 86% (Chinese cabbage), 45% (eggplant), 36% (sweet pepper) and 31% (tomato). Major causes of loss included trimming (at harvest and after transport), bruising and water loss. VSU recorded supply losses of up to 13% (tomato), 70% (cabbage), 30% (eggplant) and 21% (ampalaya). These assessments did not include loss in value due to quality, as this was difficult to reliably record in different markets.
1.6.	Supply chains for Samal Is mangoes mapped and quality assessed at minimum four points in chain	Data generated on harvest maturity and quality, harvest losses, market segmentation, and waste through different marketing chains including • Local fresh market • Export fresh market • Processing • Economic analyses conducted	Losses for mangoes were estimated as being approximately 8% at harvest, 6% at wholesale and 10% at retail. However, this is likely a major underestimate – mangoes are still considered saleable with significant rots, it is simply that price is reduced. For example, mango wholesalers reported that only 10% of the fruit purchased was good enough quality for export. The remainder went to local markets. A reject bin analysis demonstrated that 2/3 of losses at wholesale were due to disease and rots, with the remainder caused by physical damage. Most fruit that was intact but deemed unsuitable for export was rejected due to skin damage – discoloured lenticels and latex burns. Insect damage was also a major issue.
1.7.	Supply chains for vegetables produced using improved methods (through the Integrated Crop Management project) mapped and quality assessed	Data collected on changes in quality, damage incidence and weight for a range of fresh vegetables produced using improved methods e.g. protected cropping, integrated disease management, improved nutrition	Issues were encountered with these activities due to Super-typhoon Yolanda. This destroyed most if not all of the protected cropping structures on Leyte shortly before this activity was scheduled. Recovery was slow, with the result this planned activity could not be completed.

No.	Activity	Outputs/ milestones	Achievements
1.8.	Major causes of loss of vegetables and mangoes identified, critical points for intervention strategies prioritised	• Data analysed to determine critical points within supply chains • Intervention points prioritised • Strategies developed to reduce losses • Economic analyses conducted	Intervention strategies have been tested on factors that include: • Handling • Harvesting • Packing • Evaporative cooling / refrigerated storage • Postharvest treatment (alum, chitosan, guava and mangosteen extracts, chitosan 1-MCP, salicylic acid, $KMNO_4$, washing agents, heat treatments, desapping agents, ripening agents)
1.9.	Causes of under-skin browning examined in Australian mangoes	• Review of literature on pre-harvest effects on mango postharvest quality • Microscopy and analytical methods used to examine under-skin browning symptoms and define the disorder	Literature on skin disorders of mango was extensively reviewed as part of the PhD thesis of Anh Tram San entitled “Lenticel discolouration, under-skin browning and RCD in Australian mango fruit cultivars”. Microscopy revealed differences in the anatomy of USB and RCD. USB involves starch retention and deposition of phenolic compounds in cells surrounding the epithelial cells that line resin ducts. In contrast, RCD involves accumulation of phenolics inside the lumen of resin ducts. USB could be induced by terpinolene and D-limonene, both of which are components of ‘Honey gold’ mango sap. USB was associated with afternoon spurt sap and whole sap, but not by ooze sap. It was more severe in the afternoon as compared to in the morning due to increased concentration of volatile components within the sap.

Objective 2: Reduce losses and improve quality through development of effective postharvest intervention strategies.

No.	Activity	Outputs/ milestones	Achievements
2.1.	Supply chain intervention strategies tested for Australian custard apples	Based on previous research, effects of at least two factors tested on outturn quality of custard apples	Activity removed

No.	Activity	Outputs/ milestones	Achievements
2.2.	Intervention strategies tested for Samal Is mangoes	Interventions tested at minimum 3 critical points within mangoes supply chains. These may include; • Changed harvest method • Postharvest dipping • Evaporative cooling • Packaging materials At least 2 supply chains used to assess effects on losses.	Trials on Samal Island mangoes have examined: • Effect of harvest method (careful, normal or rough) on retail quality • Effect of maturity at harvest (115 to 125 days after flower induction [DAFI]) on speed of ripening, flavour attributes and rots • Potential for latex burn at different times of day (by measuring latex volume) and ways to mitigate latex burn through washing treatments • Effectiveness of various desapping treatments • Bruising volume due to drops from different heights and at varying maturity stages • Temperatures during carbide treatment and effect of duration of carbide treatment (1–3 days) on ripeness and rot development on removal • Use of different ripening agents (RipeStuff™, EthylGen, methyl jasmonate, Ethrel and calcium carbide as well as a number of bio-ethylene sources) • HWTs, including conventional and rapid methods. • Alternative fruit bagging materials such as HDPE and polyethylene fleece Trials have focussed on replacement of calcium carbide for ripening rather than other aspects of this objective. This issue is a high priority due to the significant dangers to fruit ripeners using this compound, the potential for contamination of the ripe fruit, and the major potential improvements in postharvest quality if mangoes are ripened more appropriately.
2.3.	Intervention strategies tested for key vegetable crops	At least one intervention strategy tested for each of the five vegetable supply chains previously studied. These may include; • Harvest method • Packing method • Evaporative cooling • Postharvest treatment (coatings, heat treatments, fungicides)	**Eggplant**: Perforated and non-perforated plastic bags for retail sale; Fumigation with 1-MCP. **Ampalaya**: Hot water dips; Plastic film overwraps; Storage conditions; ethylene absorbent ($KmnO_4$); Fumigation with 1-MCP. **Chinese cabbage**: Plastic packaging; Hot water dips for processed product; Use of alum and newspaper. **Tomato:** Hot water dips; Storage conditions; Effect of washing agents. **Sweet pepper:** Fumigation with 1-MCP; Chitosan fruit coating; Storage conditions (evaporative cooler or ambient); Hot water dips.

No.	Activity	Outputs/ milestones	Achievements
2.4.	Effects of pre- and harvest conditions on postharvest quality tested for Australian mangoes	• Anatomy of physiological mango skin disorders elucidated • Influences of pre-harvest and postharvest practices (e.g. plant nutrition, transport and handling conditions) tested in relation to USB	Light microscopy, hand sectioning and serial block-face scanning electron microscopy were used to examine differences in resin canals, cell discolouration and lenticel structure. Anatomy of different disorders elucidated as described in objective 1.9. The influences of pre- and postharvest factors were examined. It was demonstrated that afternoon harvest, cold stress (10°C) and physical stress (vibration during transport) all increase susceptibility to USB. Changes have been made by industry to harvest and postharvest practices as a result of these findings.
2.5.	Compare conventionally grown products with those produced in ICM project	Shelf life, quality and returns to growers compared for products with improved soil and nutrient management, under protected cropping or with integrated pest and disease control.	Shelf life trials have been conducted on tomatoes, ampalaya, sweet pepper and eggplant grown under protected cultivation compared to those grown in the open field. Trials included the effects of different types of mulch on storage quality. In general, vegetables grown under protected cropping had significantly longer storage life than those grown in the open. This effect was due to reduced disease and weight loss in the protected plants. For example, reduced colour change and disease in ampalaya significantly improved postharvest life. Mulch type had less effect. Ampalaya from grafted plants were compared to those from non-grafted plants. Fruit from the grafted plants had less weight loss, improved visual quality and reduced disease after storage compared to ampalaya from non-grafted plants. This is likely due to the latter plants being healthy and disease free, whereas the non-grafted plants were affected by bacterial wilt. The results therefor confirm that improving pre-harvest plant health can improve postharvest outcomes.
2.6.	Samal Is packhouse operations reviewed and optimised	Intervention strategies put into practice using the centralised packhouse on Samal Is. as a case study. This will include testing a prototype hot water showering / brushing machine, using optimum harvest and packing methods	The development of a centralised packhouse did not proceed as planned. Instead, studies were conducted at SPFFC. Postharvest practices of the mango exporter were reviewed, and reject bin analysis and supply chain temperature monitoring studies were conducted. Small HWT systems were purchased for UPMin and VSU, allowing them to conduct a series of trials examining HWTs for both vegetables and fruit.

No.	Activity	Outputs/ milestones	Achievements
2.7.	Best practice guidelines and training materials developed for key vegetable crops	Report prepared detailing the results of intervention strategies and defining best practice guidelines. This will include a study of the logistics required and economic analysis for each of the tested strategies.	In November 2016 the VSU and UPMin teams spent three days working together on a Best Practice guidelines writing workshop. As an outcome from this meeting, UPMin has produced eight A4 trifold brochures on quality indices, defects and diseases as well as best practice postharvest management for sweet pepper, tomato, Chinese cabbage and eggplant (total = 8). The brochures were put together using Photoshop software to produce print-ready files. VSU has produced English and local language versions of detailed best practice guides on ampalaya, eggplant, tomato and cabbage. These are longer documents still in A4 format in Word. In both cases the materials include experimental data and recommendations based on trial results.
2.8.	Best practice guidelines developed for minimising mango skin disorders	Report prepared on the biochemistry and causes of physiological mango skin disorders • Management recommendations formulated for industry • Paper(s) prepared for publication	A report has been prepared detailing the biochemistry and causes of physiological mango skin disorders. Paper(s) have also been prepared for publication, particularly based on the PhD work of Anh Tram San. Best practice management guidelines have been formulated for industry. The results have been communicated individually and at industry events to Honey Gold growers who all market through Piñata. As a result of these recommendations, most Honey Gold producers have changed to night harvesting. This practice change markedly reduced USB as a serious postharvest issue. One grower has stated that without this solution to the issue of USB on Honey Gold, he would have removed this variety from his orchard. In addition, UPMin has developed two A4 trifold brochures on Best Practice recommendations and quality indices for Carabao mangoes. These include many of the findings from the trials conducted on Samal Island mangoes. For example, harvesting carefully, washing to remove latex and – if using calcium carbide – ripening for two days instead of three.

No.	Activity	Outputs/ milestones	Achievements
2.9.	Training workshops conducted with supply chain partners	Workshops will be held with all supply chain members (including up to 300 farmers) to inform them key findings (outcomes and outputs) from the trials and provide training in best practice postharvest handling methods	UPMin has conducted 14 training events with approximately 1,135 mango and vegetable growers, and other supply chain members. This included a postharvest course for 66 farmers and 14 UPMin students held in Marilog, Mindanao. The course focussed on improving vegetable quality and, by engaging with both farmers and students, ensured that all participants learned from each other as well as from the taught materials. Recent courses have targeted ethnic minority groups in the mountainous areas near Quezon. Approximately 60% of participants were women. VSU has conducted a series of training workshops (January and February 2016 and February 2017) with farmers from Leyte, Samar and Cabintan. A total of 154 farmers and 121 agricultural technicians and teachers attended. Moreover, presentations at conferences (e.g. the Southern Philippines Agriculturists convention 18/5/2018, presentations by J. Ekman and C. Hamilton Bate, >1,000 attendees) have provided postharvest information to many not directly involved with the project.
2.10.	Implementation of Ripestuff™ for ripening mangoes in Australia and the Philippines	Trials in the Philippines and Australia will determine the optimum release method, quantity of material required and effects on shelf life and quality of using encapsulated ethylene (Ripestuff™) for ripening mangoes	This was undertaken as an extension to the main project. Model chambers were used to characterise Ripestuff™ ethylene release under varying humidity and air pressure conditions. Results were used to improve the delivery system design and test its efficacy to ripen fruit in woven bamboo baskets. Ten experiments were conducted at UPMin, and seven at UQ. Angelyn Laccap travelled from UPMin to UQ for training on working with Ripestuff™.

Objective 3 - To develop active, profitable and sustainable linkages between farmers and retailers

No.	Activity	Outputs/ milestones	Achievements
3.1.	Determine opportunities for value added products	This part of the project to be done in conjunction with other ACIAR Philippines projects, particularly Vegetables ICM, Value Chains and Tropical fruit as well as commercial partners. Opportunities to develop new value added products or alterations to existing products will be identified and prioritised.	Trials at UPMin have examined HWTs and UV-C treatments to extend postharvest life of minimally processed *Chop Suey* vegetables (carrots, sweet pepper, chayote and Chinese cabbage). Similar trials at VSU also examined HWTs, but for fresh cut vegetables used in *pinakbet* (squash, okra, eggplant, ampalaya). Initial trials have been conducted by the VSU team examining the potential for fresh cut jackfruit. This has been done in conjunction with the Jackfruit ICM project, which is examining agronomic issues as well as processing opportunities. Jackfruit that was harvested 150 days after fruit set had better colour than fruit harvested after 80, 100 or 120 days. Trials using this maturity found improved postharvest appearance of packaged fruit, however flavour was not assessed. The UPMin team has identified an opportunity to include processed vegetable crops (sweet pepper, tomato, green onion) in locally produced canned tuna. Initial trials have been conducted with a local company, and are ongoing. A third option for further investigation involves including vegetables in pasta. A Masters student in Food Science is now studying opportunities to create different coloured pastas with added health benefits by including vegetables.
3.2.	Determine postharvest management strategies which match outturn quality to consumer requirements	This part of the project to be done in conjunction with other ACIAR Philippines projects, particularly Vegetables ICM, Value Chains and Jackfruit as well as commercial partners. Strategies to deliver the fruit or vegetables that consumers prefer will be identified and tested under market conditions. This may include different ripeness stages, grading, sizes or quality attributes	Trials have shown that both polypropylene and high-density polyethylene bags improve firmness and reduce darkening of jackfruit pulp, even if the fruit is stored unrefrigerated. HWTs were tested for helping to preserve fresh cut jackfruit. However, only 30 seconds at over 40ºC reduced undesirable colour change.

No.	Activity	Outputs/ milestones	Achievements
3.3.	Prototype products developed and tested in the marketplace	Some/all of this work may be subcontracted to UPLB under guidance of E. Bayogan.	Prototype products were not developed, as the fresh cut testing with HWT and UV-C did not achieve the required quality level.

Objective 4 - To build postharvest research capacity in the Southern Philippines

No.	Activity	Outputs / milestones	Achievements
4.1.	Attendance and participation in IHC2014, Brisbane	Marilou Benitez, Aljay Valida and EB participate in the International horticultural congress in Brisbane. EB also spends 2 weeks in Australia and assists with custard apple supply chain study	Marilou Benitez, Aljay Valida and Emma Bayogen attended IHC2014. The trip included: 10 Aug - EB, MB and AV visited Asian vegetable farms, supermarkets, orchard areas and Uni of Western Sydney campus at Richmond 11 Aug - group attended Food Safety Conference at Uni of Sydney + AHR laboratory visit 13-15 Aug - group attended pre-congress postharvest training at Mapleton and Nambour 17-22 Aug - attendance at IHC2014 in Brisbane 25-28 August - EB trained in microscopy with Anh Tram San at Uni Qld and EcoSciences precinct
4.2.	Basic postharvest equipment supplied, UPMin & VSU staff trained	Initial laboratory setup and workshop to determine experimental design, methods etc. • Basic equipment supplied (penetrometers, balances, loggers, refractometers etc.) • Workshops conducted on experimental design and analysis • Initial supply chain 'practice' study conducted with all project participants	UPMin – laboratory equipment supplied includes data loggers, gas analysers, benchtop titrators, a colorimeter, scanning spectrophotometer, penetrometers, digital refractometers, balances, pH meter, hot water bath, pipettes, freezer, laptop computer and other office supplies as well as many other small laboratory items. VSU – laboratory equipment supplied included refrigerated cabinets, an evaporative cooler and numerous small laboratory items including data loggers, benchtop titrator, colorimeter, penetrometers, digital refractometer, balances, pH meter, hot water bath, digital camera, and other small laboratory items. Workshops have been conducted on use of all laboratory equipment, including penetrometers, titrator etc. Additional workshops on photography as well as experimental design and statistical analysis of data.

No.	Activity	Outputs / milestones	Achievements
4.3.	Initial student scholarship project completed,	Initial student project examining a postharvest issue completed and report submitted Scholarship availability advertised to potential postharvest students	Thirty 3rd year and Honours UPMin students have completed postharvest theses with support from the project.
4.4.	Postharvest laboratory and coolrooms constructed	• Postharvest laboratory furniture purchased and installed (UPMin) • 3 coolrooms installed and tested (UPMin) • MAP analysers purchased (UPMin and VSU) • Colour meter and MAP analyser purchased (VSU) • Standard operating procedures written for new equipment	A full postharvest laboratory and coolrooms has been constructed at UPMin. This is a significant future resource for the southern Philippines, where previously no postharvest facilities were available. The work has included purchase and installation of new laboratory benches and cupboards, renovation of a container van to use as 20°C storage space, three full cold rooms and one cold room with cool-bot / airconditioner system rated to approx 10°C.
4.5.	Initial workshops conducted with supply chain participants	Initial training workshops conducted with supply chain participants to discuss project results and prioritise further research activities	Workshops and training events are detailed in section 2.9 and 4.3

No.	Activity	Outputs / milestones	Achievements
4.6.	Workshop on postharvest management of mango	Workshop conducted with researchers, Samal Is Co-op members and supply chain members on optimal postharvest handling of mango	Research workshops have been held in conjunction with members of the Mango ICM project team and Value chain projects in July 2016. Mango stakeholder workshops were held in March 2016 and February 2017. Three training workshops have been held as part of the "Season long training" of mango farmers on Samal Island (Feb 2016, March 2017, March 6, 2018). Each was attended by at least 30 growers and contractors. Workshops have examined pre-harvest effects on postharvest quality, as well as the importance of good postharvest management (J. Ekman and E. Bayogan). The final event had a strong focus on food safety, and included guest presentation by Clare Hamilton Bate, GM Freshcare. A two day food safety workshop was held with 18 staff from SPFFC. This was intended as a pilot workshop which could be extended more widely, particularly to other companies. As a result of the workshop a folded A4 brochure was produced outlining food safety for mango farmers and contractors. In total at least 480 farmers, extension workers, teachers and supply chain members have attended mango training courses conducted as part of this project.
4.7.	All workshops finalised	• Workshops held with all supply chain participants, including total of 300 farmers, 20 wholesalers and 10 retailers. • Specialised retail workshop (20 participants) held focussed on reducing losses at point of sale	UPMin. 14 trainings were conducted involving 1,135 supply chain partners and extension workers (280 male; 264 female; 591 unspecified) VSU – A series of training events conducted. In total 154 farmers and 121 agricultural technicians and teachers attended.

No.	Activity	Outputs / milestones	Achievements
4.8.	Experimental results presented at International congresses and in journals	• EB, JA, JE and UPMin postdoc attend two International conferences and present results generated by project activities • Papers submitted to peer refereed journals for publication	21 papers published in peer-refereed journals. 6 under review/in press. 40 oral and poster presentations made at conferences.
4.9.	Student projects finalised	All student projects finished (total=9) and reports submitted	A total of 30 student projects on postharvest management of fruit and vegetables have been completed. Nine additional BS Biology students (who have graduated) used the postharvest equipment and upgraded postharvest facilities for their undergraduate theses in postharvest biology (Refer to Appendix 1)

7 Key results and discussion

Objective 1 – To determine where and why postharvest loss occurs in supply chains for selected fruits and vegetables

Vegetable supply chain mapping – Mindanao

The supply chain of vegetables was traced in mid-2014 to early 2015. Farmers and traders of Chinese cabbage, eggplants, tomato and sweet peppers from Southern (Kapatagan, Digos City, and Davao City) and Northern (Bukidnon and Cagayan de Oro) Mindanao were surveyed and interviewed. The supply chain of target vegetables follows a traditional chain wherein farmers' produce are brought into large public markets by selling it to agents/traders, wholesalers, consolidators, processors, and retailers (Figure 3). Most of the produce in Kapatagan is brought to Davao City while some are delivered as "kargada" by agents/traders to other provinces in Mindanao and Visayas. A portion of the produce is sent to nearby markets.

The supply chains in Bukidnon and Cagayan de Oro follow a traditional pattern (Figure 5). The produce come from different municipalities in Bukidnon and are brought to Bulua Public Market in Cagayan de Oro City. Bulua serves as the gateway of produce to nearby provinces in Mindanao, Visayas and Luzon.

Produce is sold to traders who bring it to large public central markets. These wholesalers in the central markets sell direct to the public as well as to smaller retailers and resellers operating within some of the larger supermarkets. Consolidators and vegetable processors are more likely to sell produce to institutional markets such as supermarkets, fast food chains, hotels and restaurants (Digal and Concepcion, 2004).

Interviews conducted at selected wholesale markets (Valencia, Bukidnon and Bulua, Westbound, Cagayan de Oro City) in 2016 identified an additional player in the supply chain; the financers. They finance farm inputs in exchange for harvested crops. They also function as retailers or wholesalers in the supply chain. Financers were also included in the Kapatagan supply chain on Chinese cabbage, in which instance they function as agents/traders (Murray-Prior et. al., 2003) (Figure 5).

Chinese cabbage is mostly supplied by Bukidnon farmers (Figure 4). Figure 6 shows in detail the more complex supply chains that follow sale from Bukidnon into different markets. The supply reaches the wholesale market at Bulua, Westbound, Cagayan de Oro, Valencia, Bukidnon and Bankerohan, Davao City

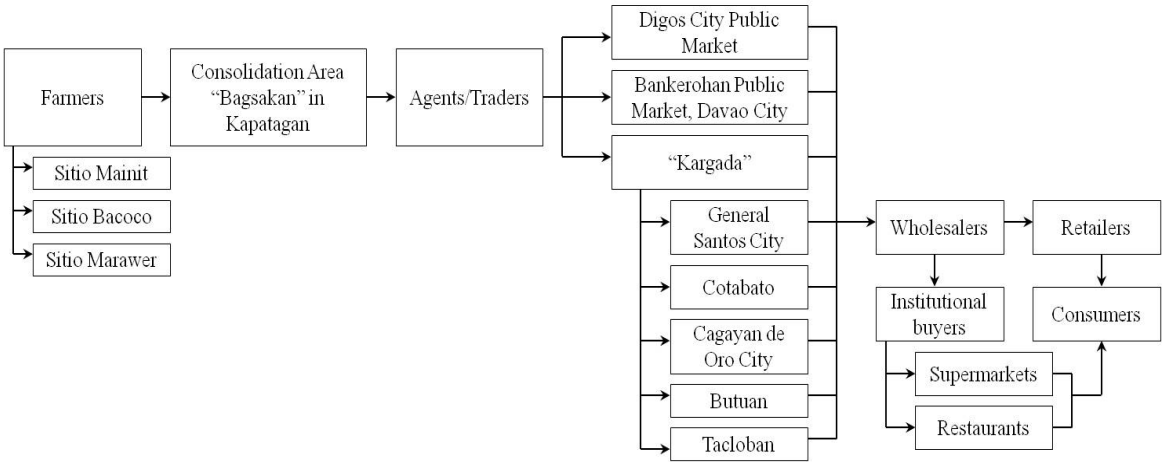


Figure 3. Supply chain of target vegetables follows a traditional mechanism wherein farmers' produce is brought into large public markets by agents/traders, who then sell it on to wholesalers, consolidators, processors, and retailers.

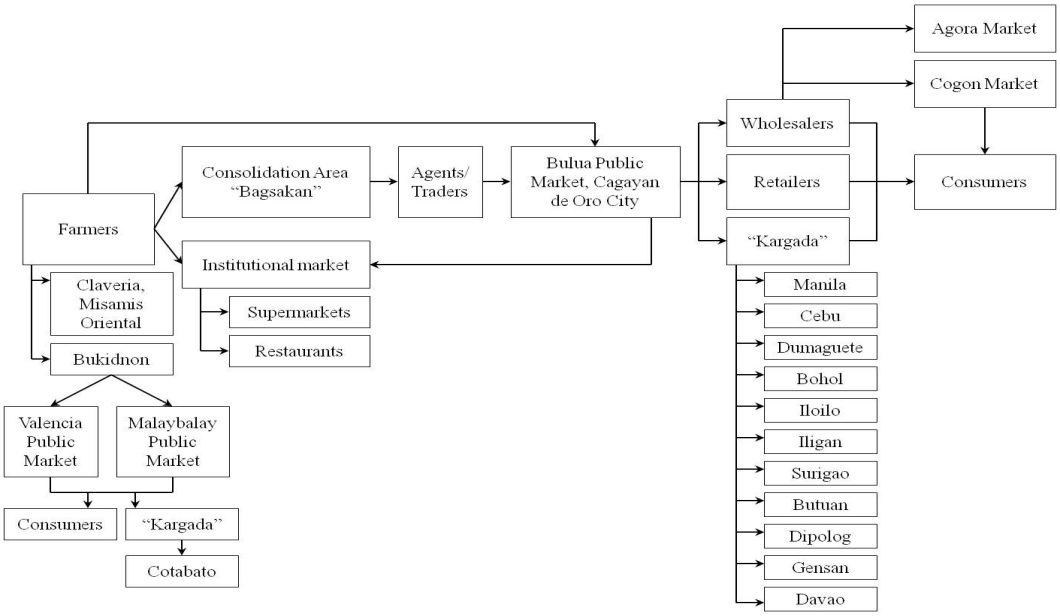


Figure 4. Supply chain of Chinese cabbage, eggplant, sweet pepper and tomato in Northern Mindanao.

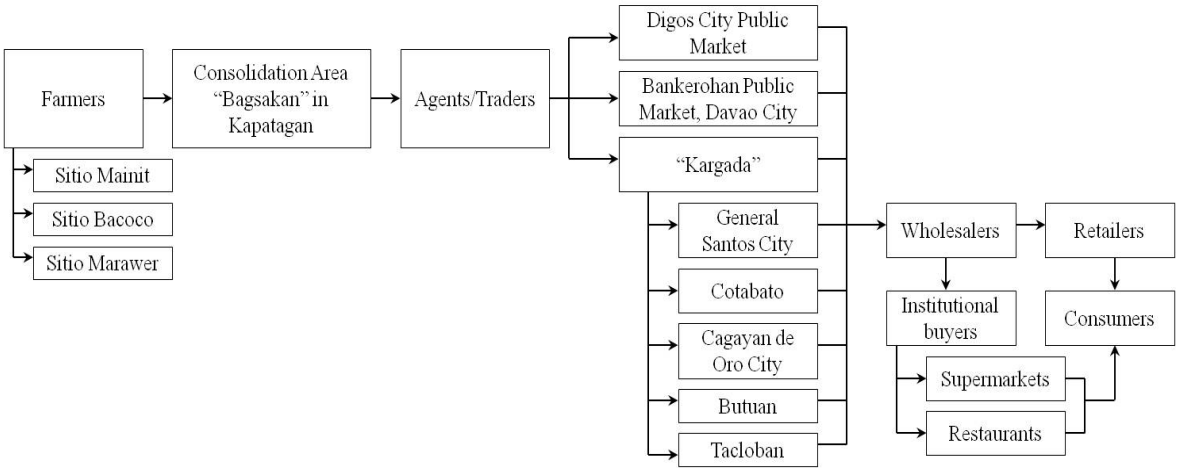


Figure 5. Supply chain of Chinese cabbage, eggplant, sweet pepper and tomato in Kapatagan, Digos City, Davao del Sur, Philippines.

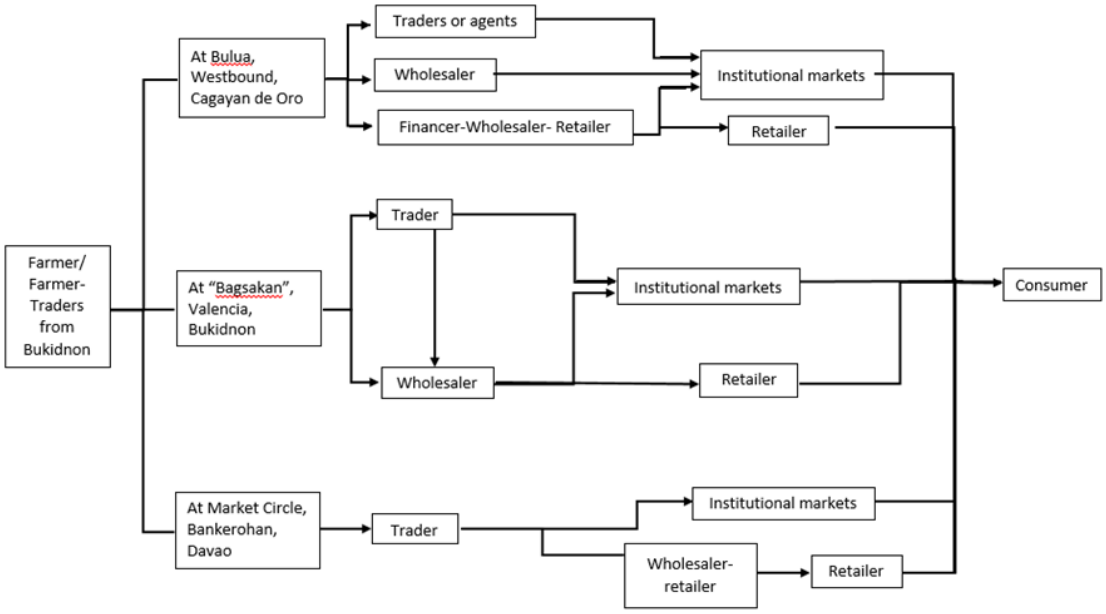


Figure 6. Supply chain of Chinese cabbage produced in Bukidnon.

Vegetable handling practices

Generally, proper postharvest management is almost non-existent in the Philippines. One of the issues is that vegetables are handled by many players in the supply chain. Each player has limited responsibility, and is unlikely to be impacted if the end quality of the product is poor by the time it reaches consumers. The lack of traceability, limited responsibility and supply chain complexity contribute greatly to postharvest losses. Furthermore, non-rigid packages, overpacking, unpaved roads, high temperatures and inefficiencies in the prevailing transportation system make produce vulnerable to postharvest losses.

Very little postharvest management was done by the vegetable farmers on their produce. Postharvest management was more likely observed by traders, wholesalers, and retailers. Sorting at the farm simply consisted of classifying produce into marketable and non-marketable (Figure 7). Further quality grading, or sorting into different sizes or ripeness stages, farm does not usually occur. This may disadvantage farmers once they sell to institutional buyers, where standards relating to size, ripeness, and other quality factors are mandated.

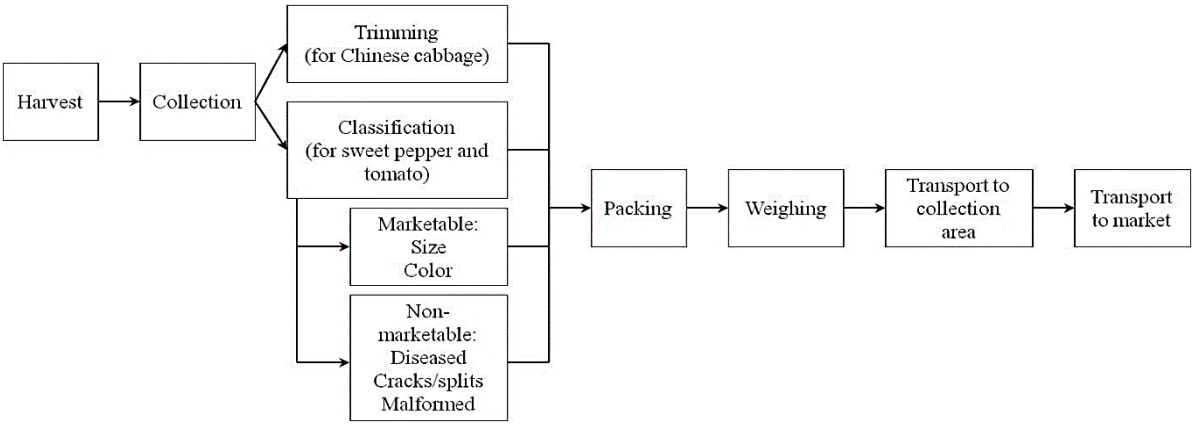


Figure 7. Handling chain of vegetables in Kapatagan, Bukidnon and Cagayan de Oro City.

Vegetable postharvest losses

Disease, mechanical damage and wilting were the main causes of loss. For example, for sweet pepper, a loss of 39% was observed at wholesale due to cracks and splits. Total loss was calculated by combining waste at harvest as well as damage and weight loss during transport, at wholesale and during retail. Total losses for sweet pepper, eggplant and tomato were 70%, 50% and 28% respectively (Figure 8).

Total losses were highest for Chinese cabbage at 90%, due to the large amount of trimming at wholesale and retail. For Chinese cabbage, losses of 28% and 43% occurred at harvest and after the first trimming only at wholesale, respectively. Damaged leaves were common, resulting in over-trimming. Trimming losses in the wholesale market in Davao City and Cagayan de Oro were measured. Trimming losses at 43.9% and 28.5% were accounted after trimming of heads at these two wholesale markets, respectively. Many factors are attributed to trimming loss such as diseased leaves, rotting, mechanical damage and over trimming.

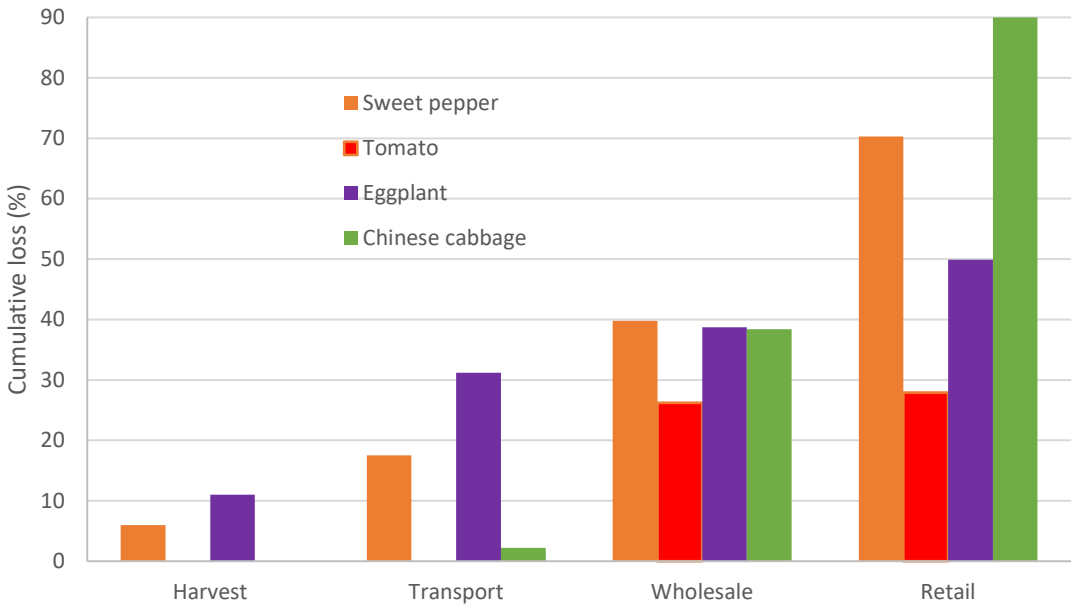


Figure 8. Postharvest losses of vegetables from harvest to retail

Packaging section (i.e., top, middle, bottom) and maturity stage (i.e., green, breaker, turning, orange) of the vegetables affected the visual quality of tomato, sweet pepper, and Chinese cabbage after transport. Tomato and sweet pepper located at the middle or bottom portions of the packaging had lower visual quality than those at the top. However, in Chinese cabbage, those located at the top had lower visual quality than those at the bottom due to physical injury and water loss.

Mango supply chain mapping

The Carabao mango supply chain followed a similar system as the vegetable supply chain. Most farmers engage a mango contractor to manage their crop from flowering through to harvest. The mango contractor then gives financial and technical support such as application of pesticides and fertiliser, flower induction and labour for maintenance and harvesting. The contractor may either arrange for a harvest team to pick the fruit, or sell the fruit “all in” while it is still attached to the tree to wholesaler or processor/exporter. They then arrange harvest and grading of the fruit.

Companies sell the best quality mangoes to China, Japan, Korea, Hong Kong, the second grade may go to Manila, while mangoes of lower quality are sold to wholesalers at Bankerohan Public Market. Institutional buyers such as small retailers and supermarkets purchase mangoes at these wholesale markets.

Fruit processors purchase lower grade fruit, ripen and dry or freeze for export (Figure 9).

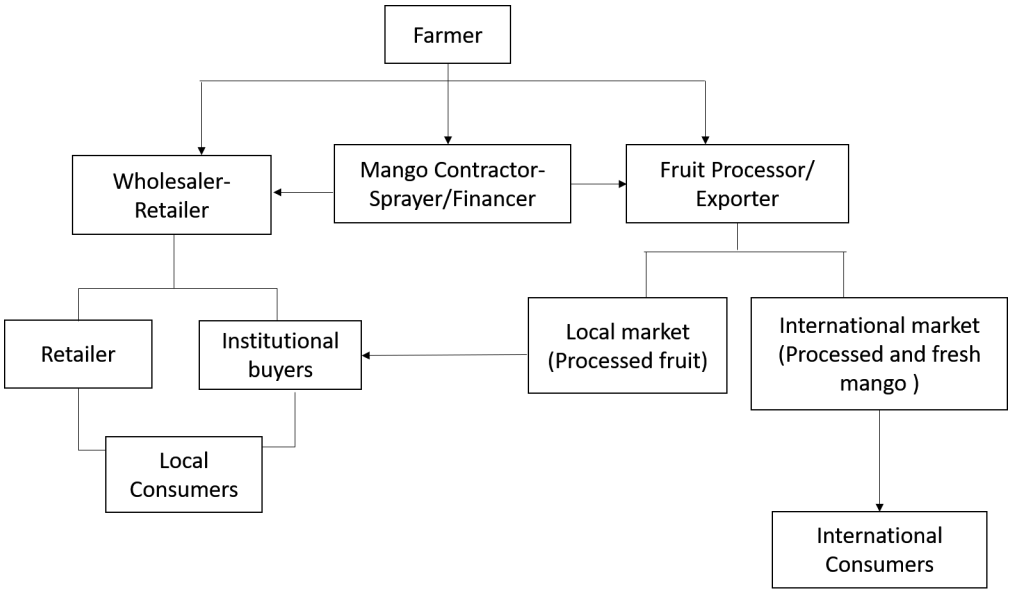


Figure 9. Supply chain of ‘Carabao’ mango fruit in Davao Region

Mango handling practices

For locally sold mangoes, there is almost no postharvest management apart from ripening. Upon arrival at the central public market, mangoes are packed in bamboo baskets that can hold 20-25 kg or mangoes and are ripened using calcium carbide for three days under ambient conditions. Upon opening, they are then displayed in ambient market conditions.

However, for export quality mangoes, some improved postharvest management practices are implemented by fruit exporting companies. SPFFC was visited and their operations and handling system were observed. At SPFFC, harvested mangoes are received and transferred into plastic trays while grading. Fruit undergoes flotation, which measures mango fruit maturity based on specific gravity using 1% salt solution (Lizada, 1991). In

the flotation test, immature fruit float while mature fruit sink, since specific gravity increases with maturity. This is followed by a short HWT to control disease. Fruit are then re-graded, before vapour heat treatment to meet quarantine requirements, then cooling, packing and storage (Figure 10).

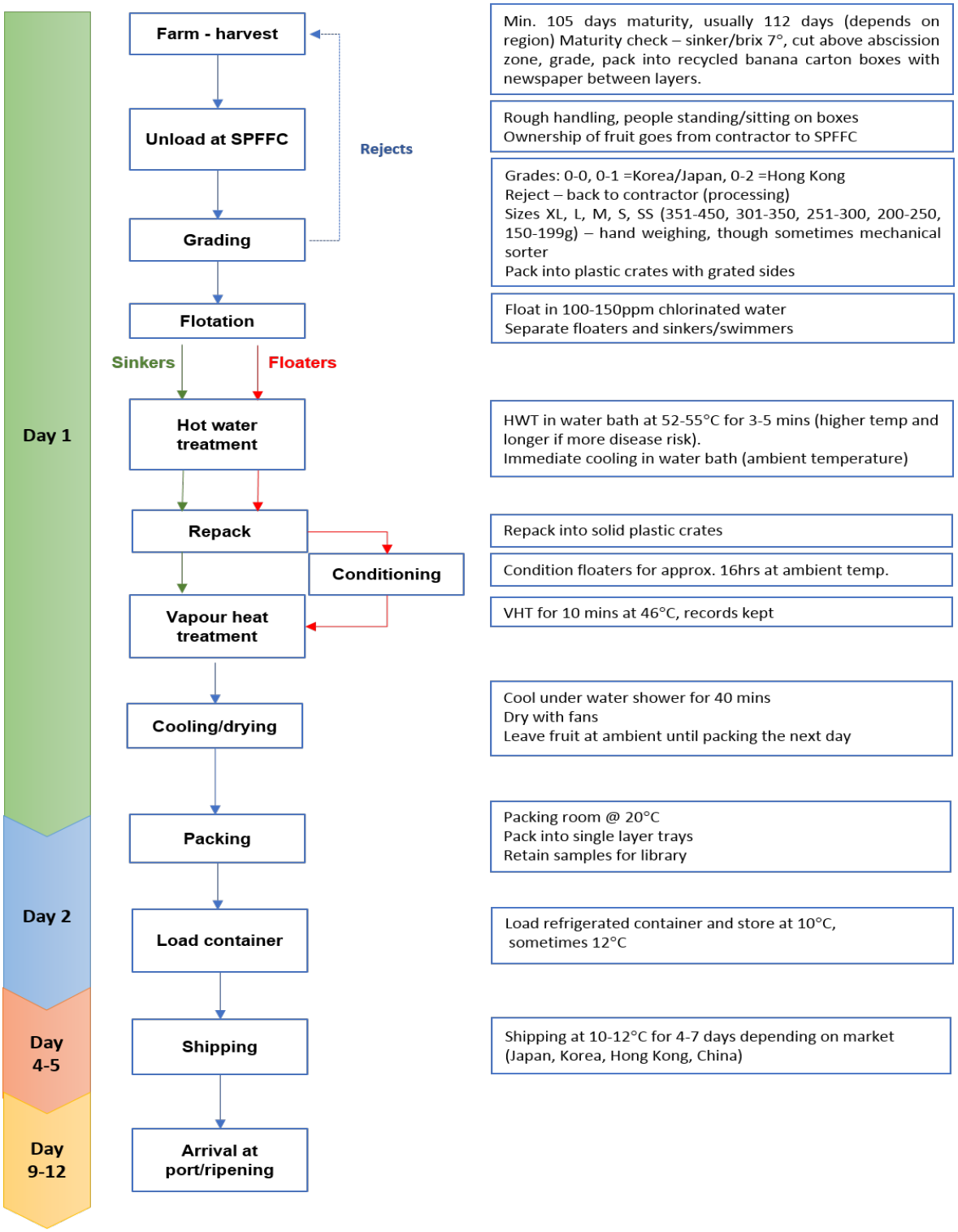


Figure 10. Postharvest practices observed at a mango export packhouse in Davao.

Mango postharvest losses

Postharvest losses in Carabao mango were assessed. At harvest, the main causes of rejection in mango included disease, insect damage, undersized, latex burn, and fruit cracks. Common defects observed for Carabao mangoes in the wholesale market were cracks, bruises, anthracnose and SER. At the wholesale market, losses before and after ripening with calcium carbide were at 0.3% and 4.1% respectively. However, the majority of losses occur between wholesale and retail, once the mangoes are ripe and soft (Figure 11). Even this is likely to be a significant underestimate, as it does not include loss of value – fruit with some disease are still sold, but at a reduced price.

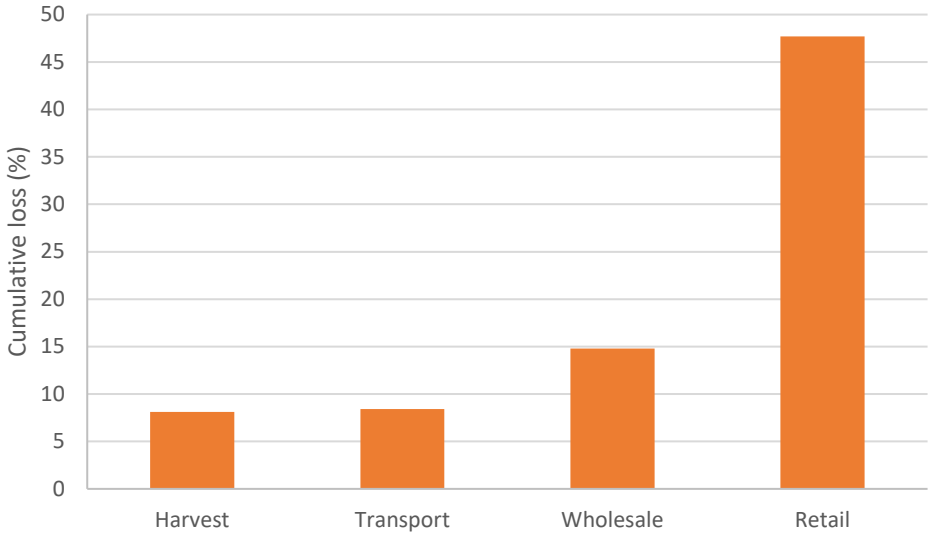


Figure 11. Postharvest losses of mango from harvest to retail

Mango quality in the Philippines is generally inadequate for export. At least 50% of mango fruit delivered to an exporter in Davao are rejected and sent back to the supplier. Reject bin analysis showed that most of the fruit were rejected due to lenticel discolouration and latex injury. These were followed by insect damage, yellowing/ other, undersized, bumps, ant damage (‘ant urine’), misshapen, rub, cuts and sooty mould (Figure 12, Figure 13). Insect damage (‘ant urine’) was observed as a prevalent peel blemish on reject ‘Carabao’ mangoes for export. The progression of ‘Carabao’ mango (untreated and heat-treated mango) diseases and quality defects from an export company were monitored in an ambient room condition. Progression of defects was observed under ambient conditions; fruit that were hot water-treated showed faster yellowing but less disease (SER and anthracnose) over the untreated fruit.

Fruit rejected by exporters can still be ripened and sold by supermarkets. However, prices are much lower than in export markets. Improving pre-harvest practices as well as the postharvest handling system would increase the volume of fruit available and suitable for high value export markets.

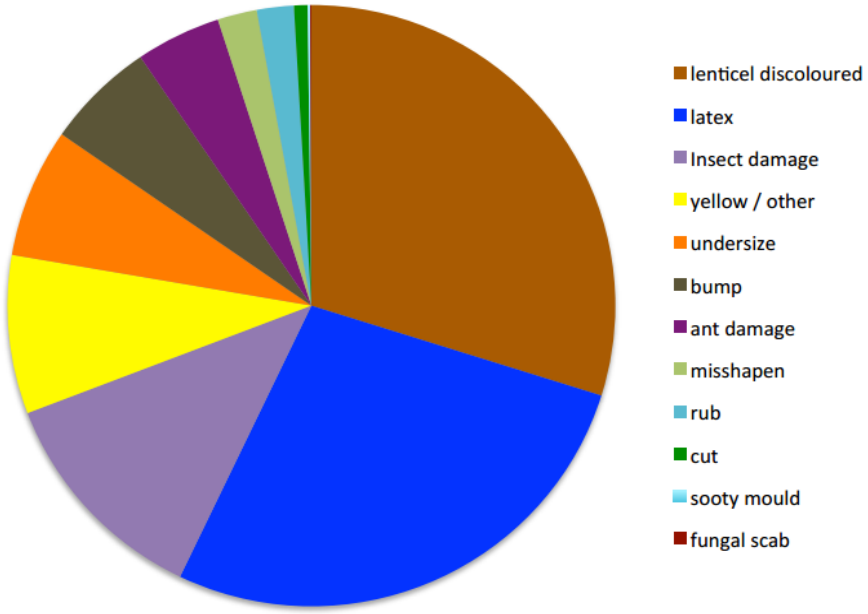


Figure 12. Reject bin analysis of mangoes at SPFFC.

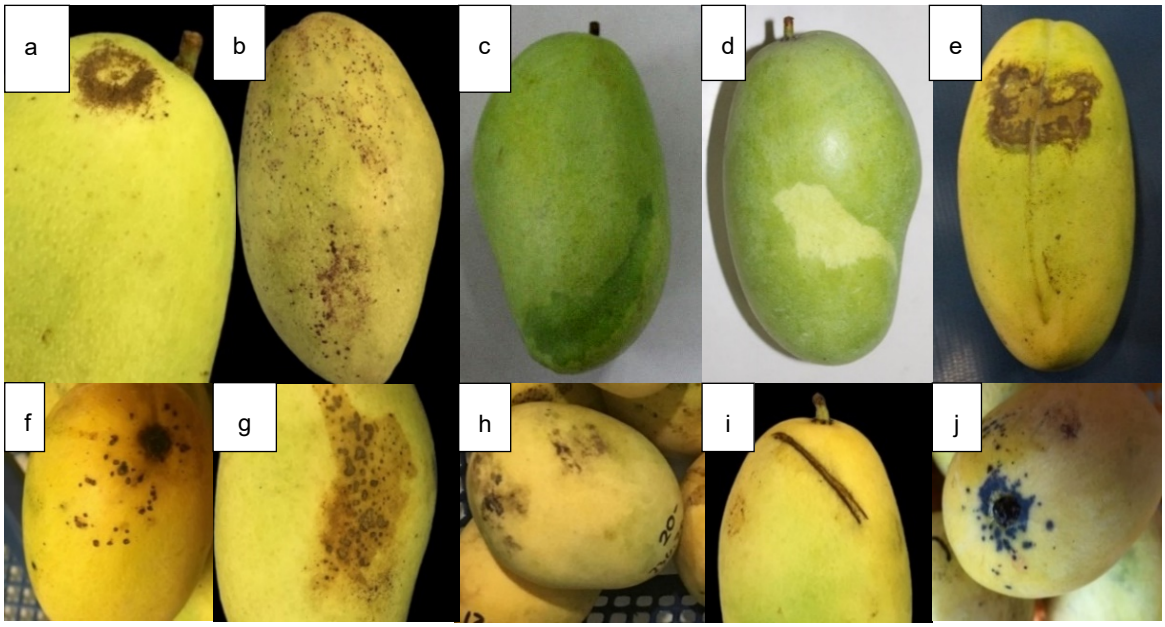


Figure 13. Some of the defects of 'Carabao' mango from the reject bin analysis. (a) insect damage; (b) lenticel discolouration;(c) Chimera fruit; (d) Chimera fruit ;(e) ant damage; (f) fungal scab; (g) latex injury; (h) sooty mould; (i) cut; and (j) rots.

Causes of under-skin browning in Australian mangoes

LD, USB, and RCD are three fruit skin disorders of concern to the Australian mango industry.

LD is confined to lenticels on the fruit skin. It was suspected that irradiation may differentially induce LD on cvs. ‘B74’, ‘Honey Gold’, ‘Kensington Pride’, and ‘R2E2’ fruit. Irradiation at 0.5 kGy significantly ($P<0.05$) increased LD and also delayed the loss of

green skin colour of all four cultivars. There was generally little increase between 0.5 and 1.0 kGy. The least pronounced effect was on cv. 'Honey Gold'. Irradiation also diminished aroma volatile production by cvs. 'Kensington Pride' and 'R2E2'. The morphology of LD was examined. LD was evident in tissue sections as the browning of cells around lenticel cavities. No such browning was evident in cells around non-coloured lenticels. Coloured polymerised phenolic compounds evidently accumulate in cells around the darkened lenticels. Three-dimensional structural visualisation of LD was completed.

USB is a physiological disorder evident as spreading sub-surface grey-brown lesions in 'Honey Gold' mango fruit. In contrast, RCD in 'Kensington Pride' mango fruit is evident as dark brown discolouration of ramifying sub-surface resin canals. These two largely cultivar specific browning disorders were compared and contrasted at the cellular level. USB was characterised by dark brown cells around the epithelial cells that line resin ducts. This disorder involves starch retention as well as deposition of phenolic compounds. In contrast, RCD was distinguished by localised browning inside resin duct lumens. Again, the browning per se evidently involved accumulation of polymerised dark coloured phenolics. Polyphenol oxidase and peroxidase enzyme activities were determined to be associated with both USB and RCD browning.

Objective 2- To reduce losses and improve quality through development of effective postharvest intervention strategies

In the Philippines, a range of trials were conducted on 'Carabao' mango, target vegetables (sweet pepper, eggplant, tomato, ampalaya (bitter gourd) and Chinese cabbage) as well as other crops (santol, rambutan, potato, chayote).

In Australia, trials examined the effects of pre-harvest and harvest conditions and ripening practices on Australian mangoes.

Mango bagging

It had been observed that skin damage and/or latex burn were a major cause of rejection at harvest, with a large percentage of fruit downgraded from export quality due to this issue. It was hypothesised that bagging fruit with newspaper was contributing to this issue; newspaper was relatively abrasive, created a microhabitat for ants, and did little to protect the fruit from insect damage. Newspaper may also influence effectiveness of pesticide sprays and residues on the fruit skin.

Four trials compared the traditional practice of bagging mangoes with newspaper with alternative materials including spun-bonded high density polyethylene and non-woven spun-bonded polypropylene. Physical defects, rots, shelf-life and visual quality were assessed at harvest and at table-ripe stage.

- The initial trial was conducted examining pre-harvest bagging of mango fruit with non-woven spun-bond polypropylene ("white fleece") (0.0320 mm thick) or a thicker Tyvek material. Mangoes bagged using white fleece resulted in better quality fruit at harvest. Newspaper reduced shelf life compared to the other two bagging materials due to faster ripening and earlier onset of SER during storage.

- Mangoes bagged with white and black fleece had a consistently higher proportion of mangoes in the top two quality grades than those bagged with newspaper (Figure 14). It was observed that there was a reduction in insect damage in the bags, as well as incidence of sooty mould and fungal scab. This is likely due to a better seal in the fleece bags, as well as better ventilation compared to newspaper. There was no consistent effect of bagging on postharvest quality at ripe stage.

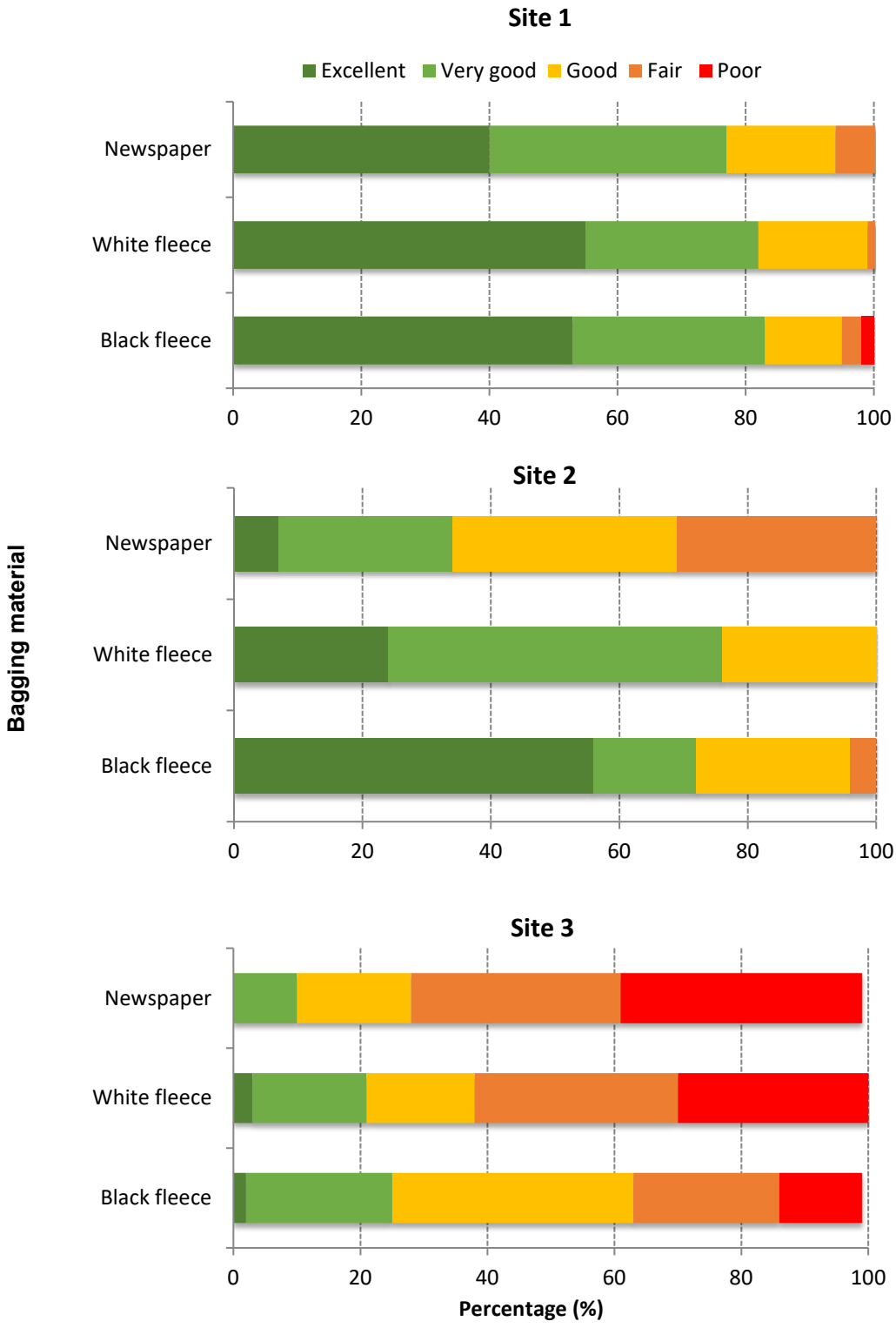


Figure 14. Visual quality of bagged 'Carabao' mango fruit at harvest from three sites in Mindanao, presented as the percentage of fruit within each grade.

Mango latex and desapping treatments

Latex from the cut pedicel can burn mango skin. Trials investigated the volume of latex according to: time of the day; time from harvest to destemming; and pedicel location at destemming.

- Trials on Samal Island found that latex flow is highest in the early morning and lower at midday and during the afternoon (Figure 15).
- Harvesting later in the day, delaying de-stemming and washing mangoes with water alone all have the potential to reduce latex damage.
- The volume of latex exuded at the pedicel base decreased as destemming was delayed further from harvest.
- Latex volume did not vary with pedicel length.
- Washing mangoes at harvest with water had the potential to reduce latex injury.

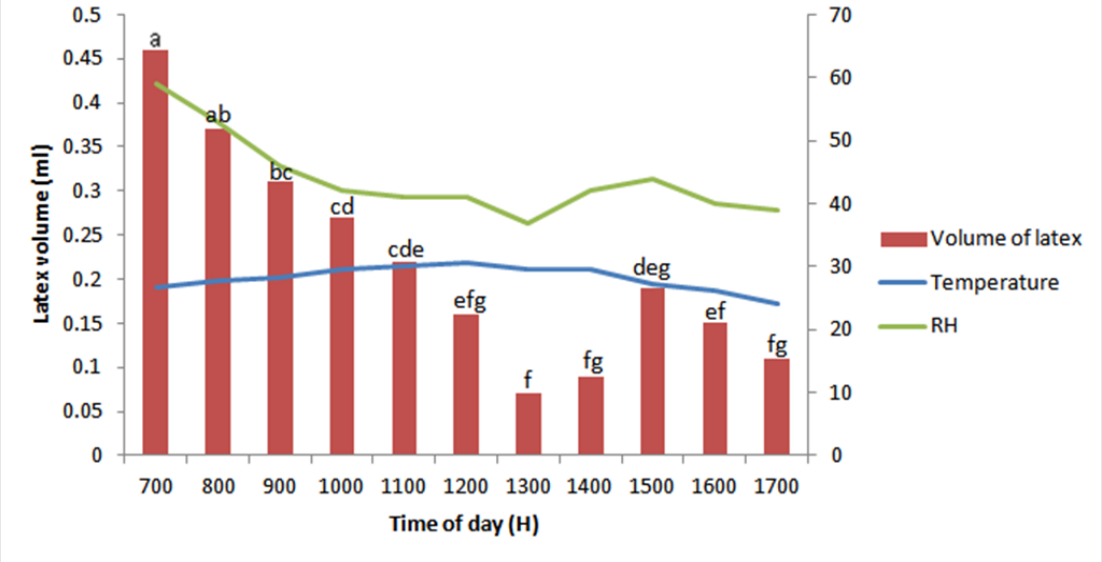


Figure 15. Latex volume of 'Carabao' mango according to time of day. Bars with common letters are not significantly different using LSD at *P*≤0.05.

Mango handling/bruising

The effect of fruit handling at harvest on bruising was evaluated in trials comparing careful and normal harvesting practices, as well as impacts imposed on the fruit from simulated drops.

- Careful harvesting (no dropping of fruit) doubled the percentage of export quality mangoes after ripening compared to normal harvest practice, while only 4% of fruit dropped at harvest were export quality. It also reduced incidence of stem-end rot (SER) by 27% and anthracnose by 33 % compared to normal practice.
- The effect of physical impacts on fruit increased as the fruit ripened – green fruit were somewhat resistant to damage, whereas ripe fruit were easily bruised or split. Although mangoes dropped while mature green did not always develop obvious bruising upon impact, the texture after ripening was poor, with retention of green colour in the impacted area (Figure 16). Underneath the impact site was white areas visible in the flesh. Fruit dropped while green had higher respiration rates and increased ethylene production compared to undamaged mangoes.

Figure 16. External and internal bruising of 'Carabao' mangoes dropped after harvest at various heights, and evaluated at table ripe stage.

Mango harvest time of day

- Keeping fruit in a shaded area during harvest reduced weight loss by about 50% compared to fruit exposed to the sun in the four hours after harvest. Highest fruit surface temperature was recorded in fruit exposed to the sun.

Mango harvest maturity

- Flotation using 1% salt solution differentiated the density of mangoes better than using water alone. It also defined further the difference between sinkers and floaters which helped screen mango fruit with better quality.
- Harvesting fruit at 120-125 DAFI resulted in better quality compared to fruit harvested at 100, 105 and 110 DAFI (Figure 17). Total soluble solids (TSS) increased with progression of ripening while titratable acidity (TA) decreased with maturity stage at table ripe stage (TRS).

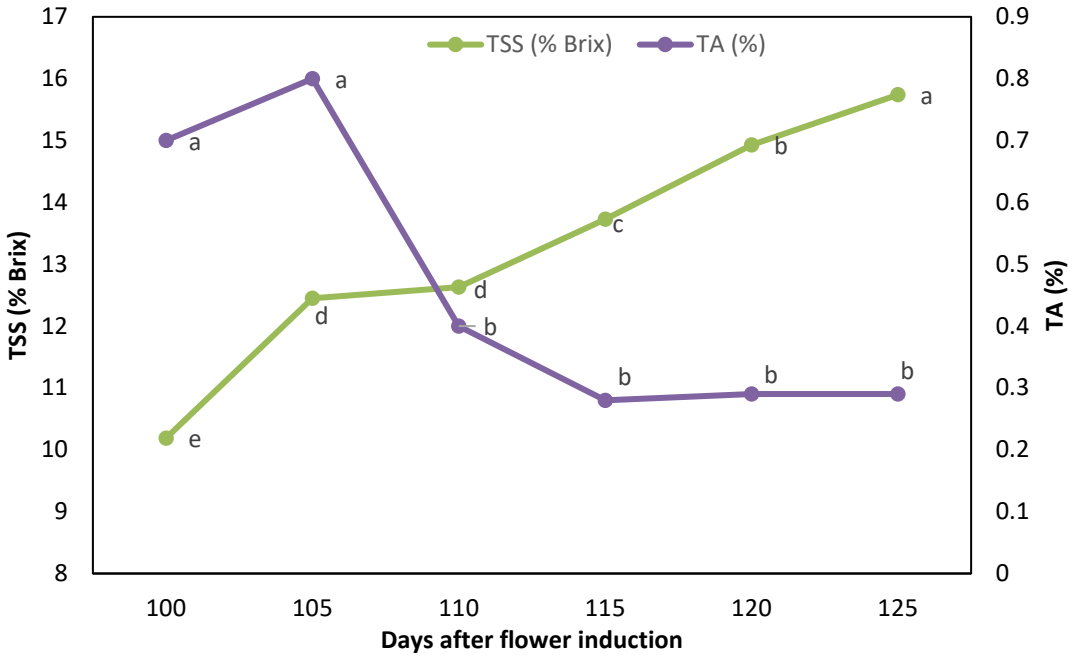


Figure 17. Total soluble solids (TSS) and titratable acidity (TA) of 'Carabao' mango as affected by maturity at harvest (days after flower induction). Points with common letters are not significantly different using LSD at *P*≤0.05.

Mango skin disorder interventions - Australia

- The effect of harvest time over the diurnal cycle was investigated with regard to the propensity of cv. 'Honey Gold' fruit to develop USB. Fruit harvested during the day were relatively more susceptible to developing USB than were those picked at night. Fruit harvested at 1000, 1400 and 1800 hrs exhibited higher incidence of USB than did those picked at 2200, 0200 and 0600 hrs (Figure 18).
- The concentration of key aroma volatile compounds in the fruit sap was significantly higher at 1400 hrs as compared to all other harvest times. In complementary work, sap extracts were applied to skin abrasion points on additional fruit. Treatment with spurt sap from fruit picked at 1400 hrs caused higher browning incidence and severity as compared to treatment with spurt sap at 0600 hrs.
- Thus, fruit harvested in the afternoon are more prone to developing USB than are those picked at night and early morning. This diurnal variation in sensitivity was associated with changes in the concentration of fruit sap volatiles. In this context, night and early morning harvesting afforded the opportunity to reduce both the incidence and severity of USB on cv. 'Honey Gold' fruit.

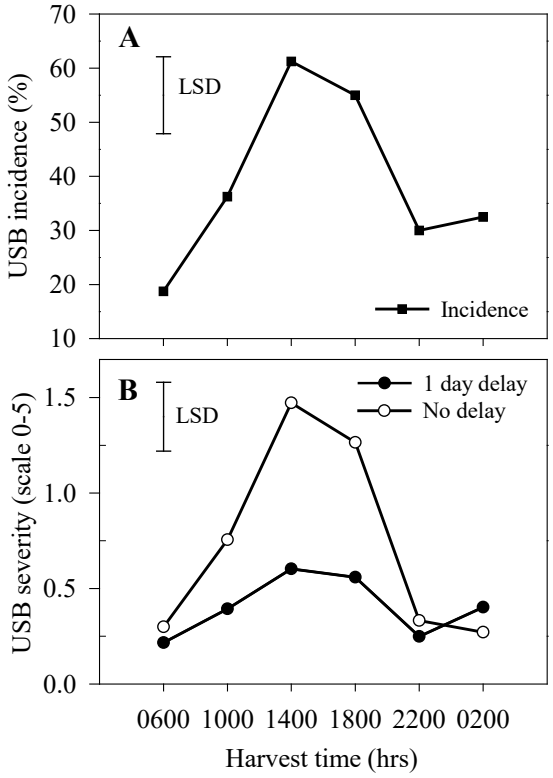


Figure 18. Under skin browning (USB) induced by the abrasion test. (A) The incidence of USB from the diurnal harvest cycle. (B) The average severity of USB from the diurnal harvest cycle. The LSD (P = 0.05) bar on graph A is for comparison between harvest time and on graph B for the interaction between harvest time and delay treatments. Fruit were placed in the cold room after 1 d of abrasion (termed '1 d delay') and fruit were placed in the cold room within 2 h of abrasion (termed 'no delay'). If the difference between means is less than the vertical bar, then there is no statistically significant difference between those means (P>0.05).

Mango hot water treatment

- Heat treatments on mango maintained good quality and effectively controlled anthracnose and SER. Regardless of the time of HWT (within 24h or past 24h but not more than 48h after harvest) onset of anthracnose and SER was delayed by 1 to 2 and 2 to 6 days, respectively.

Mango ripening

Mangoes are mostly ripened in the Philippines using calcium carbide inside large bamboo baskets. Calcium carbide is a known carcinogen, and temperatures inside bamboo baskets exceed optimal ripening temperatures. Trials investigated the effects of this ripening system on mango quality, as well as ethylene sources to replace calcium carbide:

- Temperatures inside baskets of mangoes ripened with calcium carbide increased from approximately 25 to almost 40°C for up to two days and temperature declined thereafter. Although fruit appeared in good condition when the baskets were opened, SER and anthracnose developed rapidly. The effect was most severe in fruit positioned in the middle and base of the basket, in which 70% to 90% of fruit had reduced market value after 2 days of storage in ambient conditions. To reduce

the effect of high temperature on mango quality, fruit can be ripened using calcium carbide for 48 hours instead of 72 hours.

- A comparison of ethylene sources identified that calcium carbide treatment reduced the days to TRS (from 6.6 to 3 days) of mango fruit with better visual quality and lower weight loss at TRS. A more acceptable quality of ripe mango fruit was noted in calcium carbide treatment compared to alternative ripening agents. Bioethylene sources, such as *Gliricidia sepium*, mango and 'Cardava' banana, were not as effective as calcium carbide, or higher concentrations of ethephon in reducing the number of days to ripen mango. On the other hand, Ripestuff™, showed potential as a safe alternative to calcium carbide, although optimization of its concentration and optimal environment for effective ripening is required.
- Ripening was more rapid in calcium carbide-treated fruit than those treated with acetylene, Ripestuff™, methyl jasmonate and Ethy-Gen® treated fruit. Fruit treated with calcium carbide ripened the fastest (3 days) but with earlier onset of decay (5-6 days) and shortest shelf life (Appendix 5).
- Subsequent refinements to the Ripestuff™ delivery system showed that mango fruit could be ripened in baskets with the same efficacy as with calcium carbide. Furthermore, the improved system required as little as 1 g Ripestuff™ per 5 kg fruit (0.2 $g.kg^{-1}$) to achieve this result, as compared with 5 $g.kg^{-1}$ calcium carbide. Predictive models developed for ethylene release from delivery systems of varying design provided improved understanding of the mechanisms involved (Appendix 5).
- Treatment of 'Carabao' mangoes with 10 µL L^{-1} 1-MCP delayed mango ripening by 2 days, however once ripe, the number of marketable days was not increased.
- Trials in Australia with the EIC trademarked Ripestuff™ included proof of concept case studies with commercial shipments truck-trained from Northern pack sheds to Southern markets. While mango fruit quality outturn results were variable, the potential efficacy of using Ripestuff™ for ripening fruit in-transit was clearly demonstrated (Appendix 5). Factors potentially contributing to variability between shipments (viz., temperature, ethylene and respiratory gas levels, and relative humidity) were characterised in terms of effects on fruit quality at outturn in parallel laboratory-based simulation experiments. Based on the simulation experiments, a prototype/ demonstration spreadsheet model to predict outturn quality was produced. A later simulation experiment suggested that in-transit ethylene release from Ripestuff™ may be promoted by infrasound (viz., small air pressure oscillations of 1-20 Hz) encountered in moving trucks as a result of flexing of the vehicle body, external turbulence, vehicle acceleration, and/or altitude changes. Characterising these infrasound levels in fruit consignments would enable Ripestuff™ delivery systems to be tailor designed for in-transit ripening applications.

Other fruit - ripening

- 'Cardava' banana ripened fastest using calcium carbide, followed by ethephon treatment, while *Gliciridia sepium* was the least effective ripening agent. Nonetheless *G. sepium* leaves did reduce days to full yellow compared to the control. Because of the possible hazards of calcium carbide and ethephon to the wholesalers and consumers, it is further suggested that the use of *G. sepium*

leaves as a ripening agent of 'Cardava' bananas be optimized in terms of the concentration and the manner of treatment.

- An improved Ripestuff™ delivery system was found to ripen 'Solo' papaya with the same efficacy as with calcium carbide (Appendix 5). This delivery system also produced uniform rapid ripening in 'Cavendish' banana significantly faster than in untreated control fruit and so likely to rival that of calcium carbide had it been tested. In both cases, water was added to the delivery system to promote ethylene release. However, later work on mango fruit showed that minor modifications to the delivery system could achieve ethylene release and fruit ripening without water addition. More specifically, correlating the number of holes in the delivery system lid to an appropriate mass of Ripestuff™ allowed ethylene release rates to be manipulated (Figure 19). Application of this latest delivery system design to other fruit crops is therefore recommended.

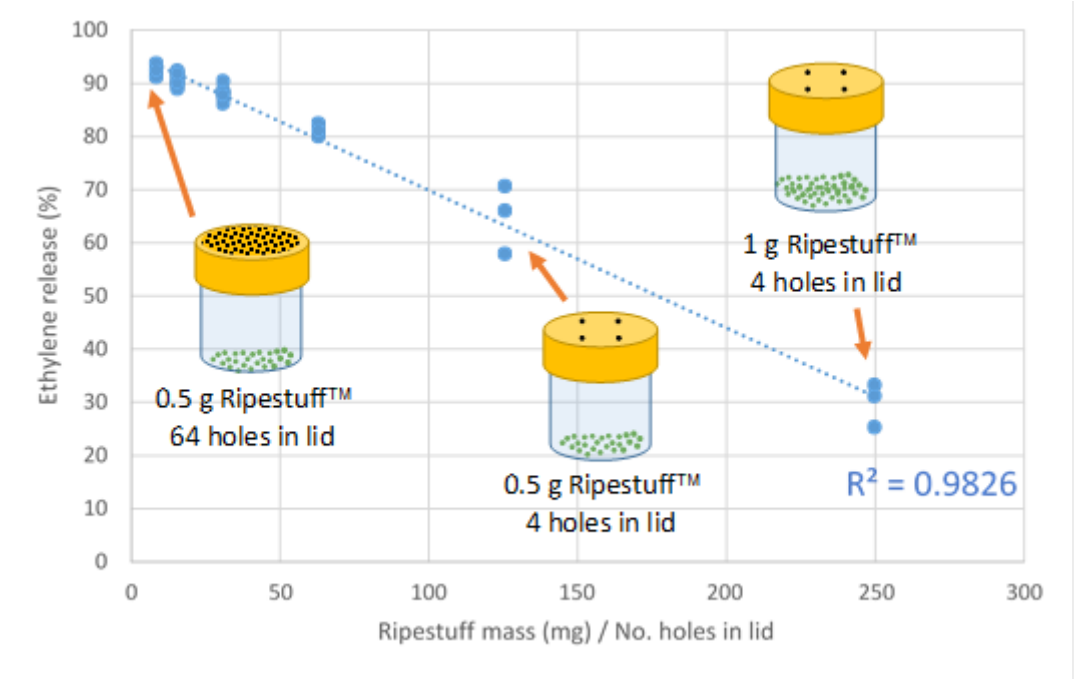


Figure 19. Relationship between Ripestuff™ quantity to whole number ratio and ethylene release at 72 h from prototype delivery systems in a 2 L static chamber at 23°C and 94% RH (P < 0.001).

Other fruit - postharvest treatments

- Gibberellic acid (GA3) at 150 and 300 µL L^{-1} delayed ripening of 'Saba' banana more at increasing concentrations, as shown by lesser yellowing (lower peel colour index), firmer fruit and lower pulp to peel ratio. A higher GA_3 concentration may hinder ripening of 'Saba' banana.
- Weight loss was least in 'Bangkok' santol fruit treated with 1000 nL L^{-1} 1-MCP followed by 10 and 100 nL L-1. The pH, TSS and polyphenol oxidase (PPO) activity of treated fruit were lower than the control, however, TA was higher in treated fruit.
- Visual quality of 'Rongrien' rambutan was maintained by 10 nL L^{-1} 1-MCP which also delayed browning and development of decay for up to 4 days. 1-MCP-treated

samples had higher TSS and Vitamin C than the control. Application of 1-MCP at ambient conditions was able to extend the shelf-life of rambutan for up to 4 days.

Vegetable packaging

- The use of polyethylene (PE) bags, in eggplant, tomatoes, Chinese cabbage and sweet pepper was evaluated. Vegetables packed in PE bags showed better quality and less shrivelling while the addition of paper towels best maintained the quality in tomato.
- The benefits of packing eggplant in cartons was demonstrated. Bruising of 'Banate King' eggplant was reduced in cartons compared to those packed in sacks (Figure 19). Fruit in the upper third of the container sustained less bruising. Weight loss was less in fruit in the top portion of the sack, than those in the lower portion. Visual quality was better maintained due to less shriveling of fruit from both the top portion of the sack and those in the carton.

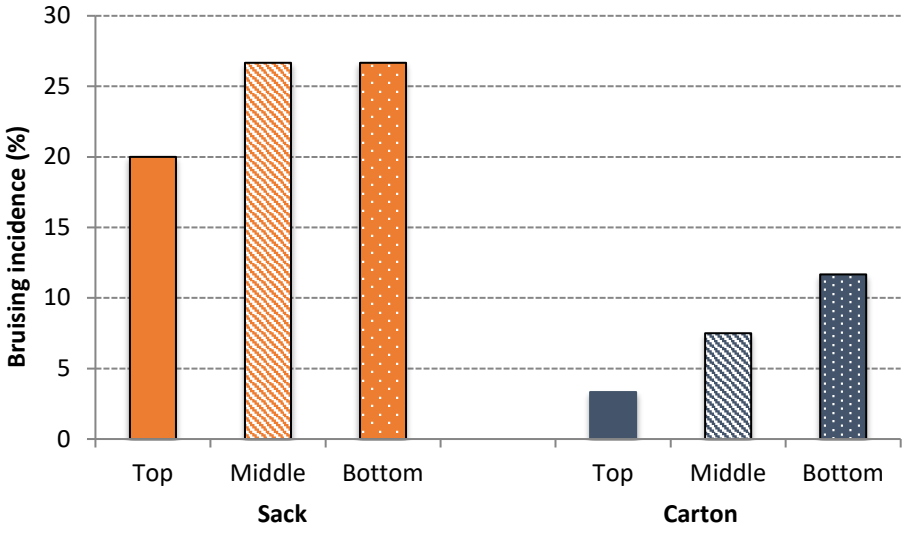


Figure 20. Incidence of bruising in 'Banate King' eggplant after simulated transport in traditional sacks versus small carton boxes. Fruit were selected from the top, middle and bottom of each package type. Bars with common letters are not significantly different using LSD at *P*≤0.05.

- Chinese cabbage packed inside MAP had less wilting, trimming loss, and better visual quality than those left unpacked.
- Storing bitter gourd in polyethylene (PE) bags for up to 3 days improved shelf life, with reduced fruit yellowing. Shelf life was extended by 1 day when bitter gourd was bagged with $KMnO_4$. Samples packed in PE bags had lower weight loss than the control.
- Packaging tomato in PE bags, zipbags and foam trays with PVC film reduced fruit weight loss by up to 7% compared to the unpacked control.
- PE, polypropylene (PP) and zipbags reduced weight loss, and extended shelf life of eggplant.

Vegetable physical damage

- Compression of eggplant at 11 KN reduced visual quality, caused up to 18% internal bruising and resulted in weight loss and higher electrolyte leakage. This demonstrates the need to handle eggplant carefully during harvest and transport.
- Although tomatoes dropped 50-100 cm did not appear bruised, quality deterioration and decay development increased with increasing drop height.

Vegetable postharvest treatments

- Chitosan fruit coating (1.5%) delayed shriveling and decay and maintained better quality of sweet pepper. This may be the result of the antibacterial properties of chitosan and its efficacy as a semi-permeable film.
- 1-MCP treatment of sweet pepper maintained better visual quality and reduced shrivelling, starting from 4 days after treatment. Ripening was delayed, and postharvest quality of sweet pepper held in ambient conditions was better maintained using 1 or 10 µL L^{-1} 1-MCP.
- 1-MCP treatment of eggplant for six hours showed significantly better quality, reduced weight loss, reduced pulp browning and reduced electrolyte leakage. Fruit treated with 25 µL L^{-1} 1-MCP had an extra day of shelf life. Postharvest treatment of 1-MCP on eggplant maintained better quality and increased the shelf life of fruit stored in ambient conditions.
- 1-MCP was more effective in delaying ripening in tomato when it was applied at the mature green stage, as it delayed the degreening. Tomatoes treated with 1-MCP, regardless of maturity stage (i.e., mature green or breaker) when treated, had similar visual quality but tended to have less decay than the untreated control.
- Chayote fruit wrapped in cling wrap and treated with 500 µL·L^{-1} 1-MCP had significantly lower weight loss than the control fruit. The treatment also reduced sprout growth, such that emergence of the cotyledon and shoot were delayed by 4 days.
- Application of 10 nL L^{-1} 1-MCP maintained the ascorbic acid content and postharvest quality of bitter gourd. Storage of fruit in low temperature also helped in preserving ascorbic acid content and other postharvest characteristics of bitter gourd fruit.
- Hot water spray reduced weight loss, colour change and visual quality deterioration in sweet pepper which resulted in a higher number of marketable fruit.
- HWT at 45ºC for 5 minutes, followed by refrigerated storage reduced weight loss, inhibited shrivelling, delayed ripening and maintained visual quality of tomatoes. These effects were similar to the 40ºC HWD treatment. However TA and pH of tomatoes were reduced when fruit were hot water treated and stored under ambient or refrigerated conditions. A temperature of 50ºC or higher reduced quality.
- A solution containing 5% acetic acid is not recommended to use for washing tomatoes as it promoted lower visual quality and higher degree of decay. Water was as effective as NaOCl or NaHCO3 in maintaining the quality and reducing decay of ‘Superwhite Pope’ tomato.

- Potassium permanganate slowed down ripening in tomato, however decay development during storage adversely affected the tomato quality. Storing in PE bags with perforations was best in delaying decay development and weight loss. It maintained better quality of tomato with a higher number of marketable fruit during ambient storage.
- Application of 10% alum followed by wrapping with newspaper maintained visual quality and reduced the incidence of decay on the butt-end of Chinese cabbage compared to untreated samples, regardless of the position of the heads in the sack. Weight loss at ambient conditions ranged from 7.2-10.6% while trimming losses ranged from 43-52% at 3 days of storage.
- Packing Chinese cabbages inoculated with *Pectobacterium carotovorum* inside PE bags, with or without alum, reduced trimming losses compared to those which were left at ambient. Both alum and PE bag contributed to better visual quality and lower degree of decay of Chinese cabbage heads.
- Treatment with 10% alum resulted in zero to low levels of soft rot infection when applied in Chinese cabbage head. Chinese cabbage treated with 10% alum had good visual quality, low trimming loss and longer days to initial symptoms compared to those treated with guava and mangosteen extracts. Longer shelf life was exhibited by Chinese cabbage treated with 10% alum followed by samples treated with mature leaf guava extract. Trimming loss was lower in Chinese cabbage butt treated with 10% alum.
- Sprouting in chayote was affected by fruit rather than treatments of ethephon and GA_3.
- The use of cling wrap was effective in delaying the onset of sprouting in chayote while ethephon promoted sprouting and had the longest sprout length. Relative to cling wrap, higher weight loss was recorded in 1-MCP treated fruit at 10 days after treatment due to higher decay occurrence.
- Potato tuberlets treated with calcium carbide at 3 g kg^{-1} had the highest percentage of sprouting and number of sprouts per tuber. More than 50% sprouting was attained with calcium carbide (3 g kg^{-1}) at 4 weeks after treatment. Treatment with 3 g kg^{-1} calcium carbide also resulted in higher apical sprout length and weight loss. Treatment of G-0 potato tuberlets with 3 g kg^{-1} calcium carbide showed potential in breaking dormancy period and in promoting uniform sprout growth.

Vegetable cool storage

- Storage of sweet pepper in an evaporative cooler (EC) reduced weight loss, shrivelling and colour change; increasing marketable life by 9 days compared to ambient storage.
- Storing 'Señorita' eggplant in an evaporative cooler maintained better calyx and visual quality, had lower weight loss, reduced shriveling and decay, compared to 'Banate King'. Storage of both eggplant cultivars resulted in better quality due to lower weight loss and shrivelling.
- Storage in low-temperature (10^{o}C) increased the shelf-life of eggplant to twice as much of the control in ambient conditions (5 days). In 'Señorita' eggplant, electrolyte leakage (EL) decreased during low temperature storage while it increased for 'Banate' eggplant. Longer storage of eggplants at low temperature

storage deceased the number of marketable fruit due to chilling injury. Chilling injury symptoms in eggplant consisted of pitting, calyx discolouration and seed discolouration.

- Three evaporative cooler designs were compared: EC 1 - No water pump and exhaust fan, EC 2 - With water pump and exhaust fan, EC 3 - With water pump but no exhaust fan).The cost of the evaporative coolers were Php 4,644.74 (EC1), Php 8,694.74 (EC2), Php 6,939.74 (EC 3). Shelf life of tomato was extended by 2 days in the evaporative coolers compared to ambient conditions, although there were no differences between the three designs.

Vegetable preharvest effects on postharvest quality

- Postharvest quality of tomatoes grown with various mulches (part of the Integrated Crop Management project) were similar, regardless of types of mulch used. No differences in postharvest firmness, soluble solids, pH and weight loss were measured.
- Non-grafted bitter gourd fruit had higher weight loss and lower visual quality compared to grafted fruit. Disease incidence and colour change were also higher for the non-grafted bitter gourd compared to the grafted amplaya samples. Grafted bitter gourd has a reduced bacterial wilt severity, suggesting that a healthier plant results in better postharvest storage.

Objective 3 – To develop active, profitable and sustainable linkages between farmers and retailers

Opportunities for value-added products

Fresh-cuts are value-added fruit and vegetables that have been minimally processed (i.e.: peeled, sliced, shredded, trimmed, and/or washed fruits and vegetables) packed, and stored at low temperature. They have a faster rate of deterioration as a result of the wounding process that occurs during processing. Hence, proper handling practices and temperature control should always be observed.

Chop suey and pinakbet are popular Filipino delicacies that are both composed of sautéed mixed vegetables. Public wet markets in the Philippines sell fresh-cut mixes of these dishes. However, based on preliminary analysis, handling and storage practices of fresh-cut pinakbet and chop suey are not done very well. They are prepared by vegetable vendors who do not follow good manufacturing practices. Produce is often not washed prior-to or after preparation. If they are, wash water is usually used multiple times. Furthermore, products need to be sold on the day of preparation due to limited shelf-life.

Preliminary tests were made on fresh-cut fruit and vegetables. In vegetable mixes such as Chop suey, the most perishable component was evaluated (in this case Chinese cabbage), as the quality of an entire pre-mixed product is only as good as its most perishable component (Cantwell and Suslow, 1999).

Treatments to extend the storage life of fresh-cuts

- Treatments to extend the shelf-life of fresh-cuts were evaluated through two literature reviews (Appendix 3). Of particular interest were the vegetables used in the Filipino dish 'pinakbet' and chop suey. UV-C treatment was one method identified as having potential in the Philippines. UV-C does not involve immersing the produce in wash solutions, which eliminates the problem of solution residue. HWTs were the other key method identified.
- The UV-C dosage that resulted in the least damage to Chop suey vegetables was 0.008 kJ/m^2. There were no changes observed in the visual quality and colour of the control and UV-C treated fresh-cut vegetables using the specific dosage. However, microbial levels were significantly reduced. Total plate and yeast and mould counts were lower in the UV-C treated fresh-cut carrot, chayote, Chinese cabbage, and sweet pepper. Shelf-life was also increased in fresh-cut sweet pepper by 2.5 days.
- HWTs were evaluated for minimally processed Chinese cabbage. One minute treatments of 40˚C, 45˚C or 50˚C water did not increase shelf-life or days to browning compared to the untreated control (Figure 20). However the treatments had no adverse effects on the quality of minimally processed Chinese cabbage and could be used to reduce microbial contamination.

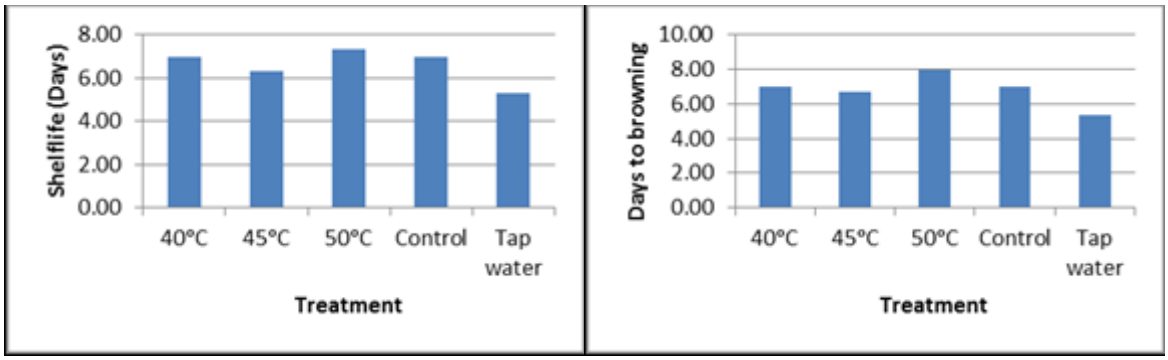


Figure 21. Quality attributes of minimally processed Chinese cabbage after 8 days of storage. Means with common letter/s are not significantly different at 5% level LSD.

- Both HWTs and MAP improved marketable shelf-life for fresh-cut 'pinakbet' vegetables (ampalaya, eggplant, okra, string beans and squash). Browning of cut surfaces was reduced with HWTs, and packaging served to reduce weight loss and consequent shriveling.
- Storing minimally processed jackfruit in ziplock bags reduced weight loss in both ambient and cold storage. However quality characteristics including colour, aroma, taste, texture, and acceptability did not differ.

Objective 4 – To build research capacity in the Southern Philippines

Conferences and publishing

Members of the project team made 40 presentations at major conferences in the Philippines, Vietnam, Cambodia and Australia. Twenty-one (21) papers have been

published in peer-refereed journals, with a further 6 in press or under review. (See Appendices 1 and 4 for published papers, and conference presentations).

Researcher training

A number of project members were provided with training in statistical analysis and postharvest handling systems (King Mongkut University of Technology Thonburi, Thailand).

Train-the-trainer workshops on postharvest management of fruit and vegetables were also provided. The material and demonstrations from these workshops were used as a basis for those presented to growers and supply chain members in the Philippines.

Laboratories, equipment and coolrooms

At both VSU and UPMin, substantial laboratory equipment was provided, as well as assistance in the development and use of a full postharvest research laboratory.

Equipment purchased included texture analysers, gas analysers, colour meters, penetrometers, balances, hot-water baths, temperature loggers, laboratory furniture, and three coolrooms at UPMIn.

Standard operating procedures were developed for new equipment.

New coolrooms developed at UPMin (left), and gas analyser in use at VSU (right).

Student projects

The project offered a series of seed grants ($500) to Honours students wishing to do a research project on a postharvest issue. Thirty (30; 3 men, 27 women) UPMin students were supported by the project. These were composed of 16 BSc Food Technology

students; 11 BSc Biology students, and 3 BSc Computer Science students. Other BSc Biology students (9 students; 1 man, 8 women) were also able to conduct postharvest research in the fully developed postharvest laboratory in UPMin. The students' research included postharvest studies in santol, rambutan, banana, potato tubers, bitter gourd, and chayote.

Refer to section 7.4 for further details of workshops and extension materials

8 Impacts

8.1 Scientific impacts – now and in 5 years

The project primarily focused on adapting existing research and knowledge to address the specific needs and conditions of the Southern Philippines. The project provided baseline postharvest losses for local fruit and vegetable supply chains, as well as results from various postharvest treatments and methods tested on local varieties and supply chains.

The project contributed to the body of knowledge on:

- How biotic (disease) and abiotic (physical) damage are caused by specific handling practices
- How changes in postharvest handling affect storage and quality of key Philippine fruit and vegetables
- Elucidation of the postharvest attributes of a variety of tropical fruit
- Locally applicable quality and damage guides for vegetables and mangoes
- Identification and development of novel value-added fruit and vegetable products
- Examination of pre and postharvest factors affecting USB, RCD and LD in mango
- Ripestuff™ ethylene release and delivery system design resulting in an effective and safe alternative to calcium carbide for ripening mango and other fruit in a Philippine wet market context.

All of the project team members have published numerous edited / refereed scientific papers during the project, as well as presented research results at local and scientific conferences (see Appendices 1 and 4). This published material will be used in the coming years by postharvest scientists, particularly in the Philippines.

Postharvest intervention trials, which included scientific publications were used as a basis for production of best practice materials for farmers and supply chain stakeholders. Use of these materials will improve postharvest practices in the Philippines. This material will also be used in future ACIAR projects, in particular to develop GAP protocols in HORT 2016/188 ‘Developing vegetable value chains to meet evolving market expectations in the Philippines’.

Significant scientific findings resulted from the work on LD, RCD and USB of mangoes in Australia. Results published in the scientific literature added to knowledge of characterisation of the disorders, helping inform postharvest practices to optimise the quality of Australian mangoes.

8.2 Capacity impacts – now and in 5 years

People

Building postharvest research capacity in the Southern Philippines has been a key impact of the project. The project teams at both UPMin and VSU have improved their understanding of postharvest management, use of laboratory equipment and methodology development through project training, workshops, conferences, and visits to Australia.

The project team have also improved their understanding of research design and statistical analysis of results through participation in trainings provided through the project. As a result, the quality of postharvest research has improved, with 21 papers published in peer-refereed journals to date. The project team were able to gain further experience and confidence through attendance and presentations at international conferences.

Thirty UPMin undergraduate students were supported by the project to conduct postharvest research projects. A further 10 undergraduate students were not directly supported, though were able to conduct postharvest research using equipment supplied by the project. A new generation of researchers with a keen interest and understanding of postharvest science has developed as a result. For example, two former undergraduate students who received support from the project to undertake undergraduate research are currently pursuing master's degrees in Postharvest Technology at King Mongkut's University of Technology Thonburi (KMUTT), Thailand.

Project research assistants have developed considerably as a result of the project, and have a strong interest in furthering careers as postharvest researchers. For example, two research assistants at UPMin: Leizel Secretaria and Christine Diana Lubaton are attending MSc classes at the University of Southeastern Philippines (Davao City) and undertaking theses in postharvest biology.

Aljay Valida (VSU) is undertaking his PhD in modelling quality attributes and shelf life of zucchini at UQ through a John Allwright Fellowship.

Angelyn Lacap who was hired as a research assistant at UPMin at the start of the project was provided numerous learning opportunities, including two trips to Australia in 2015 and 2018 to visit postharvest laboratories and facilities, and attendance at the International Mango Symposium in Darwin in 2015. Her experience in the project helped Angelyn obtain a scholarship to complete her Master's degree in Postharvest Technology in Thailand. She has since returned to UPMin and plays an important role in training younger researchers, students and farmers. Angelyn plans to continue her career development and hopes to undertake a PhD in Australia in the next few years.

These budding researchers will help fill the gap and address the insufficient expertise in the field of postharvest research in the Philippines.

Involvement in this project helped Anh Tram San and Khamla Mott in their PhD studies and associated publications at UQ.

Postharvest laboratories

At the start of the project both UPMin and VSU had few laboratory facilities, ageing equipment, and limited capacity for either teaching students or conducting postharvest

research. Because of the project, both universities now have functional postharvest laboratories, with a range of new equipment available for both research and student training.

At UPMin, the installation of cool rooms and purchase of new laboratory furniture and equipment has transformed this into a better equipped laboratory. Researchers and students can now conduct a wide range of postharvest assessments. As a result of laboratory development, more effective postharvest assessments can be undertaken, including:

- Calculation of respiration rate of different fresh products
- Analysis of colour, internal quality and physicochemical attributes (TA, pH, sugar, ascorbic acid, total phenolics, carotenoids, lycopene, polyphenol oxidase, and starch content) of fruit and vegetables
- Measurement of changes in texture, firmness, and electrolyte leakage.
- Assessment of effect of different storage environments (refrigerated, evaporative cooling, ambient) on quality and storage life
- Measurement of temperature and relative humidity in containers
- Development of photographic scales for quality assessment, grading and extension to growers

The improved postharvest facilities will encourage more students to undertake postharvest research, ultimately increasing the number of postharvest scientists in the Philippines for years to come.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

Improved understanding of where postharvest losses occur in Filipino vegetable and mango supply chains will allow future policy and business initiatives to target investment in those areas e.g. transport and storage (refrigeration and modified evaporative coolers).

Intervention strategy studies focused on low cost, practical tools for farmers and supply chain members. These were communicated directly through workshops as well as using printed best practice materials. Training provided to farmers/growers, retailers, wholesalers and extension workers encouraged and motivated the participants to apply various postharvest interventions strategies. These strategies will ultimately help reduce postharvest losses, increasing income to growers and supply chain members.

Examples of demonstrated strategies to reduce postharvest losses include:

- Use of banana leaves as liners in packages to reduce bruising
- Packing into crates rather than baskets to limit compression damage during transport
- Adding a sanitiser to water used to wash products
- Use of alum to reduce soft rot in Chinese cabbage

- Reducing the exposure time and quantity of carbide used to ripen mangoes to limit high temperature damage to the fruit.
- Use of evaporative coolers to reduce weight and quality losses in sweet pepper and eggplant, thereby increasing storage life by 3-6 days.
- Avoiding bruising of mature green tomato so as to reduce decay.
- Careful harvest of mango to avoid quality losses to bruising.

As most of these intervention strategies are low cost, they will help farmers and contractors to reduce postharvest losses at minimal expense, thereby increasing profitability.

In addition to these strategies, further advantages of protected cropping and grafting of vegetables were demonstrated in relation to improvements in postharvest quality and loss reduction. This will provide further advantage to growers who were involved in the vegetable ICM project who have adopted these technologies.

Improving postharvest quality in the Philippines will increase the level of product suitable for high end markets such as Filipino supermarkets and/or export. The Philippines is well located for export to other Asian countries and Australia. Meetings were held with Australian import / export businesses potentially interested in importing Filipino mangoes to Australia and/or exporting to other Asian destinations. Issues included availability of quarantine treatment facilities, storage conditions and shelf life at destination. Subsequent investigations have shown that suitable handling and treatment facilities are now available in Davao City. However, preharvest quality and postharvest storage life remain issues to be addressed. This project has however made some progress towards addressing those issues.

SPFFC, a mango packing and export company, was engaged as a collaborator during the project. The company collaborated on some postharvest trials addressing issues that were reducing their export opportunities, including the high grade-out of supplied fruit, and poor / uneven quality on arrival at export destinations.

In Australia, reducing the level of USB in ‘Honey Gold’ mangoes was a major achievement for the project. Research identified night and early morning harvest reduced the incidence and severity of USB. As a result, ‘Honey Gold’ growers changed their harvest practices to night and early morning harvest. Night harvest during cooler ambient temperatures also reduces stress on mango pickers, as well as reduced fruit respiration rates.

8.3.2 Social impacts

Gender

More than 50% of the participants in the workshops conducted were women. The program is therefore helping to empower women and girls, helping to provide them with potential to improve their small businesses. The majority of the research personnel, and students undertaking postharvest projects in the Philippines were female.

Numerous postharvest training activities have empowered and upskilled smallholder farmers, especially women, many of whom had not heard of postharvest management previously.

The vast majority (~90%) of the students who studied postharvest and used the new facilities and equipment at UPMin were women. It is also noted that the majority of research assistants involved in the project were women. Providing educational activities and training to this group of bright young women will enhance their future career opportunities, helping them to take on professional and influential roles and achieve whatever they want to achieve.

Health

Improvements in postharvest quality and a reduction in postharvest losses will improve quality as well as reduce prices of fruit and vegetables in the Philippines. In the long term, this can increase consumption of fruit and vegetables by Filipinos, thus improving health.

In the Philippines, mangoes are ripened using calcium carbide. The powder reacts with moisture to produce explosive acetylene gas. Calcium carbide is a potential carcinogen, and its use as a ripening agent is banned in many countries. Ripening mangoes by this method also increases disease and shortens storage life.

Developing mango ripening methods which are safer for the operator, avoid contamination of the product, and result in increased shelf life for retailers and consumers is a benefit for both Australia and the Philippines.

A product called Ripestuff™ which is a form of encapsulated ethylene will result in safer and more efficient ripening practices in the Philippines and Australia. The potential for Ripestuff™ to be used for in-transit ripening in Australian supply chains was initially tested. If successful, this will allow direct supply of mangoes from farm to supermarkets, creating more efficient supply chains. Furthermore, Ripestuff™ can be used to safely and effectively ripen Carabao mangoes in the Philippines. In the future, Ripestuff™ could replace calcium carbide as the ripening agent for mangoes in the Philippines, reducing health risks to the operator.

The use of Ripestuff™ as a mango ripening agent will help eliminate the use of the carcinogenic ripening agent, calcium carbide. This will improve health of those working in the wholesale markets, and the consumer (where residues remain in the fruit).

Mango workshops on food safety and chemical use helped address concerns of misuse of chemicals. Chemical overuse not only reduces the effectiveness of such chemicals, but also has serious implications for the health of the spray applicator and consumer. Farmers and contractors were better able to understand how to interpret chemical labels. This included understanding the ‘active ingredient’ and ‘mode of action’ sections on the labels. This will help achieve the following outcomes:

- Stop pesticide applicators wasting money by applying multiple products with the same mode of action / active ingredient
- Avoid resistance
- Reduce residues in products, and
- Avoid environmental damage

8.3.3 Environmental impacts

The primary environmental impacts have come through the interactions between the postharvest project and connected projects concerned with production issues. For example, the use of protected cropping systems and organic mulches provide a more sustainable production system for vegetables. These technologies have been researched and extended to farmers through the vegetable ICM project. The postharvest team has supported this innovation by testing postharvest life of vegetables grown using these systems. These trials have demonstrated that protected cropping systems increase, rather than decrease, postharvest storage life. Vegetables matured sooner under the protected cropping system, reducing environmental and economic costs to farmers. Mulches have less effect, but certainly do not reduce quality relative to un-mulched controls.

Reducing postharvest losses is a way to make more efficient use of land, water, fertilisers and other inputs for crop production. This will be critical in the Philippines in the coming years, as food production for a fast growing population puts pressure on the environment.

The pesticide training for mango growers will reduce pesticide residues in the environment, and reduce the risk of resistance in pests and diseases.

8.4 Communication and dissemination activities

Workshops

Key findings of various postharvest intervention studies were presented in training workshops to more than 1460 attendees. Those included farmers, wholesalers, retailers, exporters, students and agronomists. A list of all workshops is provided in Table 2.

Topics included introduction to postharvest management, harvesting systems, packing house operations, alternative storage systems, food safety, postharvest losses at the household level, and processing of value-added products. The latter topic included fresh-cuts, flours, jams, pastes, and fermented products.

Aside from lectures, demonstrations were used to make the workshops more interactive. Participants compared the weight loss of fruits and vegetables stored under the sun versus shade, compared the visual quality of packed versus unpacked leafy vegetables, observed the quality of alum-treated Chinese cabbage, compared the ripening of bruised and unbruised tomatoes, and detected the temperature change inside an evaporative cooler.

Participants reported their observations from each of the demonstrations and were able to explain the principles behind the results. They realized that even within a period of 2-3 hours, improper storage conditions can considerably increase weight loss on their produce. They also appreciated the impact that basic and cheap interventions can have in reducing postharvest losses, and how some of these could be implemented in their own systems.

After each training, the participants shared their impressions about the workshop. Most of them had never heard of postharvest management up until it was introduced to them during the training. According to a vegetable grower, attending workshops like these was

important to her because she immediately shares this new information to other members of their vegetable grower's association, which she thinks would strengthen their businesses.

The majority of participants in the seminar on postharvest losses at the household level do not own a refrigerator. Hence, they were very appreciative when a low-cost evaporative cooler was introduced to them.

Mango postharvest training workshop on Samal Island, May 2018

Table 2. List of workshop/training activities over the course of the project

Workshop topic	Team member(s)	Location	Date	Audience	No. attendees
Postharvest handling and packaging techniques of fruit and leafy vegetables	MM Benitez	Cabintan, Ormoc City, Leyte	January 2016	Farmers	35
Postharvest management and packaging for vegetables	Marilou Benitez and Michael Sudaria	Ormoc	January, February 2016	Farmers	Not recorded
Postharvest handling and packaging techniques of fruit and leafy vegetables	MM Benitez	Cabintan, Ormoc City, Leyte	February 2016	Farmers	29
Postharvest management for mangoes	Jenny Ekman and Emma Ruth Bayogan	Samal Island	February 2016	Farmers, contractors, wholesalers	40

Workshop topic	Team member(s)	Location	Date	Audience	No. attendees
Export of Filipino mangoes to Australia and other Asian destinations	UPMin team	Davao City	February 2016	Australian import businesses	Not recorded
Mango package of technologies	Emma Ruth Bayogan	University of Southeastern Philippines, Davao City	March 2016	Students	Not recorded
Postharvest handling of vegetables	UPMin team	Ladi-an, Marilog, Davao City	May 2016	Farmers, supply chain members, UPMin students	80
Meetings to discuss collaboration in postharvest trials	UPMin team, Australian collaborators	SPFFC, Davao	July 2016	SPFFC staff	16
Postharvest handling of vegetables	UPMin team	Pamuhatan, Marilog, Davao City	September 2016	Farmers and supply chain members	15
Postharvest handling of vegetables	UPMin team	Upper Sabang, Marilog, Davao City	October 2016	Farmers and supply chain members	23
Postharvest management	MM Benitez	San Roque, Mayorga, Leyte	November 2016		23
Postharvest management	MM Benitez	Abuyog, Leyte	November 2016		22
Postharvest management	MM Benitez	McArthur, Leyte	November 2016		21
Postharvest management	AD Valida	Samar	December 2016		24
Postharvest management	MM Benitez	Marabut, Samar	December 2016		28
Postharvest management of mangoes	Emma Ruth Bayogan	UPMin	February 2017	Mango stakeholders	Not recorded
Postharvest training for retailers/wholesaler	UPMin team	UPMin	February 2017	Retailers/wholesalers	2
Postharvest management of mangoes	UPMin team	Samal Island	February 2017	Farmers, suppliers of inputs, contractors	30
Vegetable postharvest handling and processing	MM Benitez	Baybay City, Leyte	February 2017		40

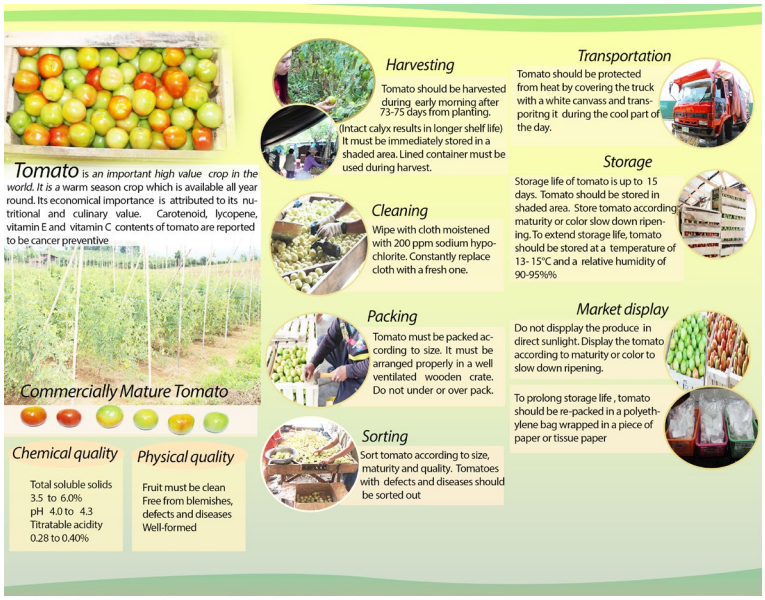
Workshop topic	Team member(s)	Location	Date	Audience	No. attendees
Postharvest handling of mango fruit	UPMin team	Mankilam, Tagum City	March 2017	Mango farmers	Not recorded
Preharvest factors affecting postharvest quality of mango. Ripening and storage of mango. Postharvest management of mango.	UPMin team	Mankilam, Tagum City	March 2017	Farmers	40
Postharvest training	MM Benitez	Dulag, Leyte	July 2017		6
Postharvest training	MM Benitez	Dulag, Leyte	July 2017		28
GAP of vegetable production	FR Rivera, E Hinayon	Libagon, Southern Leyte	July 2017		47
Climate smart high value vegetable production technologies	MM Benitez	Bohol	November 2017		23
Postharvest handling of vegetables	UPMin team	Mankilam, Tagum City	February 2018	Farmers	88
Vegetable postharvest handling	UPMin team	Mankilam, Tagum City	February 2018	Farmers	Not recorded
Postharvest handling of fruits	UPMin team	Mankilam, Tagum City	March 2018	Farmers	Not recorded
Reduction of postharvest losses at the household level	UPMin team	UPMin	March 2018	Homemakers	Not recorded
Postharvest handling of mango and other fruit	UPMin team	Mankilam, Tagum City	March 2018	Mango farmers	91
Controlling postharvest losses at the household level	UPMin team	Tugbok District, Davao City	March 2018	Homemakers	37
Postharvest handling of fruits and vegetables	UPMin team	Laak, Compostela Valley Province	April 2018	Farmers	Not recorded
Postharvest handling of fruit and vegetables	UPMin team	Laak, Compostela Valley Province	April 2018	Farmers	73
GAP of vegetable production	MM Benitez	Baybay City, Leyte	April 2018		34
Postharvest handling of mango	Jenny Ekman and Emma Ruth Bayogan	Davao	May 2018	Agriculturists	500

Workshop topic	Team member(s)	Location	Date	Audience	No. attendees
Postharvest handling and storage of vegetables	UPMin team	Agusan del Sur, Agusan del Norte	June 2018	Farmers and technicians	40
Vegetable postharvest and packaging	UPMin team	Bayugan City, Agusan del Sur	June 2018	Farmers and supply chain members	Not recorded
Vegetable handling and storage of vegetables	UPMin team	Cabadbaran, Agusan del Norte	June 2018	Farmers and supply chain members	Not recorded
Postharvest management	MM Benitez	Baybay City, Leyte	September 2018		41
Tour of the Postharvest research facility in UP Min – shared information about postharvest studies	UPMin team	UPMin	December 2018	Philippine Science High School (PSHS) students	Not recorded
College of Science and Mathematics Research Colloquium (UP Min) - presentation on mango ripening	UPMin team	UPMin	December 2018	Science students	Not recorded
Tour of the Postharvest research facility in UP Min - shared information about postharvest studies	UPMin team	UPMin	January 2019	Central Mindanao University (CMU) faculty	Not recorded
Tour of the Postharvest research facility in UP Min - shared information about postharvest studies	UPMin team	UPMin	May 2019	Senior High School Teachers (Molecular Biology Camp)	Not recorded
				TOTAL	**>1476**

Extension materials

Eight (8) postharvest best practice and grading guides were developed for key crops, including mango, tomato, sweet pepper, eggplant, and Chinese cabbage. Some of the materials were also translated from English to Cebuano (See Table 3 and Table 4 for a list of the materials developed, and Appendix 2 for the full documents).

A total of 7,814 pieces of extension materials were distributed.



Tomato postharvest handling guide.

Mango postharvest handling guide

Table 3. English extension materials

Title	Author/s	Date
Sweet Pepper Quality Indices, Defects and Diseases	Bayogan, EV, JH Ekman, and AC Majomot	April 2016
Sweet Pepper Appropriate Postharvest Handling	Bayogan, EV, JH Ekman, and AC Majomot	April 2016
Tomato Postharvest Handling	Bayogan, EV, JH Ekman, LB Secretaria, and CS Lubaton	October 2016

Tomato Postharvest Quality, Defects and Diseases	Bayogan, EV, JH Ekman, LB Secretaria, and CS Lubaton	January 2017
Chinese Cabbage Postharvest Handling	Bayogan, EV, JH Ekman, LB Secretaria, and CS Lubaton	January 2017
Chinese Cabbage Postharvest Quality, Defects and Diseases	Bayogan, EV, JH Ekman, LB Secretaria, and CS Lubaton	January 2017
Mango Postharvest Handling	Bayogan, EV, JH Ekman, DC Joyce, LB Secretaria, and CS Lubaton	February 2017
Eggplant Postharvest Handling	Bayogan, EV, JH Ekman, CS Lubaton, and LB Secretaria	February 2017
Mango food safety (draft)	JH Ekman	March 2019

Table 4. Cebuano extension materials

Title	Author/s	Date
Pag-atiman sa Kamatis Human sa Pag-ani	Bayogan, EV, JH Ekman, LB Secretaria, CS Lubaton, and MM Sudaria (Translator)	November 2017
Pag-atiman sa Atsal Human sa Pag-ani	Bayogan, EV, AC Majomot, and JH Ekman	November 2017
Pag-atiman sa Mangga Human sa Pag-ani	Bayogan, EV, JH Ekman, DC Joyce, LB Secretaria, CS Lubaton, and MM Sudaria (Translator)	November 2017
Pagdugang ug Bili sa mga Gulay ug Prutas: Recipes	Monterde, VG, EV Bayogan, and JH Ekman	March 2018
Pagdugang ug Bili sa mga Gulay ug Prutas: *Produkto na Pinulbos*	Monterde, VG, EV Bayogan, and JH Ekman	April 2018
Pagdugang ug Bili sa mga Gulay ug Prutas: *Acidified Foods*	Monterde, VG, EV Bayogan, and JH Ekman	April 2018
Pagdugang ug Bili sa mga Gulay ug Prutas: Fried Foods	Monterde, VG, EV Bayogan, and JH Ekman	April 2018

9 Conclusions and recommendations

9.1 Conclusions

1) Postharvest losses in vegetable and mango supply chains

Very little postharvest management occurs in the Philippines, and product is mishandled by many in the supply chain. Significant losses occur at each stage, as each handler has limited responsibility and is unlikely to be impacted if the end product quality is poor.

Non-rigid packaging, overpacking, and rough roads all contribute to mechanical damage of vegetables in the Philippines. High temperatures are the other key factor contributing to postharvest losses of up to 90% in some vegetable supply chains.

In addition to preharvest quality issues, mango quality is limited in the Philippines by lenticel discolouration, bruising from drops at harvest, latex injury at harvest, and postharvest rots. The major postharvest losses for mangoes occur after ripening, partly the result of well above-optimum ripening temperatures when using calcium carbide to ripen fruit in small baskets.

In Australia, significant progress was made in better understanding the causes of the skin disorders USB, LD and RCD, as well as defining the symptomology of the disorders.

2) Intervention strategies to reduce losses and improve quality

Best practice guidelines and grading scales were developed for vegetables and mangoes. Training workshops were held to disseminate these materials and promote the key intervention strategies identified, including:

- Fleece materials for mango fruit bagging had the potential to improve preharvest quality
- Moving mango harvest to later in the day, delaying de-stemming, and washing with water all had the potential to reduce latex damage of ‘Carabao’ mango
- Eliminating dropping of fruit at harvest doubled the percentage of export quality fruit
- Significant progress was made towards the replacement of the mango ripening agent calcium carbide, with a safer alternative called Ripestuff. This has the potential to reduce health risks to fruit ripeners, reduce potential contamination of ripe fruit, and make improvements in postharvest quality of mangoes.
- In Australia, susceptibility of ‘Honey Gold’ mangoes to USB was reduced when day harvest was moved to night. This was rapidly adopted by the Australian industry.
- The benefits of evaporative coolers as a low cost storage option for vegetables were demonstrated
- The use of packaging and rigid cartons and crates reduced the physical damage of vegetables compared to the large sacks traditionally used

- Preharvest effects on postharvest quality of vegetables were also demonstrated with produce from the ICM project, including vegetables produced using mulches, protected cropping, and grafting.

3) Value-added products

Opportunities for value added products were identified, including cut jackfruit, and ready-to-use vegetable mixes for chop suey and pinakbet. Treatments including UV-C, HWT and MAP were trialled to maintain quality of these products. Unfortunately, these had limited success within the project time frame. Further work is therefore required to optimise postharvest life for these products.

Opportunities for inclusion of processed vegetables in locally produced canned tuna, as well as pasta were identified, and initial trials conducted.

4) Postharvest research capacity

Attendance at international conferences has provided inspiration to younger staff members in the team at VSU and UPMin. It also provided the more experienced team members the opportunity to establish more professional contacts, and further develop their postharvest research programs.

Research methodology, analysis and reporting was improved throughout the project as a result of training and feedback provided to the team. Research results were presented at numerous conferences and 21 papers published in peer-refereed journals. Two PhDs were supported in Australia.

Postharvest laboratories were developed at UPMin and VSU, with postharvest analytical equipment provided, as well as training in its use. As a result, there are now more students conducting postharvest research projects at the two universities, with 30 student projects funded by the project.

Extension skills of the research team were also developed through train-the-trainer style workshops. The team then provided training workshops to more than 1460 Filipino growers and supply chain stakeholders in postharvest management.

9.2 Recommendations

- A major outcome for this project was postharvest capacity building at UPMin and VSU. The project has successfully developed expertise among the research staff involved, and provided facilities and equipment for further work. It is strongly recommended that future ACIAR projects continue to utilise this resource. Continuing support in this way will ensure that the laboratories develop and grow, and that postharvest expertise in the southern Philippines continues to expand.
- The postharvest training provided in this project could also be extended through the East West Seeds and Landcare networks, potentially as part of the new GAP project: HORT2016-188.

- Key findings, quality standards and postharvest best practice guides should be incorporated in GAP standards in HORT2016-188.
- Increasing the use of refrigeration in supply chains in the Philippines could provide the single largest reduction in postharvest losses. While the modified evaporative coolers were somewhat beneficial, small scale on-farm refrigeration can not only reduce postharvest losses, but provide farmers with the opportunity to store small amounts of produce, and supply the market at optimal prices. The “Cool-bot” system developed by University of California Davis, and successfully installed at UPMin, provides a low-cost solution. This technology should be further promoted to small and medium sized businesses involved in fresh produce storage and handling.
- Ripestuff™ ethylene release mechanism studies resulted in development of prototype delivery systems that produced uniform ripening of mango, papaya and banana fruit in newspaper-lined baskets. It seems clear that this advancement could provide immediate benefits for many other SE Asian countries, and for many types of fruit – not just those listed above. For example, in the Philippines and elsewhere avocados are not actively ripened under controlled conditions. The result is that fruit is either sold hard and inedible, or extremely soft, often with advancing multiple rots. Application of the Ripestuff™ could improve quality of many other climacteric fruits. It could also reduce the use of calcium carbide, which is known to be a dangerous carcinogen.
- Initial work on alternative materials for mangoes provided encouraging results. However, this was an opportunity identified during the project, rather than a focus of specific project objectives. It is not known whether these materials can exclude fruit fly, or whether their use could help farmers and contractors reduce their reliance on chemicals. Further optimisation of bagging practices could provide multiple benefits for fruit quality and reduced chemical use, and should be further investigated.
- While USB on ‘Honey Gold’ is now almost completely manageable, further work is required on LD and RCD in terms of reducing their incidence and severity on harvested mango fruit. Unlike USB, these two disorders afflict a broad range of cultivars, including those in the Philippines and Australia.
- Further development of value-added products alongside the private sector in the Philippines would support efforts to incorporate more fruit and vegetables into the Filipino diet.

10 References

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11 Appendices

Double click on the Appendix icon to open PDF.

11.1 Appendix 1. List of papers, presentations and student projects

Appendix 1

11.2 Appendix 2. Postharvest best practice guides

Appendix 2

11.3 Appendix 3. Literature reviews on fresh-cut products

Appendix 3

11.4 Appendix 4. Published papers in full

Appendix 4

11.5 Appendix 5. Ripestuff™ research reports

Appendix 5