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Increasing vegetable production in Central Province for Port Moresby Markets

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2 Executive summary

Vegetables have been an integral part of the diet of populations of modern day Papua New Guinea (PNG) for thousands of years, based around subsistence gardening producing a wide range of edible indigenous plants, and more recently vegetables introduced by and for Europeans. Urbanisation and change in demographics offers opportunities for the development of viable commercial vegetable production and marketing enterprises. This project focussed on vegetable production in Central Province of PNG for the rapidly expanding market in Port Moresby, the National Capital. The project used (i) Rapid Value Chain Analysis (RVCA) to identify which vegetables provide potential commercial opportunities, and needs for biophysical and socio-economic research, and (ii) Appreciative Inquiry (AI), to provide socio-economic insights, effective community engagement practices and identify training needs.

Biophysical research included land resource assessment, evaluation of cultivars of candidate crops (tomatoes, capsicums, French beans, broccoli, cabbage and carrots), at Laloki and Koiari Park (coastal lowlands near Port Moresby), Sogeri (~400m elevation) and Tapini (~800m elevation), and comparison of traditional, improved and intensive production systems at Laloki and Sogeri. Field work was complemented with a genome and controlled environment study of broccoli adaptation at the University of Tasmania. Value Chain Analysis was also used as a basis of work on developing improved Value Chains supported by demonstrations of production of candidate crops at villages in Rigo-Koiari (lowlands), Sogeri and Tapini. Training in basic crop agronomy, business and banking was carried out for both women and their daughters and men and their sons, and for staff of PNG organisations with interests in Geographic Information Systems

Land resource assessment has provided much improved data on both topographic and soil characteristics and limitations. Soil fertility is highly variable, because of diversity of parent material and intensity of weathering eg the Ferrosol at Sogeri is very low in extractable P.

Substantial differences in both yield and quality, and evidence of edaphic variation eg blossom end rot in some tomatoes, and insect damage among cultivars were found. Potentially commercially valuable cultivars were identified for coastal lowlands and Tapini, with less definitive results for Sogeri. The production system trials indicated that traditional and improved systems produced similar results, but the highly intensive was less productive. However, these trials had only short durations, and need to be continued for many years for comprehensive and reliable results.

Socio-economic research was particularly successful with understanding of communities, their function and needs, and the importance of collaborative, team and partnership oriented approaches to introduction of new agricultural practices, marketing and value chain function. There were some clear successes in train-the-trainer activities and follow up by them in expanding knowledge to their villages. Economic analysis revealed that labour cost, often not considered in assessment of crop viability by smallholder producers, is a major cost component in vegetable production. Establishment of improved value chains proved to be difficult, for reasons beyond the control of the project. However, critical issues and points along the value chain were identified and will provide guidance to future activities designed to meet the needs of producers, consumers and participants along the value chain.

The project also produced a significant number of publications and captured a substantial body of knowledge that will be of benefit for wider use eg in future projects. It also provides a model of engagement with participants in the production of vegetables and their delivery to

consumers through improved value chain function, and provided guidance on infrastructure development to support the value chain. This report concludes with a number of recommendations for future research and development partnerships with PNG collaborators.

3 Background

Papua New Guinean society is not yet industrialised, with as recently as 2004, 82 per cent of citizens over 10 years of age engaged in agriculture (Coppel 2004), which provides income and employment opportunities to the rural population. Most of these people obtain a large proportion of their domestic food requirements from the use of customary (community) land.

Prior to the expansion in resource projects and associated economic activity and export income, agriculture, excluding forestry and fisheries, accounted for 21 per cent of GDP and 17 per cent of total exports (Coppel 2004), despite the pessimistic view of resource suitability for agriculture expressed in Bleeker (1975). These proportions may now be declining though agriculture (including fisheries and forestry) remains around 30% (Global Finance 2013) to 32% (MSU 2012) of GDP of US$16.65b (World Bank 2013a) and remains the mainstay of economic wellbeing for the great bulk (75% (MSU 2012)) of the population. The sector is still seen as a basic source of economic growth, sustainable development and wellbeing of people and nation because it enables rural people to meet family needs and commitments, and contributes to reducing unemployment, poverty, and urban drift problems (Ministry of Agriculture and Livestock 2006). This priority is evident in the PNG budget strategy for 2014 (Minister for Treasury 2013), the budget increasing allocation of funds to economic development (Small and medium enterprises) and agriculture from PNGK491.6m in 2013 to PNGK777.9m in 2014 and remaining around this level until 2017.

PNG is highly culturally diverse though society is generally patrilineal, placing women in an inferior position in decision-making, particularly with regard to money. Customary land tenure is concerned with networks of kin and the obligations of clan and community. Thus, as society is constructed within the framework of kinship, external interventions must be careful to maintain the balance of men's and women's roles in the household and in resource management (Gustafsson 2004). However, in PNG women do around 70% of the work in agriculture (World Bank 2013b) and are increasingly taking on important leadership roles (World Bank 2013b). Also, loss of professionals ('Brain Drain') is now recognised as a constraint to PNG development (Gibson and McKenzie 2010), so capacity building and utilisation of skilled people to the benefit of the PNG economy is essential.

There has been long-standing concern about the adequacy of Port Moresby's fresh food supplies. Rice importation from Australia, and of fruit and vegetables from Australia, New Zealand and elsewhere are symbols of continuing dependence, especially on Australia, as well as being difficult for the balance of payments (Benediktsson 1998). There has been little if any change to this situation, except for an increasing diversity of sources of vegetables, in the intervening years. Perhaps paradoxically, intensive vegetable production occurred at the '12-mile', just outside Port Moresby on the 65 ha Australian Army Farm and Gardens, and produced enough vegetables for up to 15 000 ration packs/day during the Kokoda Campaign of World War II (James 2008). Therefore, it is known that vegetables can be produced in the lowlands near Port Moresby, though current production is very limited and application of modern technologies and concepts of sustainability are needed (Birch et al 2009).

Small holder vegetable producers in the Central Province of PNG produce a range of vegetables for the fresh market and for sale through supermarkets. Vegetable crops are traditional staple foods in PNG, and have been the major contributor to food supply and food security for many years, perhaps as many as 6000 years. However, production and yields are declining, with consequent adverse outcomes for the population's diet and economic wellbeing. Suitability of land resources and their management, soil fertility decline, pressure on land and

renewable resources from population increase, pests and diseases and lack of market information are some of the major constraints to improving the vegetable industry. Central Province has a potential to produce a wide range of vegetables, as it did during World War II but current production is not adequate to meet increasing demand. The principal vegetable crops remain starchy staples, predominantly kau kau (sweet potato) and taro, but there is interest in expanding production of brassica crops, (e.g. 'ball' cabbage) and onions, though expansion in other crops (both exotic and indigenous) is also expected. Also, research on these additional vegetable crops would benefit existing crops as the constraints that limit productivity, marketing, profitability and sustainability are likely to be similar.

Whilst there are a few producers who have become dedicated and specialised market gardeners and a few large producers using advanced techniques eg hydroponics, most suppliers are opportunistic and only intermittently involved in commercial vegetable growing. This occurs because of competing demands from such activities as customary social obligations and coffee growing and other lucrative tree crops. Subsistence needs are still met to a large extent by the household's own production on customary land and households are therefore not compelled to rely on regular sales to obtain daily necessities. This results in the opportunistic behaviour and a lack of consistent supply by smallholders (Benediktsson 1998), a situation perhaps exacerbated by young people moving to more lucrative urban pursuits and to the resources (minerals, natural gas) industries.

There is though a growing proportion of smallholders who are interested in more intensive commercial vegetable growing. Many already work multiple gardens growing up to 4 – 5 different crops for market. Pests and diseases, the high price or shortage of chemicals, fertiliser and seed, bad weather, a shortage of labour and issues relating to security as well as problems with marketing fresh produce due to post-harvest quality losses, transport and road conditions, oversupply, low and variable prices, and waste from surplus and oversupply are major concerns (Spriggs and Chambers 2007; Wilson and Hehona 2008), and thus constraints to their activities.

Women are substantially involved in production but many are also engaged in the marketing of fresh produce, particularly in the local informal markets. They face considerable problems with appropriate transport and other facilities, with harassment and bullying as well as with retaining enough income for family purposes (Benediktsson 1998; Spriggs and Chambers 2007).

Generally, the marketing system in PNG is grouped into two types: the open or 'informal' market and the direct market. In the informal market farmers are mainly supplied by the 'self marketers' (mostly women) who sell their produce in small stalls to buyers, such as in municipal (controlled by the local level governments) or road-side markets, but they do not have any long-term relationships. Direct markets include supermarkets, hotels, restaurants and marketing to institutions and mining camps who buy direct from the suppliers rather than buying in open markets and where there is some established relationship between the buyers and sellers (Spriggs and Chambers 2007). The size of markets is unknown although a number of studies have attempted to estimate it. Imports to PNG were 9,000 tonnes in 2003 and there is evidence that current markets cannot meet the Port Moresby demand (Liripu 2008; Worinu 2007). The 160% increase in value of Australian fresh and processed vegetable exports to PNG (Australia's 11th largest vegetable export market), from AU$2.7m in 2007-08 to $6.9m in 2011-12 (AusVeg 2013) clearly indicates that local production is inadequate to meet demand.

Papua New Guinea's (PNG) population is growing at approximately 2.1% per year, (CIA 2009) increasing the demand for food. In and near the capital, Port Moresby (PoM), this increasing demand is compounded by the internal migration from rural regions to peri-urban areas and increased food demands from an expanding middleclass and mining and gas professionals. Also, while a number of highland regions grow a

range of temperate vegetables, remoteness from Port Moresby - poor transport infrastructure and services severely constrain consistency of supply of quality vegetables, a situation similar to that for kau kau (sweet potato) (Chang et al. 2007). By contrast, areas in Central Province are much closer to Port Moresby and are connected by reasonable roads. They include lowlands with a relatively dry season from April to October and nearby cooler highlands (Sogeri Plateau, Goilala Plateau). Central Province is therefore a logical focus for investment to contribute to PoM's increasing demand for vegetables.

Also, there are limitations to sustainability of current vegetable production in Central Province (Birch et al 2009). While about 50,000 tonnes of PoM's estimated 141,000 tonne/yr fresh produce comes from PoM's peri-urban gardens (FPDA 2008), soils on the slopes used for vegetable production are rocky, highly erodible, drought prone and difficult to irrigate (Bleeker 1975; Blake *et al.* 1973), and are unlikely to sustain long term production for these reasons and lack of security of tenure. Vegetables are also produced on several alluvial flood plains and on the Sogeri Plateau, which have better soils and water supplies, and access to Port Moresby by road. Vegetables are also produced in the Goilala area, an economically disadvantaged area of Central Province, and a priority of Central Province and National Governments for support and improvement of socio-economic conditions. The number of farmers involved is difficult if not impossible to determine, as much of the vegetable supply, especially where sold through informal markets, is excess to domestic requirements of subsistence farmers. Retail prices are highly variable, reflecting inconsistency of supply, and are often high compared to Australian retail prices, despite quality being variable and inconsistent (Birch et al 2009). Details of prices over an extended period are difficult to obtain, and those in supermarkets indicate that there is significant price variability among retail outlets (Birch et al 2009). The relative size of markets for individual products, derived from FPDA Feeding Port Moresby Study, NARI and NZAid sources showed a predominance of green leafy vegetables (including broccoli) and root vegetables, with usually lesser importance of other groups except zucchini (also a large market).

In summary, the main issues that this project addressed and which are more fully described in section 4 are:

- Value Chain performance
- Resource Assessment
- Adaptation and productivity of cultivars of a range of crops
- Socio-economic research
- Training and extension

4 Objectives

The project Aim was

"**To develop efficient and effective value chains in Central Province that are based on sound use of natural resources, to meet growing demand for fresh vegetables in Port of Moresby**."

The Aim was to be achieved through the following objectives:

1. **To establish two examples of efficient, effective and sustainable vegetable value chains in Central Province to enhance profitability of enterprises at all stages in the value chain and household income security for chain participants by:**
   1.1. Surveying participants in smallholder and large scale vegetable value chains in Central Province to identify and rank barriers to profitable and sustainable supply;
   1.2. Developing, implementing and reviewing best practice value chain management models for participants in each stage of the focal chains;
   1.3. Develop and implement vegetable post-harvest handling models for smallholder and large-scale production systems;
   1.4. Develop, implement and review programs to increase the participation of women and young people from Central Province in vegetable production and marketing;
   1.5. Analysing Australian high input, high value horticultural chains to characterise Australian and PNG vegetable value chains and provide guidance to value chain efficiency measures.
2. **To identify, evaluate and implement resource management and agronomic practices that increase yield and improve quality and reliability of vegetables delivered by farmers to the value chain by:**
   2.1. Conducting field trials with smallholders and large scale operators to test practices to overcome soil and water management and crop protection barriers for vegetable production;
   2.2. Conducting detailed crop adaptation studies under controlled conditions;
   2.3. Carrying out GIS studies land suitability (incl. wetness, slope, hydrology and climate) of land in highlands and lowlands of Central Province).
3. **To develop and extend effective agronomic and resource management practices for sustainable vegetable production and land management to smallholders and large scale operators by:**
   3.1. Working in collaboration with national agencies to assemble information from the biophysical and other value chain work into prototype extension packages;
   3.2. Evaluate effectiveness of prototype extension packages by surveys of consumers of extension materials
4. **To identify areas within Central Province with land resources and climate suited to vegetable production and provide a mechanism to extend project outcomes to them by:**

4.1. Quantifying arable land resources and potential for sustained vegetable production assessed using NARI GIS analysis and on-ground assessments;
4.2. Developing a VegePAK Decision Support System (DSS) to capture existing information and new information from the project, and provide for incorporation of additional local information so the project findings can be applied in additional areas of Central Province

5 Methodology

The project was conducted within a Value Chain Analysis (VCA) framework, a systems approach that enables the incorporation of both qualitative and quantitative methods for the identification of constraints to the efficiency and effectiveness of value chains and of priority social, market and bio-physical improvement projects. Participatory Action Research (Reason and Bradbury 2001) and Appreciative Inquiry (Cooperrider, Whitney and Stavros 2001) processes were employed to conduct value chain development and social research with smallholders and larger-scale producers particularly in the Laloki area, and other participants throughout the chain. Action Research is an iterative process that was used to focus on the efficiency and effectiveness issues in chain material flows, relationships, communication and information flows. Appreciative Inquiry techniques work from the best of 'what is' to pursue 'what might be' and therefore is different from historical development methods which highlight situational problems. Because Appreciative Inquiry is more positively focused and supportive of an indigenous culture it was chosen as it may improve the potential of achieving real community change over time (Mikkelsen 2005).

5.1.1 Identify the project participants and the focal vegetable chains

A: Selection of retailer/Wholesaler participants and the potential focal vegetables

Initially, this project focussed on working with retailers, wholesalers and institutions in Port Moresby to identify:

- Potential high return vegetable products;
- Consumer attributes required to develop a competitive advantage;
- At least one retailer and wholesaler who have the capacity and the willingness to commit to improving their upstream supply chain.

These businesses formed the basis for linking farmers with markets, and the process began the matching and linking of downstream participants with smallholders as follows.

B: Identify production sites, select smallholder participants and focal vegetable/s

Concurrently, in collaboration with NARI and FPDA at Laloki, and Central Province Administration (CPA), potential production sites in Central Province were identified and surveyed for agronomic, soil, water and nutrient management practices to identify the major bio-physical constraints to vegetable production. Potential communities and producers were identified by stratifying critical soil, water, climatic, social and human capital factors. From these data, a group of smallholders and a large-scale producer were selected on the basis of experience, capacity, location, motivation to work beyond fulfilling the family consumption requirement, registration as ILG (Incorporated Land Groups) and willingness to commit to the project. The potential communities and producers used the information gained from the retailers/wholesalers and, through discussion with their local FPDA, NARI and CPA officers, selected the focal vegetables and 'best bet' varieties for chain improvement. This process took account of both the physical and human resource capacity restraints.

5.1.2 Analyse the value chains selected by smallholder participants

Once the chains and the participants were identified, the project team analysed the material product flows, relationships, communication and information flows. This was used to identify functions, processes, structures and conditions that impeded or could have impeded the efficiency and effectiveness of the chains. In particular, it was used to highlight issues associated with market understanding and information, relationships and social issues either within a chain or in the communities in which chains arise, and capacity constraints including financial, physical and telecommunications infrastructure and skills deficiencies. An Australian component analysed a Tasmanian broccoli value chain (see 2.1.2iv) to guide the establishment and operation of high value chains in PNG.

5.1.3 Identify and carry out relevant research on appropriate interventions to improve individual and community production capacity, land resource management and chain competitiveness

Using the data from the analysis outlined above, integrated collaborative 'chain improvement projects' were identified and planned, thus beginning a process of designing new chains specific to the focal vegetables and the participants. These projects were guided by the bio-physical, market and social research above, and participants identified interventions /improvements along the chains to enhance their efficiency, effectiveness and sustainability (Bonney et al. 2007; Kaplinsky and Morris 2003; Simmons et al. 2003). The in-country bio-physical research was conducted in conjunction with NARI and FPDA in Central Province to address the production constraints for both low input (smallholder) and high input (large scale) producers. A series of field experiments and GIS studies addressing agronomic, soil, water and nutrient management barriers and land resource constraints were conducted over 5 years in Central Province, at Laloki, Sogeri and Tapini, and in the Rigo-Koiari area. The emphasis was on developing sound soil and water management/utilisation and agronomic practices appropriate to the region and the capacity of the participating farmers. An Australian component addressed the adaptation of candidate cultivars of broccoli to the high temperature PNG lowlands, and the lower temperature PNG highlands, both having near constant photoperiods.

(a) Land Resource Studies

Soil Description and Analysis

Resource assessment was undertaken by soil profile description, soil chemical analysis (12 profiles) and Geographic Information Systems (GIS) analysis. Soils with potential for agricultural development were identified in the coastal lowlands (NARI Southern Region Centre (NARI-SRC) Laloki, Pacific Adventist University (PAU), Koiari Park and farmer cooperatives near Kwikila in Rigo district) and in the more elevated areas of the Sogeri Plateau and Tapini. Detailed soil profile descriptions and sampling were undertaken for profiles at NARI – SRC, Laloki, PAU, Rigo-Koiari, (2 sites, small holder farm sites), Sogeri (Sogeri High School, Vesilogo Village) and Tapini (previous DAL field site) . Soil pits were dug at all sites to at least 1 m depth (manually or by soil auger) and soil profile morphological characteristics were described for all soil horizons sampled. Standard chemical analyses were undertaken by NARI Chemistry Laboratory using analytical procedures outlined in Rayment and Higginson (1992).Soil chemical analyses were carried out for the above sites and for specific sites where experiments were located. Soils were analysed for pH, cations (Ca, Mg, K, Na, Al) cation exchange capacity, base saturation, P (Olsen method), organic carbon, total N, DTPA Fe, Mn, Cu and Zn, and sand, silt and clay contents. C/N, Ca/Mg, Mg/K ratios and %base saturation were also calculated These data and full soil descriptions and discussion of these data are presented in Appendix 8).

Land resource assessment

Papua New Guinea Resource Information System (PNGRIS) data were initially analysed and considered to be an over extrapolation of the natural resource data sets available. Consequently, P-band GeoSAR radar elevation data, X-band GeoSAR Magnitude Radar Imagery, Regional Scale Geological Data and field observations of soils coupled with data from crop trial plots were used as primary data sources for the study. X-band and P-band radar data is collected concurrently from each side of a survey aircraft at an elevation between 10,000 and 12,500 metres. The X-band wavelength penetrates clouds and reflects from tree canopy to deliver surface model data in forested areas and accurate terrain elevation in open areas. The P-band wavelength penetrates both clouds and tree canopy to deliver terrain elevation and surface feature extraction in forested areas. These characteristics make GeoSAR ideal for mapping large areas of mixed land cover particularly in Tropical areas such as Papua New Guinea (Williams and Jenkins 2009). The regional scale geological data provides the only credible bedrock information available for the selected study areas. Tiled P-band radar surface points which penetrate all but the densest vegetation provide a high resolution model of the terrain. The points were provided by the Defence Imagery and Geospatial Organisation as ASCII point data with spacing of 2.5 metres, and were gridded to a mosaic of 10 m Digital Elevation Model (DEM) surfaces using the ArcGIS “3D Analyst” extension. This data provides a more accurate and higher resolution representation of the local topography than the publically available 30 and 90 metre Shuttle Radar Topography Mission (SRTM) data or from Google Maps.

Using the 10 m DEM derived from the GeoSAR Radar data a four class Topographic Position Index (TPI) was generated using Land Facet Tools Extension for ArcGIS (Jenness *et al* 2011). This extension divided the topography into Ridges, Upper Slopes, Gentle Slopes and Valleys. Using this classification “Lower Slopes” of less than and equal to 10^{o} were selected as potential suitable sites for intensified agriculture. This broad topographic classification was further constrained by the lithology or soil parent material underling the previously identified lower slopes. The areas deemed most suitable for intensified agricultural production were identified as those areas underlain by intermediate or mafic rocks or derived alluvium and colluvium which provide for deeper and base rich soil parent materials. Thus their derivative soils generally provide the potential for the more productive and sustainable agricultural lands. Limited numbers of soil profiles were described and soil types noted in road cuttings and gardens in the district.

Use of resource assessment data

Resource assessment data were used to identify constraints to production, soil and land management practices that may be needed, and in the case of GIS analyses, availability of land within identified (and described) land capability classes.

(a) **In country agronomic (crop and cultivar) and crop system research**

Field experiments were established at Laloki (NARI-SRC) (2011, 2012, 2013), PAU, Koiari Park (2011, 2013), Sogeri (Sogeri National High School and Vesilogo Village) (2011 and 2012-13 respectively), and at Tapini (2012, 2013). There were two types of trials: (i) crop evaluation trials (agronomic trials) in which candidate crops, chosen according to locality and expected adaptation, were grown and assessed for characteristics and agronomic responses (Table 1) under intensively managed practices of irrigation, nutrient supply and pest and weed control; and (ii) cropping system trials (details in Table 2), in which local traditional crop production system (TPS), low input improvements on traditional system (LIS) and a high input system (HIS) were compared. Tables 1 and 2 provide experimental details for each location and year, resource data (soil data, rainfall and limited other weather data were recorded according to capacity of equipment at or near the sites), and

Table 3 describes criteria used in assessment of crop quality. Note: Quality was assessed using market standards as appropriate for individual crops. Quality was rated on a scale of one to five where: 1-2= very good quality; 3=good, 4-5=bad to poor quality. Procedures for implementation of the trials are described in full in Appendix I, though some changes were made during implementation to accommodate practical limitations encountered. Photographs of trials and important features and constraints encountered retained.

Statistical analysis

All data were subjected to appropriate statistical analysis, in most cases, being Analysis of Variance, using Genstat. All differences are reported at the P=0.05 level of significance, and significantly different results were identified from New Duncan's Multiple Range test.

Use of data

Experimental data were used for a number of purposes:

- Assessment of crop performance (agronomic characteristics, yield and quality)
- Assessment of system performance
- As a basis for economic analysis, using Gross Margins analysis and a detailed assessment of labour costs.
- To inform value chain participants of likely yield and quality of vegetables produced in each of the locations where work was conducted.

Table 1: Summary of crop and cultivar trials by location, year, crop and data collected.

Location	Year	Crops grown	Data collected
Laloki (NARI)	2011	Tomato (6 cvv), Sweet pepper (capsicum - 6), French bean (4)	Crop phenology, fruit/pod characteristics, yield and quality, pest and disease incidence
	2012	As 2011, except 8 cvv of tomatoes (in two plantings) and 5 of French Bean	As 2011
	2013	Sweet pepper (capsicum, 3 cvv), French bean (5)	As 2011 and 2012
PAU	2011	Tomato (6cvv), Sweet Pepper (6), French bean (4)	Crop phenology, fruit/ pod characteristics, yield and quality*, pest and disease incidence
Tapini	2012	Broccoli (6 cvv), English Cabbage (6), Carrot (6)	Crop phenology, head (root in carrot) characteristics, yield and quality, pest and disease incidence
	2013	As 2012, except 5 cvv of broccoli and 5 for carrots	As 2012
Sogeri National High School	2011	Tomato (6 cvv), Sweet pepper (4 cvv), Broccoli (6 cvv) (Tomatoes failed due to soil conditions)	Crop phenology, fruit characteristics, yield and quality, pest and disease incidence
Vesilogo Village	2012-2013	Sweet pepper (5 cvv), English Cabbage (5 cvv), French bean (5 cvv)	Crop phenology, fruit/head/pod characteristics, yield and quality, pest and disease incidence

(b) Demonstration Trials

In addition to the replicated research trials demonstration trials were established in two locations (Rigo/Koiara – Girabu Village and Sogeri – Kailaki Village) with a further site at Tapini delayed for safety reasons.

(c) Plant Adaptation Study – Controlled Environment and Genome Study

A controlled environment study using growth chambers for control of temperature and photoperiod was conducted with broccoli, to assess its adaptation to a range of temperature environments with near constant photoperiod experienced in Papua New Guinea. The controlled environment study was complemented by genome studies to gain understanding of genetic control of environmental adaptation. Four broccoli cultivars evaluated in field trials at Sogeri, PNG, were selected for further study at the University of Tasmania. The cultivars were chosen based on their performance in the field trials; Green King and Southern Comet, producing marketable heads while the others, Marathon and Summer King, failed to produce inflorescences. The studies addressed two hypothesises; that the cultivar differences at Sogeri could be explained by differences in (i) vernalisation requirements or (ii) optimal temperature for growth and development.

Broccoli plants were grown from seed in seedling trays (5x5 cm) planted on the 4th of April, at a temperature of 20 ± 4 °C, with 12 hours of light per day. After two weeks, individual seedlings were planted into separate 15.2 cm pots and four plants of each variety were then placed randomly in each of the three growth chambers. Each chamber was set to one of the following day/night regimes; 30/25°C, 25/20°C and 20/15°C (12 hours/ 12 hours). The growth and development of the plants was monitored each week by measuring the height, flower development, number of leaves and the stage of development of each plant. The potting mix comprised a mixture of 80% (volume), composted Pine Bark and 20% (volume), coarse Sand. Dolomite (4 Kg/m3), FeSO4 (0.75 Kg/m3), Wettasol granules (0.75 Kg/m3), and Osmocote Plus (16%N, 3.5%P, 10%K, 2.4%S, 1.2%Mg, 0.02%B, 0.05%Cu, 0.4%Fe, 0.06%Mn, 0.02%Mo, 0.01%Zn) (3 Kg/m3) were added.

Table 2: Agricultural system trials comparing traditional (TPS), low input improvements (LIS) to TPS and high input systems (HIS) by location, system, crop grown and data collected (at both sites, the experimental areas were formed into beds for each treatment).

Location and year/s	System	Inputs	Indicator crop	Data collected
Laloki (2011, 2012, 2013)	TPS	Irrigation – hand watering Soil Management - slash and burn, manual preparation Pest and Disease Management – culling for disease, hand removal of pests and weeds, applying wood ash	Tomato	Crop phenology, fruit characteristics and quality*, yield, pest and disease incidence
	LIS	Irrigation – surface micro-drip irrigation Soil Management - machine preparation, drainage, composting and mulching (kunai grass, to approximately 7.5 cm on average) Commercialised fertilizers (NPK and Urea @rate of 200 kg/ha, 150kg/ha respectively) Pest and Disease Management – plant derived pesticides, inorganic pesticides, fungicides (e.g. mancozeb), culling for disease, hand removal of pests, weeds	Tomato	Crop phenology, fruit characteristics and quality*, yield, pest and disease incidence
	HIS	Irrigation – surface micro-drip irrigation Soil Management - machine preparation, N, P, K fertilisers (mixed and urea) (Commercialised fertilizers -NPK & Urea @ rate of 200kg/ha, 150kg/ha respectively) Pest and Disease Management - Commercial pesticides and fungicides (Karate, Othene & mancozeb using their respective rates) culling for disease, hand removal of weeds	Tomato	Crop phenology, fruit characteristics and quality*, yield, pest and disease incidence
Sogeri (Vesilogo village) (2013)	TPS	Irrigation – hand watering Soil Management - slash and burn and manual land preparation Pest and Disease Management – culling of diseased crops, hand removal of pests and weeds, applying wood ash	English cabbage	Crop phenology, head characteristics, yield and quality, pest and disease incidence
	LIS	Irrigation – surface micro drip irrigation Soil Management - manual preparation, drainage, composting and mulching (kunai grass, to approximately 7.5 cm on average), N, P, K fertilisers (mixed and urea) Commercialised fertilizers (NPK & Urea @ rate of 200kg/ha, 150kg/ha respectively)	English cabbage	Crop phenology, head characteristics, yield and quality, pest and disease incidence

		Pest and Disease Management – plant derived pesticides (e.g. chilli and soap, neem powder), inorganic pesticides and fungicides (e.g. mancozeb), culling for disease, hand removal of pests and weeds		
	HIS	Irrigation – surface micro drip irrigation Soil Management - manual preparation, N, P, K fertilisers (mixed and urea) (Commercialised fertilizers -NPK & Urea @ rate of 200kg/ha, 150kg/ha respectively) Pest and Disease Management – Commercial pesticides and fungicides (Karate, Othene & mancozeb using their respective rates) culling for disease, hand removal of weeds.	English cabbage	Crop phenology, head characteristics, yield and quality, pest and disease incidence

Table 3: Parameters of crop characteristics used to assess crop quality

Crop	Quality characteristics assed on crop
Tomato	Fruit shape, size, colour, firmness
Capsicum	Fruit shape, size, colour
French Bean	Pod shape, size and colour
English cabbage	Head shape, compactness and size
Broccoli	Head shape, colour, size and bead size
Carrot	Root shape, tip fill, colour, size, smoothness and skin translucence

DNA extraction and FLC2 PCR

(i) DNA Extraction

Genomic DNA was isolated from 7-day old seedlings using a modified CTAB protocol as outlined by Ridge (2013). Harvested plant tissue was frozen in liquid nitrogen and ground to a fine powder in a mill mixer by adding a tungsten carbide bead to each tube containing the frozen plant tissue. 500 µL of extraction buffer (100 mM Tris-HCl pH 8, 1.4 M NaCl, 20 mM EDTA, 2% w/v CTAB, 20 mM 2-β-mercaptoethanol) were added to each tube prior to incubation at 60°C for 15 min. 500 µL of Chloroform:Isoamylic alcohol (24:1) was then added to the tubes and the contents were mixed by gentle inversion. The samples were centrifuged at 14000 rpm for 1 min and the upper aqueous phase was transferred to new tubes, and extracted a second time with 500 µL of Chloroform: Isoamylic alcohol (24:1). 1 mL of precipitation buffer (50 mM Tris-HCl pH 8, 10 mM EDTA, 1% w/v CTAB) was added, and tubes were mixed gently and allowed to rest at room temperature for 10-15 minutes until a thread-like precipitate formed. The precipitate was collected by centrifugation (10 min, 14000 rpm) and dissolved in 300 µL 1.5M NaCl containing 1 µL RNase A (25 mg/mL). The solution was incubated at 50°C for 15 minutes or until the pellet was fully dissolved. DNA was precipitated by adding 600 µL 100% ethanol and was collected by centrifugation (10 minutes at 14000 rpm). After centrifugation, the pellet was washed in 70% ethanol, air-dried, and re-suspended in 50 µL sterilised distilled water (SDW).

(ii) Polymerase Chain Reaction (PCR)

All PCRs were performed in 50 µL reactions comprising 5 µL of (approx.) 50 ng/µL DNA and 45 µL master mix. Master mix reagents and proportions are detailed in Table 4. Generally, one of two Taq systems were used: either Mango Taq (Bioline, London, UK) with the included 5x Bioline buffer and MgCl2 solution; or TasPol (an in-house Taq enzyme produced at the University of Tasmania) with a 10x PCR buffer comprising 500 mM KCl, 100 mM Tris-HCl pH 8.8, 1% Triton X-100 and 15 mM MgCl2. For a small number of difficult PCRs, Titanium Taq Polymerase (Clontech Laboratories Inc., Mountain View, CA, USA) and its associated reagents were utilised according to manufacturer's instructions. PCRs were carried out in thermal cyclers with heated lids, and as a general rule, comprised an initial 5 min template denaturation step at 94°C, followed by 35 cycles of denaturing (94°C for 1 min), 1 min of annealing at the appropriate temperature, and extension at 72°C for 1 min per 1 Kb, with a final elongation step of 72°C for 10 min. Annealing temperatures were optimised according to the length and purine/pyrimidine composition of the primers. PCR products were visualised by agarose gel electrophoresis, with gel concentration dependant on the expected fragment size. Products were purified using the Wizard® SV Gel and PCR Clean-Up System (Promega, Madison, WI, USA) following the manufacturers microcentrifugation protocol.

(i) BoFLC2 CAPS Marker Design

To detect the single base deletion in exon 4 of BoFLC2 described by Okazaki et al. (2007), DNA fragments were amplified using primers designed from published

Table 4. Standard PCR reagent mixture. (Departures from the master mix composition shown below are noted in the relevant section).

Reagent	Amount/Reaction (TASPOL)	Amount/Reaction (MANGO)
PCR Buffer (Taspol:10x; MangoTaq: 5x)	5 µL	10 µL
MgCl2	0 µL	2 µL
E	1 µL	1 µL
Forward Primer (10 µM)	1 µL	1 µL
Reverse Primer (10 µM)	1 µL	1 µL
DNA polymerase	0.5 µL	0.1 µL
DNA template (added separately)	5 µL	5 µL
Sterile Distilled Water (SDW)	36.5 µL	29.9 µL
Total	50 µL	50 µL

sequence DQ222849 derived from B. oleracea var. capitata cv. "Reiho" (Ishi seed company, Japan) intron 3 (BoFLC2-PvuII-F: 5" AGGGCCTAGAGGGCATACAT-3") and intron 6 (BoFLC2-PvuII-R: 5" TTTTGAGGCTCTCGACACAA-3"). Denaturation was for 5 min at 94°C, followed by 35 cycles of denaturing, annealing and extension at 94°C for 1 min, 59°C for 1 min and 72°C for 1 min, respectively, with a final elongation step of 72°C for 10 min. The product was digested with PvuII for 8 hours at 37°C and the polymorphism was identified by 2% agarose gel electrophoresis. Representatives of each genotype were cleaned using the Promega Wizard® SV Gel and PCR Clean-Up System, and sequenced by the Australian Genome Research Facility Ltd. (Gehrmann Laboratories, University of Queensland, St Lucia, QLD).

(d) Socio-Economic research

The socio-economic component of the project employed methods of Participative Action Research to address problems with horticultural value chains that were complex, multi-faceted, real-life situations confronting farmers in a developing country. Such problems are often called wicked problems requiring resolution if farmers' goals are to be met (Chambers & Spriggs 2009; Mason & Mitroff 1981; Rittel & Webber 1973). Complexity requires thoughtful methodology to address f relationships, place based knowledge and skills and an appreciation of the total value chain. Therefore, the three approaches employed were:

(i) *Organic Research and Collaborative Development (ORCD)* proposed by Chambers and Spriggs (2009), is an iterative, evolutionary and collaborative approach to solving wicked problems in a Development context. It has strengths in its approach to collaborative planning with a whole supply chain that accommodates potential gender issues as well as its explicitly processing both the local knowledge that is so important to capacity-building in the Host Country and the contextual scientific knowledge so important to Donor Agencies.

(ii) *Appreciative Inquiry (AI)* (Cooperrider, Whitney & Stavros 2003) has a role to play in grounding the research in real-life situations of smallholders using a solution-centred and more culturally-sensitive approach than traditional problem-centred methods. It is a cooperative and participatory search for the strengths and positive forces found within every system and recognises that every system has been developed over long timeframes to cope with local environmental factors. The AI approach involves collaborative inquiry, based on affirmative questioning and theory building, to uncover and accentuate the positive in a community, enhancing cultural identity, spirit and vision. AI is selectively attentive to the best and highest qualities in a system and in doing so avoids the potential error of researchers/consultants appearing judgemental of the host culture that is inherent in the problem-centred approach. It also places agency back in the hands of farmers required leadership in the structures, processes and participants (Huxham & Vangen 2000).

(iii*) Rapid Supply Chain Appraisal (Rapid SCA).* In this context there is a need to be able to rapidly scope the performance of the whole supply chain as a dynamic system and the Rapid Supply Chain Appraisal approach overlays the Appreciative Inquiry method to do this simply and elegantly (Collins and Dunne, 2008).

All three methods share the principles of Participative Action Research of Participation, collaboration and democracy;

- Iterative learning-doing processes…knowledge-in-action;
- Achieving practical outcomes;
- Emergent, developmental properties

Organic Research and Collaborative Development (ORCD) method
The explicit incorporation of the iterative action research process involving:

- Working 'with' the chain participants;
- The initial use of non-contextualised scientific knowledge in concert with 'local knowledge' with the incorporation later of and contextualised scientific knowledge and experience.
- Pre-planning workshops with women to identify gender issues for incorporation into the later planning stage

Rapid Supply Chain Appraisal Approach (RSCA):
This incorporates four sub-systems found to be critical to a supply chain's operational efficiency and effectiveness:

- Product integrity, Communication, Value creation and Chain governance

Appreciative Inquiry (AI) - a cycle of:

- Discovery or appreciation of the best of 'what is', dreaming of 'what might be', designing what 'should be' and the destiny of how to empower, learn and adjust/improvise.

Unifying and adapting this for this ACIAR Project has necessitated the incorporation of more explicit capacity-building processes to develop participant and community knowledge of the value chain management process. This is reflected in Figure 1.

Stage 1 - Background research on the marketing system

Value chain analysis views value chains as production and marketing systems (Bäckstrand 2007; Chroneer & Mirijamdotter 2009; Collins & Dunne 2008; Jain, Nagar & Srivastava 2006; Knoppen & Christiaanse 2007) specifically the functions of the Co-innovation Roadmap (Bonney et al. 2007) involving material flows, information flows and relationships, particularly with regard to the issue of integration to achieve sustainable competitive advantage. Mapping the physical movement of vegetable products from production to the consumer as well as socio-economic mapping with regard to the individuals and businesses involved (i.e. the social rules governing the behaviour of players in the marketing system). In a Developing Country context, it may be important to include a deeper understanding of the role of women in the marketing system.

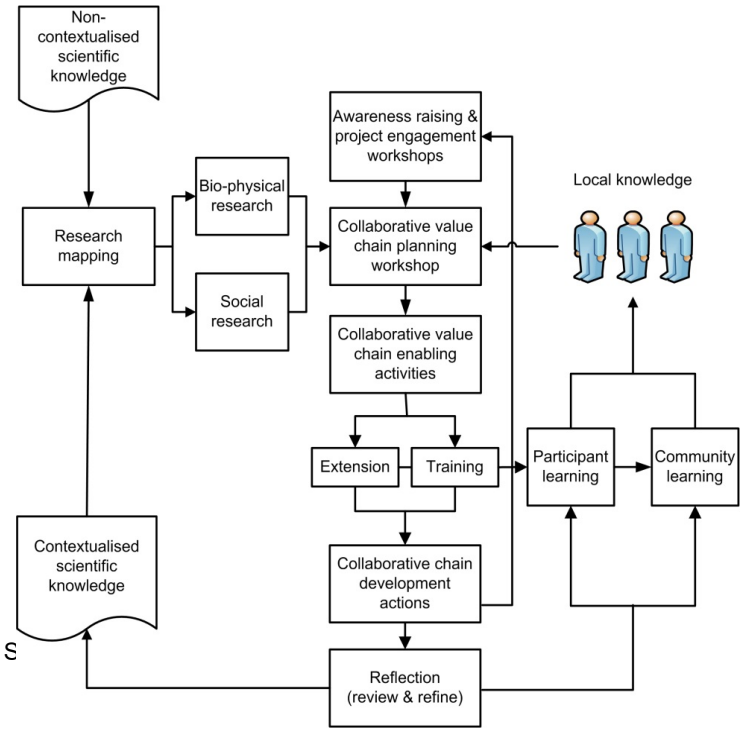
This model guided the research processes as follows:

Interviewing nominal leaders of stakeholder groups to determine constraints, givens and possibilities in product integrity, communication, value creation and chain governance:

- Gaining an initial customer perspective;
- Gaining the confidence of key in-country collaborators;
- Engaging growers and commercial stakeholders to map the chain and understand the chain dynamics;
- Making sense of it all.
- Identifying issues and problems with a sample of stakeholder groups;

- Researching relevant documents and policies with respect to the problem situation;
- Communicating relevant information to workshop participants.

Figure 1: The rapid value chain research and development method



Source: derived from Chambers and Spriggs (2009)

Stage 2 – The Collaborative Value Chain Planning (CVCP) Workshop

This stage reflects principles of working 'with' instead of 'on' people (Heron & Reason 2001):

Step 1: A women only CVCP *workshop*
An initial women's only workshop (women and their daughters) was conducted for the Rigo-Koiari and Tapini women to identify their capacities and problems in the marketing system and how the capacities could be enhanced and the problems addressed.

Step 2: A men only workshop
The men and their sons then participated in a CVCP workshop. Due to the large numbers of farmers participating in the Rigo-Koiari value chain representatives from the three main Koiari communities were selected on the basis of their ability to speak and write in English. Similarly, for the Tapini value chain the distance from the community (approx. 230 km and 6-8 hours travelling) and expense of transporting and accommodating the large number of potential participants involved constrained those who were able to actually attend the workshop at Laloki on the northern outskirts of Port Moresby. Representatives of the downstream stakeholders in the fresh produce marketing system (wholesalers, and retailers) were invited to attend the workshop at appropriate times to facilitate mutual understanding of the system and its problems; some attended separate community meetings for this purpose at other times. This interaction provided input to the action plan developed by the farmers in the latter stages of the workshop.
The workshop process was conducted in two phases:

1. *A divergent phase:*

- Participants were asked to suspend judgements, listen openly and actively to other people's issues, problems and ideas and to creatively tackle problems;
- Relevant information to participants was shared from the mapping research done prior to the workshop;
- Reference was made to the viewpoints and problems of other members of the marketing system which impact on the business of stakeholders and affect the performance of the marketing system.

2. *A convergent phase*
   - Where collaborative village plans were drawn up for the actions to be taken to improve the vegetable marketing system.

Stage 3 – This involved the implementation of the action.

The decisions of the workshop were implemented by capturing the process and outcomes in a report circulated to workshop participants;

- Monitoring the implementation of the action plan by FPDA and NARI;
- Provision of the agreed training in the action plan.

Steering committees of farmers (nominated by all stakeholders at the workshop) were formed to ensure the action plans determined by the workshop participants were carried out and reinforcing that ownership of problem-solving was in the hands of those most affected, rather than the research team.

Stage 4 – Reflection and improvement

This stage reflected a core principle of Action Research and the project method (Figure 1), the iterative process of acting, learning and then changing practices. It integrates 'non-contextualised scientific knowledge from the social and bio-physical literature with the local knowledge held by the research and extension staff in local organisations such as FPDA, NARI, PAU and Central Province-DAL as well as the collaborating chain businesses and villagers. In particular, it demonstrates the three interacting domains of:

- Research and sharing that research;
- Capacity-building to build awareness, skills and the ability to achieve goals that are important;
- Achieving practical outcomes by people working together (Senge & Scharmer 2001).

Regular meetings of the research team reflected on the actions taken and experiences, improve those actions and to develop the next phase of research. These were planned to be undertaken with the value chain stakeholder committees on an annual basis, however this proved impractical due to emergent events and social conditions within the communities involved (details in 7 Results and discussion).

Stage 5 – Participant & community learning

The outcomes of reflecting on actions and experiences were used to identify the focus of bio-physical and social research and improve social research methods. Where the value chain analysis identified a lack of context-specific scientific knowledge resulting in bio-physical research trials (e.g. suitable crop varieties or low-input soil management systems), the results led to participant and community learning through extension activities such as field days, training courses and demonstration plots. The intent was to communicate any parallel context-specific social research conducted to the smallholder participants to enhance local knowledge and context-specific scientific knowledge, thus contributing to the next iteration of planning and action to improve the efficiency and effectiveness of the agrifood value chain. However, as in the previous section, this proved

impractical due to emergent events and social conditions within the communities involved (refer 7 Results and discussion).

Operational activities

Table 5 provides more detail associated with the processes in the rapid value chain research and development model in Table 7.

Application of Methodology

Identification of broad value chain and social issues in production & marketing:
As part of the umbrella methodology of Organic Research and Collaborative Development (ORCD), information from participant smallholders was collected through surveys, interviews with individual farming families and focus groups with men's and women's groups in Rigo-Koiari, Bautama and Tapini. An Appreciative Inquiry (AI) technique was employed against a template of Rapid Supply Chain Appraisal (RSCA) as a framework to conduct group interviews presented in Table 6. Villagers spoke about their crops, what they were proud of and what they hoped to do in the future. Out of this came a desire for horticultural, business and market training for women and girls, men and boys.

Identifying community capacities and problems in the marketing system through Needs Analysis:

The results from interviews were then categorised and workshops planned to further identify training needs and priorities. The workshops process was based on Organic Research and Collaborative Development (ORCD) (Chambers & Spriggs, 2009), a collaborative problem solving approach (CPSM) for development projects (Kayrooz, Chambers, & Spriggs, 2006) and incorporated Appreciative Inquiry (Cooperrider, Whitney & Stavros, 2003) and Rapid Supply Chain Analysis (Collins & Dunne, 2008) integrated into the process. The first stage of CPSM is about divergent thinking and the second convergent thinking: the former opens up and explores issues in a creative way and the second focuses on refining solutions to issues and making collective judgements. To this end a technique of visual ethnography was employed, whereby pictures representing various points along the value chain were first presented for discussion. In the second stage, participants sorted value chain activities in terms of difficulty and then prioritised them in terms of training needs.

Process
Workshop participants were selected using the following criteria:
- Had previously undertaken training of some kind;
- Actively involved in horticulture and/or keen to develop their production;
- Member of a women's or men's agricultural organisation or association;
- Commitment to sharing their learning with others;
- Contained a mix of ages, i.e. Mothers and daughters/daughters-in-law and fathers and sons/sons-in-law.

The women's (mother/daughter) training needs and analysis workshop was conducted in September 2011 with 29 participants from two Central Province villages—Rigo-Koiari and Bautama. A year later, in September 2012, the men's (father/son) workshop was conducted with 21 participants from three Central Province villages—Rigo-Koiari, Bautama and Sogeri. Both workshops were conducted at the same venue (Pacific Adventist University) and a similar methodology of collaborative problem solving was used to identify training needs. The low level of literacy meant that the smallholders were not necessarily able to communicate effectively in writing among themselves or with staff of the research and advisory stakeholders. This challenge was overcome by using a pictorial method of assessment used to gain information in low literacy and cross-cultural settings (Catalani & Minkler, 2010; Keremane & McKay, 2010). Posters were used to identify training needs for categories of horticultural production activities (soil preparation,

planting, irrigation and crop management), marketing activities (harvesting, packaging and marketing) and business

Table 5: Operational Methodology

<table>
<tr><td colspan="2">Data Collection Phase 1 - Research mapping
• Scoping study
• Value chain and social issues mapping
  • Identification of potential markets
  • Determination of the relationships among players in the supply chain – horizontal (e.g. political, socio-cultural) and vertical coordination (between the chain levels)
  • Identification of broad social issues production & marketing
  • Selection of crops to be produced
  • Identification of parameters to be used for community selection
  • Identification of potential communities
  • Selection & engagement of community participants
• Site and crop selection
  • Identifying researchable biophysical issues
  • Identifying of issues for demonstration field plots
  • Determination of key site/crop selection parameters
  • Selection of optimal biophysical research sites
  • Design of research trials
• Development of the best practice chain model</td></tr>
<tr><td colspan="2">Data Collection Phase 2 - Collaborative Value Chain Planning Workshops
• Step: 1 Women’s Only Workshop
  • Identify their capacities and problems in the marketing system
• Step: 2 Men’s Workshop (men/sons and other stakeholders in the fresh produce marketing)
  • Based on the Research Mapping phase, agree on Workshop Objectives
  • Divergent, trust-building activities incorporating output from ‘Women’s Only Workshop’
  • Convergent, action planning for production and chain development with milestones for all levels of participants (farmers, transporters, wholesalers/retailers)
  • Appointment of FPDA to coordinate/monitor the Action Plan
• Step: 3 Post-workshop Action
  • Reporting on the workshop to participants & stakeholders
  • Briefing & training of the Action Coordinator
  • Reporting on milestones to all parties</td></tr>
<tr><td colspan="2">Collaborative Chain Development Actions</td></tr>
<tr><td>Production
• Training & operational planning with smallholders & women
• Implementation of production plan</td><td>Research
• Establishment of research trial plots
• Develop research protocols
• Train research assistants</td></tr>
<tr><td colspan="2">Reflection
• Review experience & refocus research & production activities – participant feedback
• Develop contextualised scientific knowledge – research publications</td></tr>
<tr><td colspan="2">Collaborative Chain Development Actions</td></tr>
<tr><td>Production
• Modify production & marketing</td><td>Research
• Refine research focus and operations</td></tr>
</table>

activities (banking, bookkeeping and transport) during the **divergent phase**, which was held on the first day of the workshop.

Women and men were initially asked to sit in small groups, with others from the same village. In the women's workshop, the 32 participants were seated in 4 small groups (3 groups representing Rigo-Koiari and 1 group representing Bautama). In the men's workshop, the 21 participants were seated in 4 small groups (2 groups representing Rigo-Koiari, 1 group representing Sogeri and 1 group representing Bautama). In the men's workshop 36 participants were seated in 4 small village based groups (Kataipi ward, Guari LLG, Erume, and Tapini station). In the women's workshop conducted in Tapini, the 26 participants were seated in 3 small village based groups (Koruava, Kovetapa and Erume).

Table 6: Total number of participants engaged in the CVCP Workshops

CVCP Event	Number of participants	Villages
Women's workshop 2011	29 participants	4 small groups (3 groups representing Rigo-Koiari and 1 group representing Bautama)
Men's workshop 2012	21 participants	4 small groups (2 groups representing Rigo-Koiari, 1 group representing Sogeri and 1 group representing Bautama
Men's workshop conducted in Tapini 2013	36 participants	Kataipi ward, Guari LLG, Erume, and Tapini station
Women's workshop conducted in Tapini 2013	26 participants	3 small village based groups (Koruava, Kovetapa and Erume)

The **convergent activity** was undertaken on the second day so that the participants representing different villages were more comfortable to exchange views and communicate freely and willing to sit as groups, irrespective of whether or not they belonged to the same village. After identifying 'very difficult', 'quite difficult' and 'easy' tasks on the first day, on the second day, participants were asked to form subgroups based on their age as 'older' and 'younger' women/men and to prioritise their training needs with stars indicating first, second and third priorities. The operationalising of the 'rapid value chain research and development method' incorporating ORCD, AI and RSCA was achieved through a framework of workshop questions outlined in Table 5. Broadly, the 'discovery and appreciation' and 'dreaming' stages were carried out on the first day of the workshop with the 'designing' and 'destiny' stages were undertaken on the second day.

Use of the value chain and socio-economic research data
The production, marketing and social research data were also used to develop and implement appropriate production, marketing and socio-economic development and training models that can be adapted and deployed in other chains and other PNG regions.

Table 5 identifies how data were collected in two phases which determined the timing of how they were used:

Data Collection Phase 1 – Value Chain and Social Issues Mapping

The initial Scoping Study:

- provided base understanding about the system and focused subsequent research into the bio-physical and socio-economic constraints;

- Identified the bio-physical constraints affecting production and marketing that assisted in the prioritising the critical factors for bio-physical research e.g. poor soil fertility management and inappropriate vegetable varieties for tropical production;

- Identified the socio-economic constraints affecting production and marketing that assisted in the prioritising the critical factors for marketing and socio-economic research e.g. lack of volume, quality and consistency of vegetable produce to enable stable supply arrangements and the role of women in agriculture and marketing; and
- Informed the selection of higher market value vegetables that had potential to improve smallholder family incomes and the potential, appropriate sites (altitude, climate, soil and water availability) for their production;

The value chain and social constraints informed the development of the value chain best practice model, which optimised the exploitation of strengths and reduction or compensation for constraints in the system.

Data Collection Phase 2 – Collaborative Value Chain Planning Workshop & Iterative Action Planning

- Identified the specific community and individual men and women's values, attitudes and goals regarding the vegetable production and marketing;
- Identified specific value chain and socio-economic operational issues associated with the establishment of new marketing chains that needed to be addressed;
- Identified and prioritised training needs to support production, value chain and social adaptation;
- Identified and prioritised actions for PNG partner agencies that would assist the development of the new value chains.

(e) Economic analyses of vegetable production

According to Doyle et al (2012) land resource assessment for Rigo area of Central Province showed sustainable production of vegetable can be expanded in that area. Vegetable farmers were selected to participate in a costs survey based on their willingness to participate and experience in vegetable production, and were asked to complete questionnaires and record production activities and labour costs as detailed below. Crops surveyed were tomato, capsicum, watermelon, French beans and zucchini. Data requested in the questionnaire were labour (man-days), costs of inputs used in production, crop yield and the sales (in PGK). Farmers were supplied with 100kg weighing scales, questionnaires, pencils, and mini-table clocks. Microsoft Excel was used for data assembly and Statistical Packages for Social Science (SPSS) for data analysis and presentation on a per hectare basis. Farmers were supplied with data recording sheets to record expenses and labour hours for land preparation, nursery production of seedlings, planting, weeding, irrigation, harvesting and transportation. Unpaid labour was converted to a monetary value at the minimum rural wage of PGK1.45 per hour. Other input costs were recorded for both fixed (e.g. tools, small tractor) and variable costs (fertilizer, pesticides, seeds). Bi-weekly visits to the farms were made and records were transferred to a master file. These visits enhanced consistency and quality of records, gained additional information and confirmed self-reported data sheet through interviews.

(f) Employ action research and learning for incremental improvement

As part of the implementation process, data will be collected on the impacts of collaborative improvement projects. This data will be analysed and discussed with the community as part of the action learning cycle, aimed at defining new action steps (Heron and Reason 2001). In conjunction with the FPDA, this approach will result in the focal chain participants designing and implementing new chain practices and processes for production, post-harvest handling, transport and marketing and land management. The process will involve all chain participants and be designed to improve understanding and

facilitate the development of confidence in and commitment to improved through-chain relationships. New methods of communication will also be developed to facilitate the flow of demand/supply information and customer/consumer feedback, probably based on the mobile phone services that are widely available in Central Province. As the research develops commercial outcomes,

Table 7 Unification of Appreciative Inquiry and Rapid Supply Chain Appraisal

Appreciative Inquiry Stage	*Rapid Supply Chain Appraisal (Collins & Dunne, 2008)*			
	Product integrity	Communication	Value creation	Governance & Relationships
Discovery or appreciation of the best of 'what is'	What is it about current arrangements with your Buyer that is working very well?	What information do you currently get about the vegetables that you supply to your Buyer?	Describe why you think your vegetables are better than those from other communities?	What do you know about how your Buyer does business? What would you like your Buyer to know about how you produce vegetables that would help them understand your problems?
Dreaming of 'what might be' (Goals)	How could the arrangements with your Buyer be improved to improve the quality of your vegetables when they arrive at the store?	What information from your Buyer would you like to know that would help you improve your growing and supply of vegetables to them? What information do you think they need?	How could you make sure that the vegetables you supply to your Buyer are better than other communities?	What would you like to know about your Buyer that would help you do a better job of supplying them with vegetables?
Designing what 'should be' (Actions to achieve the goals)	What will you do in the coming year to achieve these improved arrangements?	What will you do in the coming year to improve the info you give your Buyer and they give you?	What will you do to produce better vegetables during the coming year?	What will you do to improve your relationship with your Buyer in the next year?
'Destiny' How to empower, learn, adjust & improvise	What skills and knowledge do you need to learn to do this? Who do you need to give authority to in your Cooperative for this to happen? What changes to your equipment, facilities & way you work together to make these things happen?			

Appreciative Inquiry Process (Cooperrider, Whitney & Stavros, 2003)
The co-evolutionary search for the best in people and cultures. It asks questions that strengthen capacity to apprehend anticipate & heighten positive potential. It mobilises imagination, innovation &change.

communicable information and new practice models, they will be disseminated through FPDA's community-based extension models. This process of shared experiential learning can both identify and incorporate the outcomes of related bio-physical, land resource management and socioeconomic research. Such a process is both transferable and able to be absorbed into ongoing community practice beyond the duration of the project.

5.1.4 Build regional capacity

A: Identify potential future expansion of vegetable production through land resource assessment

Region-wide assessment of the arable suitability of land and water resources in the Central Province and NCD was conducted using NARI's existing GIS-based climatic, soil, landform and geological data and data sourced from the Australian Government combined with ground truthing field work. This identified potential locations for vegetable production that could underpin future expansion to meet existing and emerging needs to supply Port Moresby and also staff and communities associated with impending mining projects.

B: Develop human capacity and transferable models

Specific chain improvement projects also developed extension and training methods and materials to build skills and knowledge, educate and train the local people and develop the capacity of women in smallholder families. This included group-based practical learning process for smallholders designed to integrate experiential education in land management, agricultural production, marketing and community development, and was based on training needs surveys to identify topics considered by the local population to be

of most benefit to them. The emphasis was on the development of packages of extension and training, including ‘train the trainer’ training, to develop critical mass of productive capacity and facilitate rural community change.

6 Achievements against activities and outputs/milestones

Tables 8 to 11 which follow provide detail of achievements of activities within the four objectives of the project. Undertaking this project involved regular travel to Papua New Guinea, recorded in a reports on each trip. Copies of all reports that contained data are included observations and additional data are included as Appendix 4.

Table 8 Achievements relating to Objective 1: To establish two examples of more efficient, effective and sustainable vegetable value chains (the focal chains) in Central Province providing improved economic returns expressed as profitability and household income security for chain participants

No	Activity	Output/ Milestones	Completion Date	Comments
1.1	Survey participants in smallholder and large scale vegetable value chains in Central Province to identify and rank barriers to profitable and sustainable supply	Product quality and supply barriers identified and ranked (PC)	Yr 1, Mth 7	This was completed as planned and produced clear guidance to the barriers involved, and thus guidance on value chain performance improvement and on facilitating greater participation of women and youth in vegetable production and value chain activities (Activities 1.3, 1.4, 1.5, and to an extent 2.1 and 2.2)
		Agronomic, soil, water and nutrient management barriers identified (PC)	Yr 1, Mth 9	This milestone was met initially, as intended, at a level appropriate to guiding biophysical research. However, as the project progressed, additional information became available, providing the basis for further future research. Sites were selected on the basis of this work (Activity 2.1), and controlled environment work (2.2) designed and implemented. Scientific publications have been produced.
1.2	Workshop and interviews commenced with women and youth on opportunities and constraints affecting their participation in the value chain	Identification and/or confirmation of impediments to full participation in the supply chain	Y1, Mth 11	This was completed, with more informative and therefore more useful information than had been anticipated Outcome: Planned programs for women and youth based on interview and workshop outcomes. Impact; Constraints minimised to greater participation in the value chain.
		Integrated chain improvement projects identified in: Soil and water management Vegetable agronomy and integrated crop protection Chain and market processes	Yr 1, Mth 12	Projects in resource assessment, especially of soils, implications for soil management, integration of soil management in agronomic (production systems) research and crop adaptation/cultivar evaluation were specified. Plant protection issues (identification of pests, diseases, etc proposed as part of agronomic studies. Improvements to the value chain were identified and provision made for their inclusion, using products from agronomic studies
1.3	Develop, implement and review best practice value chain management	Best practice models developed, implemented and reviewed (PC, A)	Yr 1, Mth 12	Draft BP Model completed November 2010. Discussed and validated with partners at VC Awareness Workshop in February 2011. Refer to Figure 3 *Best Practice Smallholder*

No	Activity	Output/ Milestones	Completion Date	Comments
	models for participants in each stage of the focal chains.			*Vegetable Value Chain Management Model.*
		Second generation best practice models developed, implemented and reviewed (PC, A)	Yr 4, Mth 6	BP Model reviewed and modified.
		Best practice models evaluated (PC)	Yr 4, Mth 12	This was completed in collaboration by partner country staff in collaboration with commissioned agent (TIA) staff but at a later agreed date (December 2014) as part of project extension.
1.4	Develop and implement vegetable post-harvest handling models for smallholder and large-scale production systems.	Vegetable post-harvest handling models developed and evaluated (PC)	Yr 4, Mth 12	Only partly achieved, because of difficulties with stability and longevity of the value chains. The knowledge is available, however, implementation was less than satisfactory, even with a later date due date (December 2014) arising from project extension.
1.5	Development and implement programs to increase the participation of women and young people from Central Province in vegetable production and marketing	Programs developed, and implemented in collaboration with PNG WiA provincial leaders and FPDA Village Extension Workers (PC)	Yr 2, Mth 12 extended to June 2015	This has been achieved through a series of workshops and training activities, and has included work later than Year 2. The work has involved people from TIA, FPDA, NARI, PAU, Women in Agriculture and local cooperatives, and has linked closely with Activities 1.1, 1.2, 1.4, 2.1. It is expected to yield ongoing impacts on the functioning of the value chains. Outcome: Improved retention of young people and status of women in production and marketing of vegetables. Impact: Engagement of women and youth in mounting their own horticultural training programs in place based context (train the trainer)
		Second generation programs developed and reviewed (PC, A)	Yr 2, Mth 6	These arose from activities immediately above, and have provided the skills needed by participants to remain in vegetable production through Activities 1.1, 1.2, 1.4 and 2.1. However, enhancing the value chain function to improve income of participants has not been as successful for reasons outside the project partners control, despite their best efforts. (Note that these have become ongoing activities over the life of the project)
1.6	Analysis and reporting on evaluation outcomes of women's and youth participation programs.	Youth and women's participation programs evaluated	Yr 4, Mth 12 extended to June 2015	Much of this has been completed early, and includes publications through conferences. Outcome: Recommendations for long term adoption of change to retain women and youth in vegetable production are available, however, their long term effectiveness will depend on institutional staff staying in place and funding for activities to maintain interest, commitment and activities. Recommendations for long term adoption of change found to be acceptable and effective in retention of young people and improving status of women in production and marketing of vegetables. Impact: Demand for leadership, governance

No	Activity	Output/ Milestones	Completion Date	Comments
				and conflict resolution training in co-operatives and collaborative village enterprises. Findings in publications currently being prepared.
1.7	Value chain analyses of Australian high input, high value horticultural chains	Understanding and documentation of opportunities for improved value chains for specialised Australian produce in export markets (A)	Yr4 Mth 3	VCA on Tasmanian broccoli value chain completed. See report Appendix 7 PNG post-harvest handling data collected. Tasmanian post-harvest handling data loggers lost 2013 season. Data to be re-collected in January 2014.

PC = partner country, A = Australia

Table 9. Achievements relating to Objective 2: To identify, evaluate and implement resource management and agronomic practices that increase crop productivity by smallholders and large-scale operators and improve the quality and reliability of vegetable products marketed.

No	Activity	Output/ milestones	Completion Date	Comments
2.1	Field trials with smallholders and large scale operators identified in 1.1 to test practices to overcome soil and water management and crop protection barriers for vegetable production identified in 1.1	R and D field trials in PNG established, implemented and data collected and analysed (PC) Report on first season RandD field trials in PNG including 'best bet' agronomy (PC) Soil analysis completed, data collated and assessed in Australia (A)	Yr 2, Mth 12 Yr 2, Mth 12	These have been undertaken at a number of sites, and used to inform subsequent field work. Rigorous data on potential yields are now available for several production locations. Data have been used in extension materials and in publications. Development of a VegePAK computer based information system (Activity 4.1 did not proceed, as more effective means for extension to the local population are available eg brochures, posters in TokPisin. Scientific papers have been produced from this activity.
		Second season of R and D trials field trials in PNG established, implemented and data collected and analysed (PC) Report on second season of R and D trials field trials in PNG testing best bet options	Yr 3, Mth 12 Yr 3, Mth 12	This proceeded in a similar manner to the first season's work (immediately above). However, the timing of the PNG election interfered with work programs so not as much was achieved as had hoped to be. A reduced range of soil analyses were completed, with chosen sites and tests more focussed in specific site and crop needs. Additional scientific papers and extension materials were prepared and published

No	Activity	Output/ milestones	Completion Date	Comments
		identified in Y1 Soil analysis completed, data collated and assessed in Australia (though the range of soil analyses was limited compared to Year 1)		
		Third season of R and D trials field trials in PNG established, implemented and data collected and analysed (PC) Report on third season of R and D trials field trials in PNG including recommendations for extension packages (3.1) Soil analysis completed, data collated and assessed in Australia (A)	Yr 4, Mth 12 Yr 4, Mth 12	Three seasons' trials completed, but not at all sites in all years. Data in advanced state of analysis, and incorporated in new extension materials. Because of the constraints due to the election in 2012, the third and fourth year trials were delayed into the fourth and fifth (extension) years. Detailed data included in Appendix II and Appendix IV.
2.2	Crop adaptation studies under controlled conditions at University of Tasmania	Detailed data on adaptation to high and low temperatures in near constant photoperiod collected, analysed and reported (A)	Y4, Mth 4	Controlled environment work conducted at UTAS Sandy Bay, using growth cabinets and broccoli sourced from PNG as the experimental plant. Report produced, supplied in additional documents. Additional crops and a range of cultivars should be assessed in future work, though space constraints will always necessitate restrictions on what can be done.
2.3	GIS studies land suitability (incl. wetness, slope, hydrology and climate) of land in highlands and lowlands of Central Province	Improved maps of land suitability (PC) Increased GIS capability at NARI (PC)	Yr 3, Mth 6 Amend to Yr 3, Mth 12, and further extended into the project extension period	This work produced very detailed maps, much more detailed than originally envisaged, as much more detailed and high quality data were obtained. Work additional to that originally intended was completed, and will provide sound basis for future work in the areas studied and a strategy for work in additional areas. The mapping studies have been complemented with training activities for PNG scientists during the project extension, with very successful training activities in both 2014 and 2015. Data was used as intended in Activities 1.1, 1.2, 2.1 and in scientific publications
2.4	Affordable low and high input solutions	Affordable solutions documented and	Yr 3, Mth 12	The extent that information on improvements to local production systems have been

No	Activity	Output/ milestones	Completion Date	Comments
	for better soil and water management developed	distributed to stakeholders		documented and distributed, including low cost drip irrigation systems using a hydraulic ram pump. Progress on high input systems in particular has been limited by seasonal conditions, however, guidance has emerged that improvements to local practices rather than moving to high input production systems are appropriate. The field studies at Sogeri were extended from completion in Year 4 (ie December 2013) until the end of the project (June 2015), and were still continuing at that time. Information used in vegetable extension materials (Activities 2.1, 3.1), but as noted earlier, the computer based VegePak decision support package (Activity 4.3)has not been developed, as more efficient means of distribution of information to the local population are available.
		Extension packages developed	Yr 3, Mth 12	See above
2.5	Improve yield quality, reliability and transportability of harvested produce sent to market	Improved yield quality and transportability quantified and documented	Yr 3, Mth 12 Amend to Yr 4, Mth 6 and again to December 2014	Improvements in both yield and quality from improved agronomic practice were demonstrated. However, transportability was compromised by lack of reliable transport vehicles and road infrastructure. One purchaser in Port Moresby resorted to sending their own vehicles out to vegetable farms to collect produce so it remained in good condition on arrival in Port Moresby. Good guidance to future systems is available
		Improved reliability of supply quantified and documented	Yr 3, Mth 12 Amend to Yr 4, Mth 6 and again to December 2014	Strategies for improved reliability were demonstrated. However, instability in at least one cooperative compromised continuity of production and supply. Investigation revealed reasons for the instability and the learning can be used in future developments of a similar nature. Good guidance to practices were obtained and documented.

PC = partner country, A = Australia

Table 10 Achievements relating to Objective 3: To develop and implement effective dissemination of promising value chain activities and integrated agronomic and resource management practices to smallholders and large-scale operators.

No	Activity	Output/ milestones	Due Date	Comments
3.1	Work with partners to assemble information from the biophysical and other value chain work into prototype extension packages	Prototype extension packages addressing the specific needs of the focal chains (PC)	Yr 3, Mth 12	Material prepared for project Showcase, Mini-field days, and by FPDA and), NARI
3.2	Evaluate prototype extension packages	Extension packages evaluated (PC)	Yr 4, Mth 12, extended to end of project in June 2015	Evaluation has been undertaken as part of an interactive process, especially through the training needs workshops and training workshops themselves. Some has been formal quantitative assessment, some qualitative (Activity 3.1). In both cases, data have been incorporated in publications or will be in the near future. Two papers have been produced for the ACIAR monograph on Socio-Economic Research in PNG. Training manuals were prepared for used during2013 and 2014 (the fourth and fifth years of the project), and have been revised and are in a late stage of preparation for both hard copy and web publication. It is expected these processes will be completed by late 2015 ie just after project completion. Challenge now is to continue this work beyond the end of the project – a matter for local PNG institutions and/or further ACIAR funded project/s. The training manual referred to above is one vehicle for this to occur.

PC = partner country, A = Australia

Table 11 Achievements relating to Objective 4: To identify other areas in Central Province with land resources and climate suited to vegetable production and provide a mechanism to extend project outcome to them.

No	Activity	Output/ milestones	Due Date	
4.1	Arable land resources and potential for sustained vegetable production assessed using NARI GIS analysis and on-ground assessments	Map of arable lands suitable for vegetable production (PC, A)	Yr 3, Mth 12 extended to end of project June 2015	Maps of land capability/availability have been prepared for several locations in Central Province (Kwikila (in Rigo – Bautama area), Port Moresby , Sogeri and Tapini These are available for widespread distribution to Government and private interests. Additional more detailed maps from more detailed analysis of data completed and included. This included increasing the number of variables considered, so accuracy and reliability of maps

				were enhanced. Publications have been prepared and more are intended. Additional training of PNG scientists was integrated with these additional analyses to improve their skills. A land capability assessment using a similar approach used here is necessary to expand the areas mapped and assessed.
4.2	Review programs to increase the participation of women and youth from the Central Province in vegetable production and marketing	Programs reviewed in terms of adoption of knowledge and technology	Yr 3, Mth 12 extended to June 2015	Some aspects have already been covered in Activity 2. Outcome: Modification and/or extension of successful programs and input to train-the-trainer programs run-by PNG agencies. Impact: Training in leadership, governance and conflict resolution leading to more stable commitment to and participation in the value chain.
4.3	Develop a VegePAK Decision Support System (DSS)	Vegetable decision support system (PC, A)	Yr 4, Mth 12	It was perhaps unrealistic to expect that an effective computer based Vege PAK could be developed, experience being that the level of computer availability and system reliability, plus issues of data adequacy mean that this activity was best replaced by less ambitious (and more effective in the local context), printed material. Also, the training manual referred to above (Activity 3.2) fills part of the place intended for the VegePAK, and while a computerised system would be appropriate in the long term, its applicability requires much better infrastructure and support for updating than currently available.

PC = partner country, A = Australia

7 Key results and discussion

7.1 Value Chain Analysis

The VCA investigated the flow of fresh produce, information and communication characteristics and governance of chain relationships currently operating in Central Province supply chains in the context of consumer value attributes.

7.1.1 Consumers and market outlets

As in many other developing countries, consumer value attributes were difficult to determine by methods commonly used in developed countries so this analysis relied on a qualitative survey of the managers/buyers of market outlets. It identified that fresh produce value attributes focus on quality and the importance of price in the buying decision, which is dependent on income level. For the unemployed and working poor, price is the most important whilst for middle and upper incomes quality (in rank order: freshness, colour, freedom from blemishes, size, food safety) becomes more important. The wet markets, whether formal LLG markets or informal roadside markets or hawkers are a major source of cheap, variable quality fresh produce, particularly for the unemployed, landless urban poor or working poor. Frequently, even the relatively short distances to LLG markets in Port Moresby act as a disincentive for consumers, because of cost, insecurity and inconvenience of public transport.

The value attributes of buyers in the various market outlets are an important determinant of both daily buying practice and the developmental trend in the fresh produce supply system. However, the complexity and supply risk involved in this practice was generally driving a preference for longer term relationships with suppliers who had a larger supply capability. However, some were happy to leverage the smallholder competitiveness, desperation to sell (rather than dump the produce before they travelled home) to obtain lower prices despite the highly variable quality and volumes on offer. There was even a willingness for buyers within a single type of outlet (e.g. hotels) to collaborate together to obtain larger volume, more consistent supplies.

In Port Moresby, there are four main supermarket companies and they employ a range of procurement strategies, many encouraging smallholders by purchasing at the back door. Some also have direct supply arrangements with large farms (e.g. Sogeri Hydroponics), large collectors or farmer cooperatives. Supermarkets also grade the produce purchased and merchandise the highest quality with imports to the expatriate/high income demographics with significantly higher prices in the fresh produce department. They also have a ‘local produce’ section which is of lower quality and price. Many retailers, hotels and some institutions bought from myriads of smallholders at the ‘back door’ of their premises.

There are approximately ten four or five star hotels who accommodate international and expatriate clientele who have quality requirements similar to Government institutions. Government and government related institutions include Port Moresby General Hospital, Pacific International Hospital, Murray Barracks, Bomana Prison and the University of PNG. These outlets require consistent large volumes of fresh produce, not necessarily of the highest visual quality because it is frequently chopped or cooked so that blemishes etc can be removed. Therefore, they usually establish long term contracts with major suppliers. For organisational outlets (e.g. restaurants, hotels, institutions) food quality is only important where it can be visually critiqued by the consumer (e.g. a restaurant’s fresh salads) otherwise blemishes are simply cut out so for theses the buying decision is driven by price. Kai bars are small stores selling various forms of ‘fast food’ licensed by local

provincial governments. They comprise perhaps 5% of the market outlets for fresh produce and typically have sales of at least PGK600-800 per day with margins of 75-100%.

7.1.2 Smallholders

Smallholder farmers commonly produce food for their family group and sell any surpluses in the nearby local markets (roadside, ad hoc communal or those provided by the [LLG, whilst some supplied wholesalers, retailers and institutions on an ad hoc, opportunistic, 'discrete'[1] transactional basis.

There are few coordinated supply chains operating in the Province and these were usually associated with a registered cooperative (e.g. Rigo-Koiari Cooperative). Some produce is prepared for specific markets, usually more distant and formalised such as supermarkets, kai bars and institutions in Port Moresby. These farmers act more entrepreneurially, often have a good understanding of consumer value, and engage in distant marketing arrangements with wantoks[2] or accompany their produce to market to monitor its treatment and quality at point-of-sale. They use ingenuity to gain a critical mass of produce on a more sustainable basis, ranging from farming multiple gardens through leasing extra land to aggregating produce from other families and villages or even making arrangements with growers outside their own province i.e. becoming 'collectors' of produce. The most important attribute of these entrepreneurial farmers is their recognition of the need to increase their scale of production and delivery penetrate larger markets. Some examples included entrepreneurial farmers organising neighbours and growing on consignment or collaboratively marketing larger quantities of produce (e.g. the Chapman brothers at Bautama; Salama at Tubusereaia on the Magi Hwy).

Smallholders use diverse and often complex routes from the Central Province districts to the markets in Port Moresby as individuals and businesses seek to overcome logistical problems and gain advantage (Figure 2). Smallholders are often reluctant to collaborate for production or marketing, particularly outside their own family group. Many feel they lack the skills or are exploited or unfairly treated by other players in the chains and so are not motivated to collaborate or restrict marketing to local markets.

Currently smallholders buy first generation hybrid (F1) seeds in small home gardener packets of seeds that are often unsuited to PNG conditions. These small quantities are relatively expensive so they collect seed for a second year's production. Unfortunately, F1 hybrids revert to resemble their original parental types in the second year and consequently grow unevenly and perform very poorly, and may be more susceptible to pests eg aphids. Keeping seed from hybrid crops constrains yield and quality, and in reality is ineffective and a very expensive strategy. Agronomic research to identify more appropriate open-pollenated varieties (allowing seed collection) was undertaken by NARI – SRC at Laloki in this project.

Post-harvest practices are simple, traditional and result in high losses of fresh produce (>25%) and income. Table 12 provides actual statistics from a local supermarket on condition of anonymity. It confirms the data from other sources of the scale of waste in the fresh produce system and demonstrates clearly that its effect on overall fresh produce margins means that it is simply good business for supermarkets to import because it

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[1] *'Discrete' is an economic governance term referring to single transactions without any inference of an on-going relationship.*

[2] *A traditional system of social and business obligation based on language groups; literally those who speak the same language.*

generates a higher margin. Most smallholders don't approach production as a business but

Figure 2: Complex fresh produce marketing arrangements

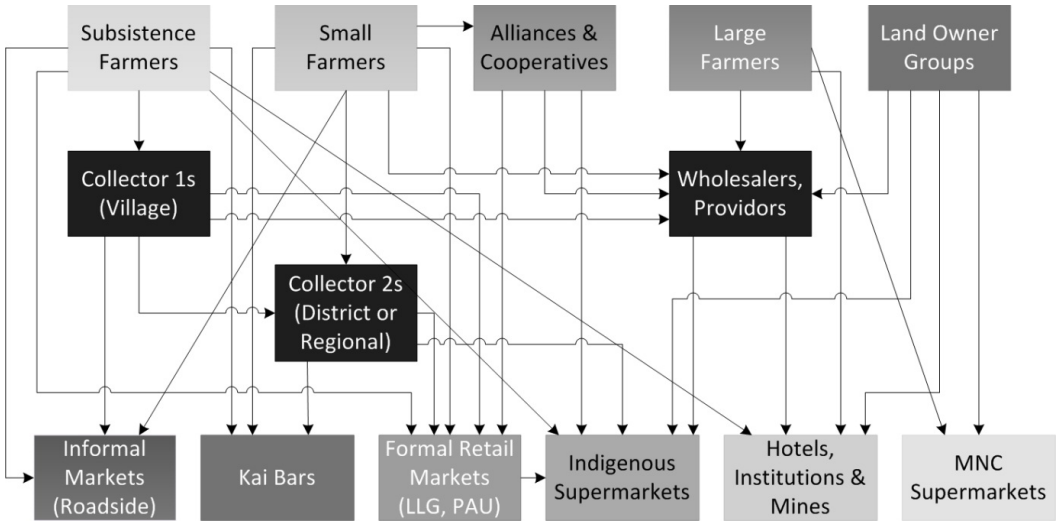


Table 12: Fresh produce consumption by a typical Port Moresby supermarket

Consumption (Kg)		
	Local	**Imported**
Purchased	890	540
Sold	720	470
Wastage	170	70
Ratios		
Purchased	62%	37%
Sold	61%	39%
Income	56%	44%
Net margin	12%	30%

as an occasional source of income to pay school fees, buy essential trade goods and special events. Hence, they don't cost their own time in production and marketing and whilst post-harvest waste is seen as a loss, it is not accounted for as a cost of production. Similarly, the cost of each individual farm household sending 1-2 people to market with only a few bags of produce is not recognised as a cost of business. Some specific challenges in post-harvest practices include minimal cleaning of produce, lack of grading, inappropriate packaging materials, no or poor access to cold chain in the transport and storage facilities, non-customised public motor vehicle (PMV) or private transport and poor feeder roads in some production areas (e.g. Tapini).

7.1.3 'Collectors' and the aggregation function

Produce 'collectors' are those who aggregate produce to gain the critical mass needed to supply particular markets. The more distant the market from the point of production, the more important is the role of the middlemen. This report distinguishes two levels of collectors determined by their scale of operations:

- The 'Collector Level 1' aggregates and markets the produce from their village neighbours or family group;
- Collector Level 2' aggregates and markets from several 'Collector 1s' and/or many family groups, tribes, districts or even regions.

'Collector 1s' often progress to 'Collector 2s' and if the scale of operation of the latter increases and they regularly supply resource projects or larger outlets in Port Moresby, they could be classed as 'wholesalers'. This progression is fundamental to the development of smallholder capability to access modern market outlets. Collectors and retail market 'middlemen' purchase produce 'by the bag' in the ubiquitous white 'poly bag' which is regarded as weighing 50Kg but according to an FPDA survey in Port Moresby,

they actually average 83Kg (G. Maino 2010, pers. comm., 5 October). Consequently, farmers are getting a much lower price than if they sold by weight.

7.1.4 Road transport to market

Smallholders mainly transport their produce to market on PMVs. Large numbers of PMVs operate on all the main roads that lead to Port Moresby but generally do not operate on secondary and tertiary roads so smallholders have to transport produce, usually in 50 kg white poly bags to the nearest main road. Some PMVs are not registered and many are not roadworthy, break down frequently and are therefore subject to frequent, lengthy police inspection. PMVs transport a mix of passengers and produce, often with the passengers standing or sitting on the bags of produce for up to 8 hours (e.g.from Tapini) on very rough roads. Some PMVs will undertake the rounds of the hotels and institutions to help smallholders sell the products. Typical charges for approx. 20km are around PGK2/person and PGK4/bag. From Rigo-Koiari (near Kwikila) to Port Moresby (about 85km) the cost is approx.PGK8-10/person and PGK20/bag for produce. However, Tapini in Goilala District is 230km on one of the worst roads in PNG and because of its isolation, the few PMVs willing to make the journey (about 2-3 per week) are charging PGK80/person and because of the high demand for travel prefer to carry people rather than produce.

Owners & drivers of PMVs are often middlemen too, undertaking buying/selling at the farm-gate or importing from the Highlands. PMVs are also available contract individual pickups of bulk loads for farmers but none have ‘chiller boxes’ able to maintain a cool chain during transport.

7.1.5 Market outlets

There are eight retail markets in Port Moresby located approximately consistent with those identified in the National Capital District Commission (NCDC) Urban Development Plan: Tokarara, Gerehu, Gordons, Hohola Lareva, Malaoro and Waigani with less formal markets at Koki and Eight Mile (NCDC 2006). These markets either have no infrastructure to accommodate vendors or have insufficient and inadequate structures resulting in overcrowding. Many vendors sit in the open shaded only by their own umbrellas. These are mainly Central Province people who are apparently kept out of the covered areas by the strong cohesion, organisation and aggressiveness of Highland vendors. This and the consequent disputes and violence is facilitated by the lack of independent security guards; the guards are apparently Wabags (Enga Province) and the Highlander vendors are largely Goilalans (NW Central Province) and Taris (Southern Highlands). Toilets and other facilities are inadequate, poorly designed, unsanitary and dangerous. The markets are often unsealed, not drained and rubbish accumulates and rots quickly. Severe crimes of all types, including murder, severe assaults, drug dealing and prostitution are frequent, and mostly against women and children.

A recent comprehensive investigation of Port Moresby’s markets by Jimenez, Au and Sandeka (2012) showed that the market violence and other environmental factors restricted both the social and economic functions of markets; the latter potentially having an important effect on fundamental family concerns such as health and education. The receival areas are particularly chaotic and dangerous in the early morning when PMVs are arriving in a crowded unloading area with produce and accompanying smallholders (mainly women). Bags of produce are immediately marked on the PMV for purchase by aggressively competing middlemen who are largely Highlanders. In the subsequent haggling with the middlemen’s young male carriers standing around the negotiations, the smallholder women (and men) often feel intimidated, seeking only to get the sale completed expeditiously so they can proceed home or to the local supermarket for supplies. These areas are a focus of much intimidation, disputes and related violence.

Smallholders who arrive later in the day have to take much-reduced prices for their produce. This is a particular problem for smallholders living close to Port Moresby in areas such as Laloki, Brown River and Bautama, when the PMVs coming from more distant places already have full loads and they must wait for later transport.

7.1.6 Discussion of opportunities and constraints

Resource developments are driving GDP growth and socio-economic change in PNG through its direct multiplier effects on construction, transport and support services. Combined with local employment benefits, the resources boom is steadily bringing improved social and economic infrastructure, although perhaps not with the pace and impact originally envisaged. Despite its well-recognised problems with control of corruption, rule of law and regulatory quality, there has been a noticeable improvement in governance and economic management and the PNG economy is expected to continue to develop rapidly (Export Finance and Insurance Corporation 2011).There are flow-on effects of the resources boom to Central Province and some of those effects are emerging. Some farmer groups are organising and coordinating production and marketing (e.g. the Rigo-Koiari Cooperative and the Chapman group at Bautama) and this approach is becoming more widely known amongst other tribes.

Broadly, supermarkets still procure their fresh produce from diverse sources ranging from wholesalers to small grower vendors. Supply chain governance is largely short term transactional exchange with opportunistic relationships but from time to time supermarkets set up direct-supply relationships. However, the trend is for buyers to reduce costs by reducing complexity through establishing direct, coordinated supply arrangements. Multi-national Corporations are increasingly focusing on emerging market opportunities in countries like PNG and are driving change in the supermarket sector to meet the needs of the burgeoning middle class. Hence, supermarkets are increasingly arranging direct supply from larger farms or grower cooperatives to reduce the complexity and risk of their fresh produce supply. This provides a significant opportunity to establish coordinated value chains that engage smallholders with the modern retailing system. The constraints to fresh produce marketing are summarised in Table 13 have provided the basis for developing the Best Practice Smallholder Value Chain Model in Figure 3.

The fundamental goals of the Best Practice model are to:

- Improve the volume, quality and consistency of fresh produce supplied thereby:
- Reducing supply risk for buyers;
- Increasing the bargaining power of suppliers;
- Improving efficiencies for all chain partners which reduces the overall cost of supply.
- Increasing the consistency and efficiency for smallholder supply thus increasing overall returns from fresh produce production and marketing.

In the implementation of this model in Rigo-Koiari, a simple visual grading system and a sale-by-weight process was employed. The co-operatives/growers graded the produce and the truck driver weighed, identified and receipted at the truck door. Payment was transferred on the day of purchase via EFTPOS to the cooperative’s bank account (for disbursement to growers) or directly to the farmer’s bank account. Whilst the price obtained by the farmers may not be close to the top of the market for the day, they will obtain a more consistent price for a much larger volume of vegetables at a fewer number of large outlets over the long term. It will reduce the peaks and troughs of unmanaged demand. They will save costs on transport, wastage of vegetables and their own time in hawking their produce around a range of outlets. It will also reduce the harassment involved in the existing formal/informal marketing system. The freight contractor is guaranteed their freight costs because contracting is on a per truck basis whether it's full or not.....that's an incentive for the co-operatives to fill the truck every time. It also reduces

the problem of driver honesty or competence. As explained in section 7.2, the Tapini value chain has not progressed to implementation for a range of reasons.

Table 13: Summary of value chain and socio-economic constraints

Sociological and Organisational Constraints	Value Chain Constraints
• Political issues, tensions & conflicts. • Land tenure – customary tenure insufficient for loans from financial institutions. • Cultural practices (e.g. wantokism) & traditional rites (e.g. marriages & funerals). • Women do 75% of the marketing with the risk of intimidation, exploitation & violence. • Availability & affordability of finance. • Few women own registered agribusinesses. • Few long term business relationships. • Few locally led & coordinated registered enterprises & cooperatives. • Population growth & food supplies. • Information availability & accessibility. • Low capacity of extension agencies. • Inadequate capacity for agricultural training. • Drift of rural labour (particularly young people) to major urban centres & other industries. • High turnover of leadership within communities/villages. • Lack of government officers resident in isolated communities such as Tapini, Goilala. • Corruption emerging in local level arrangements.	• Value chains are long, complex & informal. • Harvesting & post-harvest practices preparing produce for marketing. • Lack of local collection storage facilities. • Cool chain infrastructure inadequate. • Lack of a professional, dedicated fresh produce freight service maintaining the cool chain. • Use of PMVs which mix both passengers & produce. • Poor produce quality & high wastage adding significantly to cost (>25%). • Poor food safety & traceability. • Market information flows inadequate. • Business trust & commitment are low. • Inputs from suppliers are unreliable. • Chain coordination rare. • Lack of production & post-harvest skills. • Many chains end at ad hoc spot markets. • Financial & managerial constraints of small enterprises. • Inconsistent supply. • Unsafe, unhygienic retail markets in POM. • Poor road system.

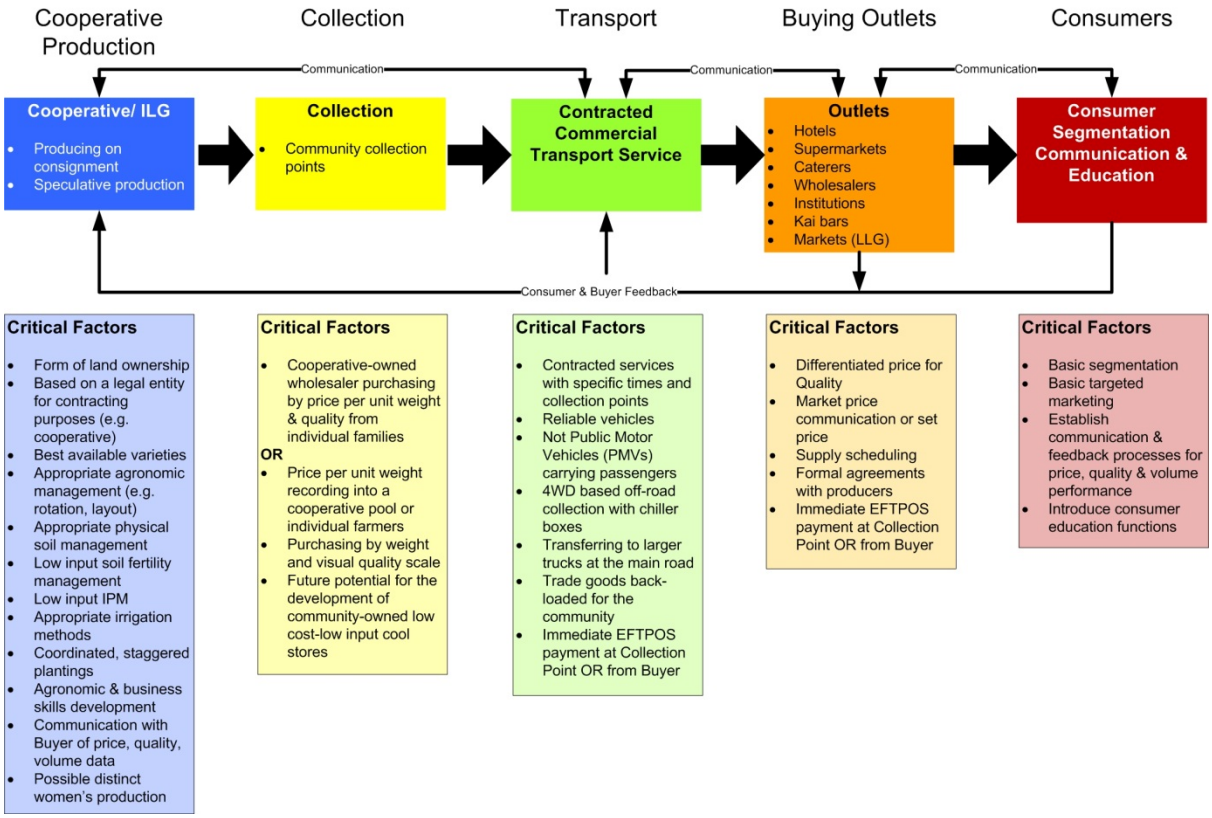
7.1.1 Discussion of the selection of project value chains

The aim of this project was to establish two chains. However, reducing Port Moresby's reliance on imports of temperate vegetables and improving household incomes in Goilala District, the poorest district in Central Province (CP) which is one of the poorest provinces in PNG, was an important consideration for the Central Province Government.

Furthermore, because Goilala provides an important opportunity for the production of temperate vegetables and the CP Government has funded an upgrade of the road to Tolukuma Gold Mine which is shared for two thirds of its length with the Goilala Road, CP Government has a priority to understand the potential and challenges involved in the production of temperate vegetables in that region. This has provided the rationale for the CP Government to request this Project to investigate the feasibility of establishing value chains from the higher altitude district of Goilala. In order to maximise the opportunity for success for the remaining project site, other communities were assessed for their 'fit' with the project's aims based on:

- Land capability;
- Experience and track record in vegetable production and marketing;
- Existence of or potential to form a production and marketing cooperative;
- Distance to market;
- Quality of leadership.

Figure 3: Best Practice Smallholder Vegetable Value Chain Management Model



On those criteria, the Rigo-Koiari Cooperative was selected on the basis that:

- They were a registered, mature cooperative with an existing manager;
- There were some 230 families with an existing level of production and marketing collaboration e.g. shared land cultivation resources, shared vegetable plant nursery, shared ownership of a trailer for transport to the main road etc;
- The community wanted to expand its operations;
- The cooperative is 85 km from Port Moresby;
- They had a professional agriculturalist who lived in the community providing leadership and the Chairman of the Cooperative was a long-standing, participative type leader.

7.2 Value Chain Improvement

The implementation of the Best Practice model has varied greatly between the two very different sites, Rigo-Koiari in the coastal hinterlands Rigo District and Tapini in the uplands Goilala District. Therefore, the results will be described separately:

7.2.1 Rigo-Koiari Cooperative, Rigo District

This Cooperative is situated in the main area of high capability in CP identified by the GIS analysis conducted by this Project. It has a large potential for horticultural production beyond the 230 families in the Cooperative; this potentially could extend to over 3,000 people. An Introductory Value Chain Awareness Raising Workshop conducted at PAU on 16th February, 2011 with 30 participants from the project stakeholders and from the District Administrators of Central Province. This included 5 participants from FPDA, 2 participants from PAU, 8 participants from NARI and 15 participants from Central Province. This was followed by a Planning Day on the 17th February with the same participants where it was agreed to proceed immediately with implementing the BP Model in the Rigo-Koiari

Cooperative whilst the logistics issues associated with conducting agronomic field trials, value chain training and implementation at Tapini, Goilala District, were investigated further.

In March 2011, following the Value Chain Awareness Raising Workshop, the Rigo men approached a large Port Moresby retail chain, the City Pharmacy Limited (CPL) Stop & Shop supermarkets and Pacific Adventist University's (PAU) Sunday market to organize a market outlet for their produce. As a result, CPL agreed to send a truck twice weekly to the junction of the Kwikila road with the track to Gerabu Village to pick up vegetables. This incorporated:

- Shared and scheduled land cultivation using the Cooperative's tractor and implements;
- Provision of seed by the Cooperative and shared vegetable seedling nursery production;
- Shared transport of produce to the main road (approx.10 km);
- Sowing of the new varieties of vegetables recommended by the Project;
- Integration of Project recommendations for new agronomic practices;
- Integration of Project recommendations for irrigation management;
- Reimbursement of 50% of the sale price to the Cooperative to fund shared services and equipment amortisation.

The Women's Collaborative Value Chain Planning Workshop was held on 26th – 27th September, 2011 at PAU. The training needs of women and their daughters from Rigo-Koiari and Bautama villages were identified as Farm Production (crop management and irrigation), Marketing (product readiness and price negotiation) and Business Skills (banking and book-keeping). This was a highly successful workshop that generated on-going commitment and activity from the participants in their villages. It also contributed to the Rigo Women in Agriculture Cooperative Society being awarded *a CPL Pride of PNG Women's Award* in 1st quarter 2012, a Corporate Social Responsibility (CSR) initiative of CPL Group. This award also provided for a marketing arrangement for the women with CPL's Stop & Shop supermarket chain (CPL Group, 2012[3]).

At this point the value of produce being marketed to CPL totalled between PGK7-10,000 per week. The value of produce marketed through the PAU Sunday Market is not known, however, the PAU Market Manager was involved in all the project's training and planning and over the next two years this market increased its overall turnover from PGK70,000 p.a. to over PGK800,000 p.a. However, despite these successes, some members of the Rigo Cooperative were not happy with the management arrangements and charges being made for cooperative's services to farmers. As a result, many farmers dropped out of production for commercial marketing to Port Moresby or resumed their traditional practices of individual marketing. Further, during 2012-13, a number of other unexpected events negatively affected the implementation of the plans from this value chain:

- The professional agriculturalist providing the impetus for the Cooperative's vision was moved to another job and location;
- The Cooperative Manager moved to full time job in Port Moresby;
- A dispute arose between Cooperative farmers and the Women in Agriculture Program over fees charged, resulting in the majority of farmers ceasing marketing through the cooperative. This then resulted in a reduction in the turnover from PGK5,000/week to only PGK3-500/week.

Project support of this initiative unfortunately lapsed till the end of 2011 due to the resignation of the key FPDA personnel. Resumption of support in early 2012 was then

[3] *Note this reports 2011 activity.*

interrupted by the PNG National Election (April-August, 2012) which resulted in a loss of focus by farmers and restricted project travel by Australian team members.

Project support resumed after the Election with the Rigo-Koiari Men's Collaborative Value Chain Planning Workshop on 20th – 21st September 2012 also included men from the Sogeri-Koiari villages, Rigo-Koiari and Bautama (a different tribal area on the South Eastern edge of Port Moresby). There was appreciation of and commitment to the specified workshop objectives. The Rapid Value Chain Research and Development Method worked extremely well. The men from different villages worked collaboratively in mixed groups and there was a high level of consensus amongst the men's groups from Rigo-Koiari and Bautama, an important and unexpected outcome. Young men showed some differences in their training priorities by identifying Banking and Planting, but shared a need for training in Book Keeping, Soil Preparation and Crop Management. The key issues requiring action for the Cooperative were:

- The need for improved post-harvest handling and packaging;
- Two-way communication in advance (buyers and sellers) of volume, quality, timing and price information prior to despatch;
- Training in agronomy, post-harvest preparation and handling skills;
- Commitment to trust-building behaviours.

Training and further operational support was provided to these groups in late 2011 and early 2012. Further details of outcomes from this workshop can be found in Appendices 4 and 5. As a result of the deeply personal and cultural nature of the issues that underpinned the rapid decline of this value chain the team was unable to ascertain their cause and address within the time limits of the project. This meant that the planned action learning cycle of improvement was not undertaken.

7.2.2 Tapini, Goilala District

The activities outlined below ***are the first agricultural research and men's and women's post-primary school training to be conducted in Goilala***. Given the risks of the road and the general insecurity of the area, this is a significant outcome. The Value Chain Analysis in 2010/11 indicated that there was one cooperative at Tapini seeking registration at that time and several more in other areas in the Goilala District at earlier stages of that process. The main 'cooperative' was well led and had the support of tribal leaders. A CP-Department of Agriculture & Livestock (DAL) officer was resident in the town as were other Government departmental officers. The District Administrator was highly supportive and enthusiastic. There was widespread enthusiasm and farmer support for the project aim of establishing varietal trials and a value chain to Port Moresby. The progress and findings of the agronomic research, conducted by the project are covered elsewhere in this report. However, it should be noted that the trial area was cleared and maintained with enthusiastic local labour, some of it voluntary. The initiation of trials was delayed by the previously mentioned staffing problem and the national election.

The Tapini Men's Collaborative Value Chain Planning Workshop was conducted on 19th – 20th March, 2013 and included 36 men from Tapini and surrounding areas of Erume, Kataipi and Guari. They identified training priorities in Transporting (logistics) vegetables, Book Keeping, Crop Management, Marketing, Packaging, Soil Preparation and Irrigation. Despite some unexpected problems with the training venue the integrated Rapid Value Chain Research and Development Method used in conducting the workshop worked extremely well and elicited a high level of participation and understanding. However, the important outcomes were unplanned and less obvious:

- This was a first time in their lifetime that participants had attended training and may have been responsible for the apparent enthusiasm;

- The Australian co-facilitator and co-developer of the Rapid Value Chain Research and Development Method became unavailable, and the PNG team delivered the Men's Collaborative Value Chain Planning Workshop independently

However, subsequently, during April there was a dispute and murder in Tapini adjacent to the research trial area. About half the town's population, (including all government officers) left, returning to home villages. Many houses were vacant and were looted by late June. Despite this, the local part time project employee paid to maintain the trial area continued to do so to a high standard. Notwithstanding, the project team had problems finding a PMV or transporter willing to make regular trips to Tapini to pick up vegetables. The few PMVs operating were making too much profit from the high demand for people transport and were not interested in vegetable transport. A transport operator initially interested in making the run with a 4WD truck with chiller box found a lower risk alternative for his investment.

The Women's Workshop was conducted on the 27th – 28th June, 2013. At the time, there were still no government officers in the town and the impetus of the Men's Workshop had been lost because no-one was coordinating planned activity, promoting the project or communicating trial outcomes. The fledgling cooperative appeared to have dissolved. Despite these problems, 26 women attended, enthusiastically participated and some clear directions were gained for future training. The evaluation of the workshop was outstanding, although it may well be that as this was the first workshop for women, the sheer novelty of the participative approach, taking time out from everyday tasks having the Australian and PNG research team making the effort to travel and 'stay at their place (Tapini) may well have skewed the feedback in our favour. Subsequently, training in business management skills has been delivered for women in Tapini. Further details of the outcomes from this workshop can be found in Appendices 4 and 5. Following the Women's Workshop, the inter-tribal conflict continued to disrupt the project because all government officers resident in Tapini evacuated to Port Moresby and there was no-one to promote and coordinate production and marketing arrangements. A final effort was made to resurrect the arrangements in May 2014, but as an additional killing occurred, access to the area was banned.

7.2.3 Conclusions about the Value Chain Improvement Phase

The Rapid Value Chain Research and Development Method integrating Collaborative Problem-Solving Method, Appreciative Inquiry and the Rapid Supply Chain Approach appears to be non-judgemental, affirmative and empowering method that elicits:

- High level participation;
- Understanding and commitment;
- Trust and collaboration.

The PNG research partners are now able to implement the Rapid Value Chain Research and Development Method without assistance. This is due to:

- The commitment and high quality of PNG staff involved in the project;
- The co-design processes adopted throughout the implementation of these phases;
- The shadowing and mentoring processes adopted during the project;
- The two weeks of value chain training held at TIA in February, 2013.

The conditions for the successful implementation of the Rapid Value Chain Research and Development Method to achieve the Best Practice Model include:

- A registered cooperative;
- A stable community environment;
- Stable cooperative leadership;
- Social cohesion and stability;
- A resident agricultural officer to provide constant support for the project to maintain its impetus.

Developing a sustainable temperate fresh produce value chain from Tapini to Port Moresby is feasible. The community are capable and keen to engage. The road quality is a significant but not insurmountable problem. The critical success factors are:

- A registered farmer's cooperative with stable leadership and robust procedures;
- Coordination of production and marketing by the cooperative;
- A resident agricultural officer living in Tapini;
- Implementation of a series of agricultural training courses to support production and marketing of fresh produce;
- A regular, weekly dedicated vegetable freight service is the key. Currently, the few available PMVs carry passengers at PGK80/head and make more money;
- A regular air freight service is feasible if a sufficient volume of high value, low volume temperate vegetables (e.g. snow peas, leeks, red capsicums) is produced in a coordinated manner – for DH-400 Twin Otters, this is approx.1470 kg.

7.3 Land Resource Studies

(a) Soil analytical data

Understanding of the quality of soil resources is fundamental to development of sustainable agricultural production systems. In many developing countries, soil resources are described at an aggregated level, as in Bleeker (1983) and Hanson *et al*. (2001) for Papua New Guinea (PNG), but this is usually inadequate for decision making on cropping practices for long term sustainability. In this study, existing information on soils and land capability in Central Province PNG has been further supported by profile examinations of soils identified as having potential for sustainable agricultural development. Soil types in PNG are highly variable due to the landscape being affected by active geological processes, significant climatic gradients and variable topographic features in a high relief terrain. Land capability and land use potential is also highly variable (Hanson *et al.* 2001). This section reports on profile characteristics and chemical fertility of soils identified as having potential for intensified vegetable production in coastal and elevated regions of Central Province, and identifies practices needed for sustainable production.

Soil profile characteristics and soil fertility

Summaries of some of the soil profile descriptions are provided in Table 14 and these data show considerable variation in physical characteristics of profiles, with impeded drainage or high water-tables indicated by the presence of mottling (Mo) and manganese nodules (Mn) at differing depths in several soils. Texture class is dominated by clays (LC – MC) and clay loams (CL) which are commonly silty (Z). Soil structure is moderate to strong in most upper profiles. The presence of carbonate in lower horizons of the Koiari Park and Rigo soils indicates high base status and low leaching regimes. Additional results are also available for Tapini, from additional work done in mid-2013. These data are included in Appendix III (Publications), and show considerable variation among the sites assessed in that study. These data will now be integrated with those below to gain a clearer picture of the soil resource at Tapini, and published separately. Detailed analytical data are available for a range of soils - PAU Koiari Park - Vertosol, PAU -Alluvial, Laloki - Alluvial, Rigo - Vertosols (2 profiles), Sogeri Lower - Ferrosol, Sogeri Upper - Ferrosol and Tapini - Dermosol , 'Mudstone', Tapini 'Sandstone', Vertosol and an Alluvial, the detailed results are included in Appendix 8. General trends only are described here, and then only for some soils. The three Vertosols (Mafic soils) in the coastal lowlands at Koiari Park and Rigo are high in exchangeable Mg, CEC and C/N, but are generally low in P. However most profiles have high exchangeable Ca and moderate to high exchangeable Mg levels, some of the Tapini soils being an exception with low Mg. All the soils have relatively moderate to high pH, except at Sogeri and one or two Tapini soils where the profiles appears more leached. Available P as measured by the Olsen test ranges from low in the sesquioxide rich soil at Sogeri, to relatively high at the research

stations/commercial farms of Laloki, PAU and Tapini. Total N and organic C concentrations are variable with values in the Vertosols being higher than in most other soils, especially in the A horizon. Both measures decline rapidly in the B and C horizons. Overall total N values are low (mostly <0.2%). There are clearly lower levels of soil organic carbon and total nitrogen in the long term cultivated sites, particularly the research stations and commercial farms. C/N ratios are highly variable (ca 5 – 20), with some quite high (>16, above which immobilisation of N is likely). Exchangeable K values are low at Koiari Park and moderate to high at all other sites. Extractable P and exchangeable K, organic C and total N were concentrated in the upper profile, though significant concentrations of P were present in the upper layers of the B horizon at Laloki and Tapini. In the Vertosols at Koiari Park, and Rigo, exchangeable Ca increased markedly in the lower profile associated with the presence of $CaCO_3$ segregations (See Appendix 8 for more details and the data).

(b) Land capability assessment

Accurate and reliable spatial data on soil types is very limited in Papua New Guinea. The only regional digital dataset available is the Papua New Guinea Resource Information System (PNGRIS). This dataset is an extrapolated modelled GIS dataset which provides only a coarse and broad interpolation of probable soils which does not provide realistic on ground soil representation. The coastal lowlands and adjacent elevated areas are known to have highly variable topography, including coastal plains, steep escarpments and dissected uplands/plateaux. Soils are also variable, with substantial areas of the coastal lowlands susceptible to inundation and steeper slopes overlain by shallow soils being susceptible to erosion (Bleeker 1983, Hanson et al 2001). For expansion of agriculture in Central Province, more detailed understanding of the location of suitable soils and their topographic limitations is needed. Historically, this would have been achieved through soil surveys, however, modern tools of GIS and radar imaging provide for rapid assessment of land capability for particular purposes. This assessment can be followed by 'ground truthing' and coupled with existing knowledge from, for example, field trials of crops and field data on soils, to assist in final assessment and decision making regarding agricultural development. This section reports on the assessment of land capability in one potential area for agricultural development in Papua New Guinea, the Rigo district to the south east of Port Moresby. This broad first pass classification identified 41,533 ha of land for potential agricultural expansion within the Rigo district (Table 15). The land was underlain by a wide range of parent material/bedrock, though most were of volcanic origin dominated by gabbro and basalt and a significant area of transported materials (9,899 ha, see Table 16 and Figure 4, an example of maps produced, others are included in the Compendium of Publications (Appendix III)). The majority of this land is centred on the town of Kwikila some two hours by road south east from Port Moresby. Of the 41,533 ha identified some 10,632 ha is listed within PNGRIS as being prone to waterlogging and inundation of varying duration and severity (Table 15). Of the 10,632 ha susceptible to inundation 2,920 ha (Inundation types 1, 2 and 5 would probably be excluded from agricultural use). Appendix 9 contains a detailed report of land capability.

Discussion

The GIS data and radar imagery has been combined to produce informative maps that can be used to prioritise areas for agricultural development. They have clearly identified potential areas, and by relaxing or tightening the constraints set when using the radar imagery, the area of potentially useable land would increase or decrease. For example, if the allowable slope was reduced to say, 7^o for agricultural systems in which soil cover was limited between crops and during cropping while canopy cover was limited, therefore increasing the erosion risk, the area of suitable land would inevitably decrease. Conversely, if the assessment was being made for land uses involving perennial pastures, forestry and fruit trees the allowable slope limits could be increased, resulting in larger areas of potentially useful land being identified. The present analysis has shown an

extensive area of potentially useful land between elevated areas and many small, narrow areas of potentially useful land in nearby valleys and small areas in elevated areas. When combined with ground based observations along roads and in village gardens augmented with limited examination of augured soil profiles, the approach of using GIS and radar imagery is proving a very useful tool for assessment of land capability. Our team has also applied this approach in several other areas in Central Province, with similarly useful output, again with initial validation from ground based observations and soil data. Nevertheless, the approach must be complemented with other information, such as the data on inundation, to gain a more accurate assessment of land capability and guide development and agronomic decisions on crops to be grown and practices used on specific sites. Clearly, there are significant areas of land available for agricultural development in Rigo district, and by extrapolation, other areas of Central Province and beyond. However, for effective development, appropriate agronomic practices will need to be developed; these being part of other work being conducted by the authors and other colleagues. Land tenure issues notwithstanding these data will assist the sustainable agricultural development process in PNG and increase employment and business prospects for local farmer cooperatives.

Table 14: Profile characteristics for selected soils in the Central Province of PNG

Laloki	**Koiari Park**	**Rigo 1**	**Rigo 2**	**Sogeri**	**Tapini**
Alluvial Dermosol	**Colluvial Vertosol**	**Colluvial Vertosol**	**Alluvial Vertosol**	**Colluvial Ferrosol**	**Colluvial Dermosol**
~40 m ASL	**~50 m ASL**	**~80 m ASL**	**~85 m ASL**	**~400 m ASL**	**~900 m ASL**
Imperfect Drainage	Imperfect Drainage	Well drained	Moderately well Drained	Imperfectly drained	Moderately well drained
A11 0 – 5 cm 10YR 4/2, ZCL M-PO	**A11** 0 – 10 cm 10YR 2/1, MC, S-PO, F, C, G	**A11** 0 – 5 cm 10YR 2/1, ZLC, S-PO, F, A	**A11** 0 – cm 10YR 2/1, ZLC, S-PO, W	**A1** 0 – 10 cm 7.5YR 3/3, LC, S-PO, F	**A11** 0 – 15 cm 7YR 2.5/1, ZCL, M-PO, W, MG
A12 5 – 12 cm 10YR 4/2, ZLC, M-PO	**A12** 10 – 25 cm 10YR 2/1,MC, S-PO, VF, C, F-MG, G	**A12** 5 – 25 cm 10YR 2/1, ZLMC, S-PO, F, D	**A12** 5 – 20 cm 10YR 2/1, ZLMC, S-PO, W	**A3** 10 – 25 cm 7.5YR 4/3, FSLC, S-PO, F, Mn, G	**A12** 15 – 25 cm 7.5YR 3/1, ZCL, M-PO, W, MG
B11 12 – 30 cm 10YR 4/3, ZLC, M-PR+M,	**B21g** 25 – 40 cm 10YR 4/1, LMC, M-AB, F, Mo, O, G	**A13** 25 – 45 cm 10YR 2/1, ZLMC, M-PO, VF, G	**B1** 20 – 35 cm 10YR 3/1, ZMC, MS, F	**B1** 25 – 35 cm 7.5YR 4/4, SCL, M-PO, F, Mn,	AB. 25 – 35 cm 5YR 3/2, ZLC, M-AB, W, CG
B12 30 – 50 cm 10YR 4/3, ZLC, S-PO+GR, Mo, G	**B22g** 40-60cm, 2.5Y 5/2, LMC, W-AB, F, Mo, S	**B21** 45 – 65 cm 10YR 3/2, LMC, M-PO, VF, CO_3, D	**B21** 35 – 50 cm 10YR 3/2, ZMC, MS, VF	**B21** 35 – 50 cm SCL, MS+M-AB, F, Mo, Mn, D	**B21** 35 – 45 cm 5YR 4/4, ZLC M-AB, W, MG
B21 50 – 75 cm 10YR 4/2, ZMC, S-PO+AB, Mo, G	**C1g** 60 – 80 cm 2.5 Y 5/2 , MC, MS, F, CO_3	**B22** 65 – 90 cm 2.5 Y 3/1, MC, MS, VF, CO_3, FG, D	**B22** 50 – 65 cm 2.5Y 3/2, ZMC, MS, VF	**B22** 50 – 85 cm 7.5YR 5/2, SLC, MS+W-AB, F, Mo, Mn, D	**B22** 45 – 65 cm 10YR 5/6, ZL,MC, M-AB, W, MG
B22 75 – 95 cm 10YR 4/2, ZLC, Mo,	**C2g** 80 – 95 cm 2.5Y6/2, MC, MS, F, Mo CO_3	**B23** 90 – 110 cm 2.5Y 3/1, MC, MS, F, CO_3, FG	**B23** 65 – 80 cm 2.5Y 3/1, ZMC, MS, VF	**B3** 85 – 120 cm 7.5YR 5/6, SLC, MS, F, Mo, Mn	**B23** 65 – 80 cm 10YR 5/6, ZMC, M-AB, W, MG
B31 95 – 105 cm ZLC	**C3g** 95 – 115cm 5Y7/8, MC, MS, F, Mo, CO_3		**BC** 80 – 95 cm ZMC, MS, VF		**B24** 80 – 100 cm 10YR 5/6, ZMC, W-AB, MG
B32 105 – 110 cm+ ZLC					**B25** 100 – 110 cm 10YR 5/6, ZMC W-AB, MG, Mo

Soil order from Isbell (2002)

Texture: CL = clay loam, LC = light clay, MC = medium clay note Z in front = silty, S = sandy, FS = fine sandy, L= light

Structure: PO = polyhedral, PR = prismatic, AB = angular blocky, M = massive

Gravel: FG = fine, MG = medium, CG = coarse,

Moist Strength: W = weak, F = firm, VF = very firm

Mottles, Nodules nd Cutans: Mo = mottles, CO_3 = carbonate nodules, O = Organic cutans, Mn = manganese nodules

Boundaries: Clear unless shown as A = abrupt, G = gradational or D = diffuse boundary.

Table 15 Geological bedrock and associated areas of land assessed as suitable for agricultural development in Rigo district, Papua New Guinea

Geological Bedrock	Area (Ha)
Basalt and andesite pyroclastics, lava and volcanic sandstone.	3,955
Basalt and andesite pyroclastics and minor lava.	924
Basalt and andesitic agglomerate, minor tuff; tuffaceous sandstone and volcanic conglomerate.	725
Basalt and minor andesite agglomerate and tuff, partly reworked	312
Basalt and pillow lava with gabbro and dolerite intrusives (dykes), minor calcilutite	381
Gabbro, diorite, dolerite, basalt and other acid differentiates.	25,285
Gravel, sand, silt, mud, clay: alluvium and beach deposits downslope and adjacent to mafic and intermediate bedrock	9,899
Massive green mafic schist derived from basalt, dolerite, gabbro, volcanic sediment; and minor calcareous and felsic schist or phyllite.	52
Total	**41,533**

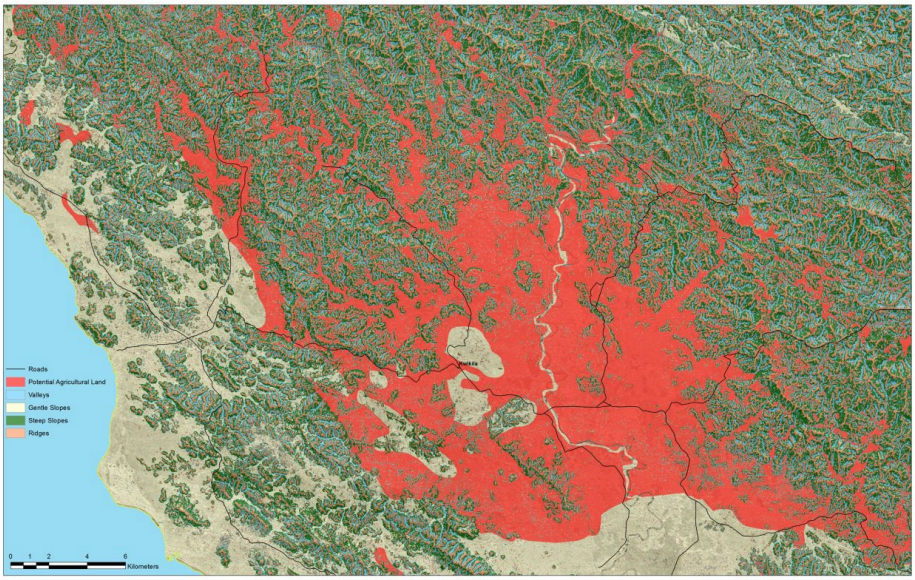


Figure 4 Potential suitable Agricultural Land (areas in red) in the Rigo Province PNG

Table 16 Areas of land subject to inundation in Rigo district

Inundation Type	Area (Ha)
1. Long term inundation	2,843
2. Near permanent inundation	6
3. Periodic brief flooding	3,909
4. Seasonal inundation	3,607
5. Tidal flooding	71
Total	**10,632**

Conclusions

We recommend using high resolution radar generated topographic coverage in combination with soil parent material classification based on the mapped bedrock lithology as a base to generate more reliable land suitability maps and show national and local government development bodies, aid agencies and the village farmer cooperatives the areas available for land use intensification and sustainable national agricultural development. The maps would then be combined with other local data to provide a sound basis for development decisions and to guide agronomic practice.

7.4 Agronomic Experiments – crop evaluation

(a) Agronomic studies (crop and cultivar evaluation)

The agronomic studies showed considerable variation in phenology, yield and susceptibility to pests and diseases within and across the experimental sites. They provided guidance to the better adapted and more productive cultivars. In the sections below, the means of key data on yield, quality and pest incidence are presented, together with commentary for each location, as locations differ considerably, either in site characteristics (soil, climatic conditions, elevation) or intensity of management. Appendix II contains detailed data on phenology and components of yield supplementing that reported here...

In the tables and commentary that follows, the following footnotes to tables apply generally, with additional crop or location footnotes used if necessary.

[1] Means within the column followed by different letters are significantly different at P<0.05
[2] N/T = Not trialled that year
[3]Quality was assessed using market standards as appropriate:
[4] DNC=Data not collected that year
[5] Quality rating scale: 1-2= very good quality; 3=good, 4-5=bad to poor quality
[6]Pests and disease infestation rated on a scale of 1-5 (0=no infestation, 1-2=low infestation; 3=moderate; 4-5=high to heavy infestation)
ns =Not significant

Laloki

At Laloki, there was considerable variation in yield of the three crops grown (capsicum, French bean and tomato, Tables 17 a, b and c respectively) with the highest yielding cultivar substantially exceeding the yield of the lowest yielding cultivar in all three crops in one or more years, though high standard errors imply that care is needed in interpreting the data and that more intensive sampling would be needed in future work. . However, quality characteristics and susceptibility to pest and diseases should also be taken into account. For instance, cultivars with a rating for disease infestation of 1 or 2 (low end of range) would be preferable. Pest and disease incidence was highly variable, as evidenced by the high standard errors in most measures in all crops, hence some caution is needed in interpreting these data, however, low incidence ratings would indicate cultivars that would be preferred in an environment where low intensity management practices are likely to predominate. Quality of the three crops was usually in the desirable ratings (1 or 2), though there were occasional incidences of less desirable ratings. Findings are summarised below:

Tomato

- Tropic Boy, Tough Boy and Spring Shine were the earliest in terms of maturity in 2011. King Kong No. 2 and Roma were the earlier cvv in 2012-2013 while Money Maker, Grosse Lisse, SRC-LE2 and 4 were mid varieties and Summer Star was the latest maturing cultivar.
- Tropic Boy produced the highest yield potential followed by Roma in 2011; King Kong No. 2, Roma and Money Maker were the highest yielding in 2012 and 2013 respectively.
- The fruits of these promising varieties were of good market quality.
- Spring Shine (2011), SRC-LE2 & SRC-LE4 and Summer Star (2012 & 2013) were the most affected by pests and diseases, Roma and Grosse Lisse were mostly affected by blossom end rot in the three trials. Nonetheless, all were affected by common tomato pests (army worm, tomato fruit worm, leaf miner) and diseases (black leaf mould, late blight, damping off).

French bean

- Contender and Gourmet Delight average of three trials were found to be the most promising out of the five cultivars that did well in 2011, 2012 and 2013 in terms of yield potential, pests & disease incidence and vegetative adaption.
- All other three entries; Bountiful Butter, Dwarf stringless and Climbing Stringless produced yields comparable yields.

- Insect (aphids) and disease (rusts) incidence were found to be very high in these four entries compared to Contender.

Sweet pepper (capsicum)

Table 17: Yield, Yield Attributes and Pests and Disease Rating of (a) Sweet Pepper (b) French Bean and (c) tomato cultivars at Laloki

(a) Sweet Pepper

Cultivar	Maturity rating	No. of fruits harvested/plant			Market weight/fruit (kg)			Potential Yield (tonne/ha)			[6]Pests & disease infestation			[5]Quality
		2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013	
SRC-CF 4	Early	[4]DNC	[2]N/T	[2]N/T	0.16^{AB}	[2]N/T	[2]N/T	6.0^{A}	[2]N/T	[2]N/T	2	[2]N/T	[2]N/T	2
SRC-CF 5	Early	[4]DNC	[2]N/T	[2]N/T	0.25^{A}	[2]N/T	[2]N/T	8.6^{A}	[2]N/T	[2]N/T	2	[2]N/T	[2]N/T	2
SRC-CF 6	Early	[4]DNC	[2]N/T	[2]N/T	0.22^{A}	[2]N/T	[2]N/T	7.6^{BC}	[2]N/T	[2]N/T	2	[2]N/T	[2]N/T	1
New Ace	Early	[2]N/T	4.2	4.1^{A}	[2]N/T	0.04	0.05	[2]N/T	8.4	16.3A	[2]N/T	2.2	2.1	1
Wonder Bell	Early	[2]N/T	3.8	1.9^{B}	[2]N/T	0.05	0.06	[2]N/T	8.8	9.12B	[2]N/T	2	2.6	1
California Wonder	Early	[4]DNC	3.7	1.3^{B}	0.19^{AB}	0.05	0.06	5.0^{E}	6.8	6.9C	4	2.4	2.2	2
Giant Bell	Mid	[4]DNC	3.5	[2]N/T	0.25^{A}	0.04	[2]N/T	8.0^{B}	7.9	[2]N/T	2	2.5	[2]N/T	3
Yolo Wonder	Mid	[4]DNC	3.4	[2]N/T	0.11^{B}	0.05	[2]N/T	7.3^{C}	7.3	[2]N/T	2	2.5	[2]N/T	3
LSD			ns	1.2	0.04	ns		0.63	ns		ns	ns	ns	

(b) French bean

Cultivars	Harvested pods/plant			Fresh weight/pod (g)			Potential Yield (tonne/ha)			[6] Pest and disease infestation			Quality
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013	
Contender	[4]DNC	18	22.8	5.2	4	6.7	2.9^{A}	13.6	11.6	1.7	2.7	3.3	2
Gourmet Delight	[4]DNC	21	19.5	4.7	5	4.7	2.6^{A}	14.2	8.1	3	2.7	3.3	2
Dwarf Stringless	[4]DNC	17.5	34	5.3	7	6.5	1.5^{B}	12.0	13.8	4	3.5	3.2	2
Bountiful Butter	[4]DNC	16.5	24.8	5.6	6	6	1.5^{B}	13.6	7.4	4	3	3	2
Climbing Stringless	[2]N/T	17.5	30	[2]N/T	6.7	7.3	[2]N/T	13.8	13.7	[2]N/T	3	3	2
LSD		1.8	6.35	ns	ns	ns	0.37	ns	ns	ns	ns	ns	

(c) Tomato

Cultivar	Maturity	No. of fruits/plant			Market weight/fruit (kg)			Potential Yield (tonne/ha)			[6] Pests & disease infestation			Quality
		2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013	
SRC-LE 2	Mid	[2]N/T	18.8	17.6^{C}	[2]N/T	0.13^{BCD}	0.06^{BC}	[2]N/T	12.7	7.4^{A}	[2]N/T	3.7	3.8^{A}	2
SRC-LE 4	Mid	[2]N/T	15.6	16.5^{C}	[2]N/T	0.14^{BC}	0.05^{C}	[2]N/T	12	7.3^{A}	[2]N/T	3.3	3.3^{AB}	2
Summer Star	Late	[4]DNC	11.8	13.9^{CD}	[2]N/T	0.11^{CDE}	0.0^{9A}	[2]N/T	11.1	5.9^{C}	[2]N/T	3.3	3.5^{A}	2
Money Maker	Mid/Late	[4]DNC	33.7	34.8^{A}	0.19^{BC}	0.1^{DE}	0.06^{BC}	6.6^{BC}	20.4	11^{AB}	2	3.7	2.8^{BC}	3
Grosse Lisse	Mid	[4]DNC	8.1	9.1^{D}	0.22^{AB}	0.15^{B}	0.07^{ABC}	6.3^{C}	17.9	4.6^{C}	3	3	2.3^{CD}	2
King Kong No. 2	Early	[2]N/T	26.3	26.4^{B}	[2]N/T	0.22^{A}	0.08^{A}	[2]N/T	29.6	12^{A}	[2]N/T	2	1.7^{D}	1
Tropic Boy	Early	[4]DNC	2N/T	[2]N/T	0.25^{A}	[2]N/T	[2]N/T	9.6^{A}	[2]N/T	[2]N/T	2.6	[2]N/T	[2]N/T	1
Tough Boy	Early	[4]DNC	2N/T	[2]N/T	0.25^{A}	[2]N/T	[2]N/T	5.3^{D}	[2]N/T	[2]N/T	2.3	[2]N/T	[2]N/T	1
Roma	Early	[4]DNC	39.4	38.9^{A}	0.11^{D}	0.08^{E}	0.06BC	7^{B}	23.1	11.2^{A}	2.3	2.3	1.8^{D}	1

Spring Shine	Early	[4]DNC	2N/T	[2]N/T	0.16[C]	[2]N/T	[2]N/T	7[B]	[2]N/T	[2]N/T	3.6	[2]N/T	[2]N/T	2
LSD			ns	7.1	0.04	0.04	21.9	0.6	ns	3.8	ns	ns	0.73	

- Varieties New Ace, Wonder Bell, Giant Bell, California Wonder, SRC-CF 4, 5 and 6 were the early maturing varieties while Yolo Wonder was the late maturing.
- Highest yielding cultivars SRC-CF 5 (8641 kg/ha) in 2011, and New Ace, Wonder Bell and California Wonder 2012 and 2013. Other varieties produced similar but intermediate yields.
- Though California Wonder was the severely affected by pests and diseases, other having low or moderate infestation in 2011, Giant Bell and Yolo Wonder were mostly affected in 2012.

Tapini

As at Laloki, considerable variation in yield and other plant characteristics and the incidence of past and disease occurred at Tapini (Tables 18 a, b and c). Also the range between lowest and highest yielding cultivars was similar – the highest yielding often around double that of the lowest – in all three crops grown. However, early harvest of carrots in 2012 because of safety and security concerns locally meant the carrots were immature, so results for 2013 are much more realistic. Again, pest and disease incidence differed among cultivars, especially in cabbages, with some having very low incidence in 2012, but higher (though still low compared to other cultivars in 2013). Again standard errors were quite high making differences that appear large difficult to detect statistically.
Summary of Tapini Data

Broccoli

- Earliest maturing varieties were Southern Comet and Southern Star at first harvest, Marathon and Shogun are mid varieties, while Summer King was the late variety,
- Southern Comet cvv produced the highest gross yield followed by Southern Star and Summer King while Shogun and Marathon were the lowest yielding in 2012.
- In 2013, Southern Comet still proved to be high yielding followed by Marathon and Shogun.
- Shogun cvv was found to be the most affected by pests and diseases while in 2012 however, Sakura was the most affected in the 2013 trial.
- All varieties were affected by common pests (cluster caterpillar, diamond back moth, spiders, semi hoppers and caterpillars). No major diseases (bacterial or fungal) were observed at all during time of harvest.

Carrots

- The highest yield cultivar is Manchestor Table, followed by Chantenay Red Cored and Kuroda Improved in 2013.
- In 2012, Kuroda Improved and Chantenay Red Cored had the highest yield all the other cultivars were comparable.
- Interestingly, all plants in all varieties did not show any pests and disease infestation effects, also no pests or diseases were observed in the trial plot area or within each variety plot in 2012.
- 2013, signs of disease crops were observed in all cultivars but at a very low incidence rate.

Cabbage

- The earliest maturing variety was Tropical Delight at 46 days after head initiation followed by mid varieties KK Cross (88 days) and KY Cross (88 days), Eureka, Racer Drumhead and King of Kings.
- KK Cross, KY Cross, Tropical Delight and Eureka are high yielding.
- Variety King of Kings was the most affected by pests and diseases. Eureka, KY Cross and Racer Drumhead were moderately affected while KK Cross and Tropical Delight were the least affected in 2012.
- However it is the opposite in 2013, KK Cross and King of Kings were observed to be the most affected with pests and disease.
- Similar to Broccoli, common pests (cluster caterpillar, diamond back moth, spiders, semi hoppers and caterpillars) and fungal diseases (soft rot) were observed.

Sogeri

As at Laloki and Tapini, considerable variation in yield and other plant characteristics and the incidence of past and disease occurred among the different crop cultivars (capsicum, French bean and English cabbage) (Tables 19 a, b and c). Also the range between lowest and highest yielding cultivars was similar – the highest yielding close to double that of the lowest– in all three crops. However, due to poor soil conditions of the first trial site identified, only one season of planting was done for French bean and English cabbage and hence the results need to be treated with caution. Again, pest and disease incidence differed among cultivars, especially in cabbages, with KY cross (equal highest yielding) having low incidence and Copenhagen Market (lowest yielding) having high incidence. A summary of Sogeri data is provided below.

Capsicum

- New Ace, Wonder Bell, California Wonder and Giant Bell are early maturing cultivars.
- Giant Bell was the highest yielding in 2011 while New Ace was in 2013 followed by Wonder Bell and California Wonder with comparable yields
- California Wonder was the severely affected by pests and diseases and had the lowest rate of survival at last harvest in 2011. However, Yellow, Yolo Wonder and California Wonder as well slight to moderately affected in 2013.
- Similar to Laloki trial, common sweet pepper pests and diseases were found.

French bean

- Bountiful butter and climbing Stringless are the highest yielding and less infested with pests and disease followed by Contender.
- Gourmet Delight and Dwarf Stringless are the most affected by pests and disease.
- Pod quality of the five cultivars where of good market quality.

Cabbage

- All cabbage cultivars produced high yielding comparable yields. Eureka (38.5 ton/ha) followed by KY Cross (37.9 ton/ha) and KK Cross (35.6 ton/ha)
- Copenhagen Market and KK Cross had high incidence of pests and disease
- However, all cultivar head qualities were of very good market quality

Pacific Adventist University

Data on fruit yield and selected fruit characteristics for capsicum, French bean and tomato are presented in Tables 20 (a, b and c) for the 2011-12 trials at Pacific Adventist University. Data from subsequent experiments in which considerable additional data were collected on plant characteristics including phenology, leaf number and leaf area, plant height and insect pest and disease status. These data, while still being processed indicated similar trends, confirming initial findings. Of some concern was the incidence of blossom end rot in all cultivars of tomatoes (the worst affected cultivars being Roma, followed by Beef Steak and Summer Star), making fruit unmarketable, and indicating that production practices for tomatoes will need to ensure adequacy of calcium supply. This would also be relevant to other large fruits, including capsicum. Insect pests, principally thrips and ‘fruitworms’, were also a significant limitation to performance especially during floral initiation period (example shown for tomatoes in Figure 5), and seed corn maggots were common on the initial development of French bean cultivars.

Importantly, there were substantial differences among cultivars of all three crops, with New Ace and Wonder Bell (Capsicum) (Table 20 (a)), Money Maker and Grosse Lesse (Tomato) (Table 20 (c)) and Gourmet and Stringless Blue Lake (French Bean) (Table 20 (b)) the highest yielding. Yollo Wonder and yellow (Capsicum), Roma and Beef Steak (Tomato) and Early Long Pod (French bean were inferior. There was a disturbingly low proportion of marketable fruit of most cultivars in the three crops, indicating edaphic or

Table 18: Yield, Yield Attributes and Pests and Disease Rating, of (a) Broccoli (b) carrot and (c) English Cabbage cultivars at Tapini

(a) **Broccoli**

Cultivar	Maturity	Market weight/head (kg)		Total harvest weight (kg)		Potential Yield (tonne/ha)		[6]Pest and disease infestation		Quality
		2012	2013	2012	2013	2012	2013	2012	2013	
Marathon	Late	0.29[B]	0.30	2.4	3.2	6.6	8.8	3.3	1.6[B]	1
Southern Star	Early	0.47[AB]	[2]N/T	5.8	[2]N/T	16.1	[2]N/T	2.3	[2]/NT	2
Southern Comet	Early	0.60[A]	0.26	5.6	4.1	15.3	11.3	3.3	2.6[AB]	2
Shogun	Mid	0.29[B]	0.23	2.5	2.5	6.9	6.8	4.0	2[B]	2
Summer King	Late	0.37[AB]	[2]N/T	4.3	[2]N/T	11.8	[2]N/T	3.0	[2]N/T	2
Sakura	Mid	[2]N/T	0.30	[2]N/T	2.1	[2]N/T	5.7	[2]N/T	3.3[A]	1
LSD		0.23	ns	ns	ns	ns	ns	ns	1.1	

(b) **Carrot**

Cultivar	Maturity	Market weight/root (g)		Potential Yield (tonne/ha)		Pest and disease infestation		Quality
		2012	2013	2012	2013	[Ω]2012	[Ω]2013	
Kuroda	Early	87	90	2.6	12	0	1	2
Kuroda Improved	Early	120	150	3.5	6.5	0	1	2
New Kuroda	Early	112	[2]N/T	3.9	[2]N/T	0	[2]N/T	2
Chantenay Red Cored	Late	115	120	2.2	7.1	0	1	1
Manchestor Table	Late	91	110	2.3	7.7	0	1	3
Top Weight	Late	104	150	1.6	4	0	1	3
LSD		ns	ns	ns	4.6	ns	ns	

(c) **English Cabbage**

Cultivar	Maturity	Market weight/fruit k(g)		Potential Yield (tonne /ha)		Pest and disease Infestation		Quality
		2012	2013	2012	2013	2012	2013	
Tropical Delight	Early	1.1[C]	0.93	10.5[C]	39.5	1[C]	2.0	2
KK Cross	Mid	1.8[A]	0.87	18[AB]	28.2	1.6[C]	4.0	1
KY Cross	Mid	1.9[A]	0.87	19.3[A]	31.0	1[BC]	2.7	1
Eureka	Mid	1.7[AB]	0.67	17[AB]	21.8	2.3[ABC]	3.3	1
Racer Drumhead	Mid	1.1[C]	0.67	11.6[C]	25.5	2.6[AB]	3.3	2
King of Kings	Mid	1.3[BC]	0.97	13[BC]	27.1	3.6[A]	4.3	2
LSD		0.49	ns	ns	ns	1.4	ns	

agronomic limitations that need further investigation. Differences among cultivars would be expected, especially as the production environment has multiple potential limitations. Perhaps this also applies to quality characteristics (eg fruit size, fruit length) and to the proportion of marketable fruit. However, the blossom end rot (calcium deficiency, probably because of undesirable Ca:Mg in soil) may have affected cultivars and crops other than

Roma tomatoes, and insect pests were a significant limitation. Both these and other limitations eg nutrient and water supply will need careful attention in future trials and under commercial conditions.

Table 19 (a): Yield, Yield Attributes and Pests and Disease Rating of (a) Sweet Pepper (b) French Bean and (c) English Cabbage Cultivars at Sogeri

(a) Sweet Pepper

Cultivar	Maturity	No. of fruits harvested/plant		Fresh fruit weight/fruit (g)		Potential Yield (tonne/ha)		[6]Pests & disease infestation		Quality
		2011	2013	2011	2013	2011	2013	2011	2013	
New Ace	Early	[2]N/T	8.9	[2]N/T	91	[2]N/T	16.6	[2]N/T	1	1
Wonder Bell	Early	[2]N/T	7.9	[2]N/T	80.2	[2]N/T	15.1	[2]N/T	1	1
California Wonder	Early	[4]DNC	7.7	58	82.4	5.5	14.4	3	2	1
Giant Bell	Early	[4]DNC	[2]N/T	60	[2]N/T	6.8	[2]N/T	3	[2]N/T	1
Yolo Wonder	Mid	[4]DNC	6.2	55	63.6	6.4	8.5	3	2	2
Yellow	Mid	[4]DNC	7.1	60	82.8	6.7	12.6	4	2	2
LSD			ns	ns	ns	ns	ns	ns	ns	

(b) French Bean

Cultivar	Maturity	No. of pods harvested/plant	Fresh weight/pod (g)	Potential Yield (ton/ha)	6 Pests & disease infestation	Quality
Contender	Early	5.3	7.7	7.1^{AB}	1^{C}	2
Gourmet Delight	Early	9.3	7.2	6.2^{AB}	3^{A}	2
Dwarf Stringless	Mid	7	8.7	5.6^{B}	3^{A}	2
Climbing Stringless	Mid	6	9.3	9.7^{A}	2^{AB}	2
Bountiful Butter	Mid	9.3	8.9	9.9^{A}	1^{BC}	2
LSD		ns	ns	3.9	0.81	

(c) English/Round Cabbage

Cultivar	Maturity	Market weight/fruit k(g)	Potential Yield (ton/ha)	[6]Pests & disease infestation	Quality
KY Cross	Early	1.2	37.9	2.7	1
KK Cross	Mid	1.1	35.6	3.3	1
Copenhagen Market	Late	0.9	31.1	3.5	3
Racer Drumhead	Late	1.1	35.5	2.7	2
Eureka	Late	1.2	38.5	2.5	1
LSD		ns	Ns	ns	

Table 20 Yield and selected fruit characteristics of (a) capsicum (b) French bean and (c) tomatoes at PAU agricultural farms (PNG) in 2011-2012 (TF = total fruit, MF = marketable fruit, UMF = unmarketable fruit, fresh weights). Values within columns followed by the same letter do not differ (P=0.05)

(a) capsicum

	TF (kg plant^{-1})	MF (kg plant^{-1})	UMF (kg plant^{-1})	Fruit length (cm)	MF diameter (cm)
Arise	0.93^{b}	0.68^{bc}	0.24^{b}	10.11^{a}	7.44^{a}
Giant Bell	1.57^{ab}	0.73^{bc}	0.84^{a}	6.77^{cd}	6.67^{ab}
New Ace	1.86^{a}	1.57^{a}	0.29^{b}	9.05^{ab}	7.05^{ab}
Wonder Bell	1.45^{ab}	1.05^{b}	0.40^{ab}	8.66^{ab}	7.57^{a}
Yollo Wonder	0.98^{b}	0.56^{bc}	0.42^{ab}	7.87^{bc}	7.53^{a}
Yellow	0.89^{b}	0.39^{c}	0.50^{ab}	6.12^{d}	6.10^{b}

(b) French bean

	TF No/plant	FW (kg/plant)	MF (kg/plant)	UMF (kg/plant)	Mean fruit length (cm)
Gourmet Delight	64.67a	0.806^{a}	0.228^{a}	0.580^{a}	7.44^{a}
Bountiful butter	36.00^{b}	0.43^{b}	0.123^{b}	0.367^{b}	6.67^{ab}
Stringless blue lake	54.22ab	0.55^{ab}	0.180^{ab}	0.330^{b}	7.05^{ab}
Stringless	60.00a	0.33^{b}	0.223^{a}	0.167^{b}	7.57^{a}
Early Long Pod	0 c	0 d	0 c	0 c	0 c

(c) tomatoes

	Number of fruit per plant			Weight of fruits (kg/plant)	
	Total	MF	UMF	MF	UMF
Money maker	14.0a	8.0 a	6.0ab	0.39a	0.11a
Summer Star	11.3ab	4.3b	7.0ab	0.24ab	0.18a
Beef Steak	9.7abc	2.8c	4.7ab	0.17b	0.42a
Roma	9.3abc	0.0c	8.7a	0.12b	0.32a
KY Grace	8.7bc	5.0b	4.3ab	0.17ab	0.19a
Gross Lisse	6.0c	4.67b	4.0b	0.38a	0.22a

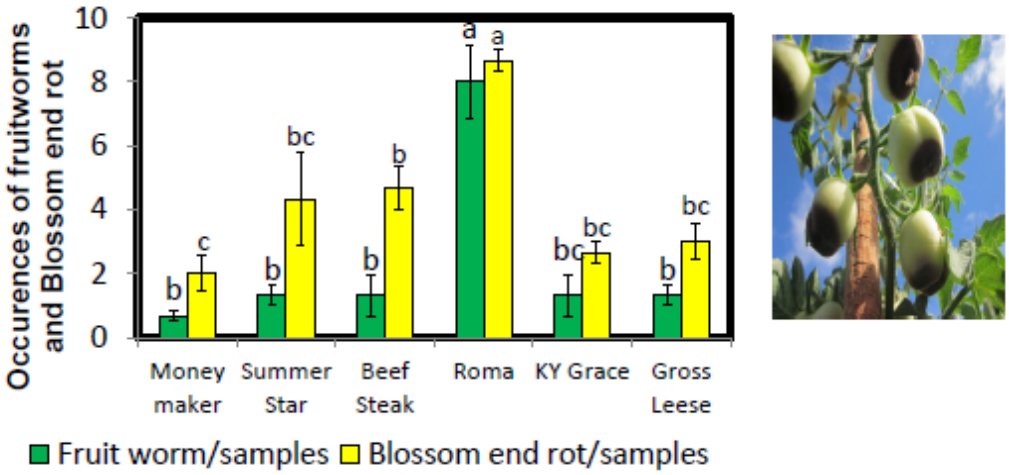


Figure 5. Relative incidence of 'fruit worm' and blossom end rot (BER) in tomato cultivars at PAU farm (within fruit worms and BER, columns with the same letter do not differ (P=0.05))

Demonstration trials

Demonstration trials were conducted at two locations – Rigo Koiari (Girabu Village) and Sogeri (Kailaki Village) to assess the performance of crops and also demonstrate practices being developed in the replicated trials. However, while extension use was made of these, few data were collected and so detailed reporting is not possible. At Girabu Village, 6 vegetable crops were grown, these being Tomato (cultivars Money Maker, Kingkong, Summer Star, Tropic Boy and Roma), Capsicum (Yolo Wonder, Yellow, Giant Bell, Wonder Bell), Broccoli (Summer King, Shogun), Head Cabbage (Eureka, Golden Acre, KY Cross, Racer Drumhead), Carrots (Kuroda, Kuroda Improved, Top Weight, Manchester Table, Chantenay Red Cored) and Beans (Beautiful Butter, Conender, gourmets Delight, Dwarf Snapbean). They were grown by two groups (i) the local Cooperative Society (using an intensive production system (System 3), with mechanised land preparation, commercial pesticides and inorganic fertiliser and (ii) a women's fellowship, which used an improved traditional system (System 2) which used mechanical land preparation, plant derived pesticides for pest and disease control and organic fertiliser. Similarly, at Kailaki Village, 6 vegetable crops were grown, though the cultivars chosen differed somewhat. Crops were tomato (cultivars Money Maker, Kingkong, Summer Star, Roma), Capsicum (Yolo Wonder, Yello, Giant Bell, California), Broccoli (Summer King, Shogun, Green King, Southern Comet), Head Cabbage (Eureka, Golden Acre, KY Cross, Racer Drumhead), Carrots (Kuroda, Top Weight, Manchester Table, Chantenay Red Comed) and Beans (Beautiful Butter, Stringless, Gourmets Delight). They were grown using System 1 (traditional low input system production), with commercial pesticides and inorganic fertilisers used only in the nursery, and plant derived pesticides in the field if necessary. Unfortunately severe insect damage occurred, making getting meaningful results impractical.

7.5 Plant Adaptation and Genomic studies

(i) Plant adaptation

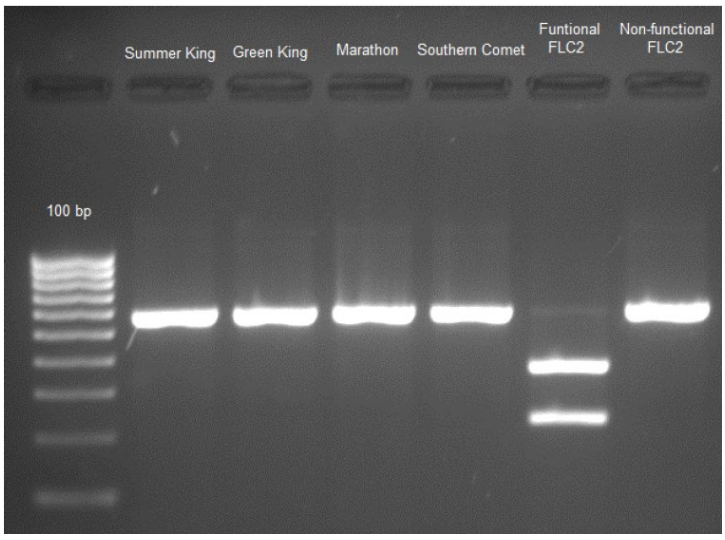
Of the four cultivars of broccoli (Green King, Southern Comet, Marathon and Summer King) used and exposed to day/night temperatures of 20/15°C, 25/20°C and 30/25°C and a 12/12 hr day/ night regime, all produced inflorescences under the 20/15°C temperature regime, with cultivars Green King and Southern Comet developing inflorescences earlier, and with few leaves than cultivars Marathon and Summer King (Table 21). A similar trend was recorded at 25/20°C with the exception of Southern Comet, however, which initiated inflorescences in the shortest period of time at 20/15°C but was substantially delayed at

25/20°C relative to the other cultivars. At 30/25°C, only the short maturing cultivars produced inflorescences by 170 DAP when the experiment was terminated. From these data, the cultivar Green King is most suited to high temperature environments, such as those experienced in the lowlands of PNG, because of its greater ability to yield inflorescences at high temperatures and the relatively short period to inflorescence development. Other cultivars could be used in elevated cooler areas, such as at Tapini.

(ii) Genomic studies

The functionality of the FLC2 gene was determined for each four cultivars to ascertain vernalisation requirements. This was undertaken because the FLC2 gene has been shown to have major role in determining flowering time and vernalisation requirements in Brassica species (Ridge 2012). All four cultivars were found to contain non-functional FLC2 (Plate 1) and therefore require little or no vernalisation. Thus the variation observed among cultivars in the trials conducted at Sogeri in PNG were more likely due to other biotic factors, such as the ability of each variety to tolerate high temperature stress, and not vernalisation requirement *per se*. This is a particularly important finding, as it indicates that selection of cultivars for the at least low to mid altitudes of PNG should concentrate on tolerance of higher temperatures, rather than vernalisation or adaptation to near constant photoperiod (in any case, response to photoperiod has been found to be small or non-existent, flowering mostly being dependent on temperature (Tan et al 2000)). Also, the failure of Marathon to produce infloresences in the high temperature regime is consistent with its failure to produce infloresences at Sogeri in 2011.

Plate 1: Gel electrophoresis results showing non-functional FLC2 genes for all four broccoli cultivars; Summer King, Green King, Marathon and Southern Comet.



Discussion - Crop adaptation and cultivar selection

Results for the four experimental locations and thus environments indicate that there are potential cultivars of each crop assessed in each environment. Performance of the various cultivars is summarised with the data for each site and will not be repeated here. Also, selecting the most appropriate for each environment will not be attempted – it is evident from the data that there is substantial year to year and site to site variability, consequently, the advice of local agricultural advisers should be sought for specific recommendations. It is important to note that the relatively small individual plot areas and low (compared to intensive production systems using mechanised agricultural practices) mean that calculated potential yields will provide rank order only. Similarly, the often high standard errors mean data must be treated carefully. Taken together, these factors indicate that in future experiments, larger plots and/or more replications will be needed to enhance the reliability and applicability of data.

Table 21: Days after planting (DAP), number of leaves > 2cm, and height from the soil to the inflorescence butt at buttoning. Values shown are means ± one standard deviation

Temperature Regime	Cultivar	DAP	Number of Leaves	Height to Inflorescence butt (cm)	Plants with Inflorescences
20/15	Green King	97.5 ± 5.7	14.3 ± 2.7	7.0 ± 0.9	100%
	Southern Comet	84.0 ± 0.0	11.3 ± 0.5	5.3 ± 0.3	100%
	Marathon	104.8 ± 3.1	16.5 ± 0.6	7.9 ± 0.6	100%
	Summer King	110.0 ± 4.6	17.8 ± 1.8	7.1 ± 0.5	100%
25/20	Green King	140.0 ± 7.6	31.5 ± 1.7	16.5 ± 1.7	100%
	Southern Comet	156.3 ± 4.7	32.3 ± 0.9	15.2 ± 1.1	75%
	Marathon	145.3 ± 8.3	33.3 ± 4.0	13.4 ± 1.6	100%
	Summer King	168.0 ± 0.0	46.0 ± 0.0	17.5 ± 0.0	25%
30/25	Green King	168.0	35.0	20.5	50%
	Southern Comet	161.0	29.0	19.8	25%
	Marathon	-	-	-	0%
	Summer King	-	-	-	0%

Experimental sites were selected to include the coastal lowlands (seasonally dry tropics), mid-altitude (where lower average daily temperatures and greater diurnal range were expected), and high altitude within Central Province, where still lower temperatures would be experienced. Information gathered in addition to yield and quality of vegetables indicated that there was variation in susceptibility to insect and disease infestation ie some cultivars were more susceptible than others, none of any crop was resistant or immune. This would be a significant production limitation, necessitating rigorous control, with presumably Integrated Pest Management techniques. Blossom end rot occurred in all cultivars of tomatoes at PAU, despite high exchangeable Ca levels, apparently due to an unfavourable Ca/Mg ratio in soils (Appendix 8), and indicates that similar symptoms are likely in large volume low surface area crops such as capsicum. Further, the soil at the PAU site was a Vertosol developed from colluvial deposits, suggesting that similar nutritional disorders could be present in similar landscapes or where similar soils occur in the coastal lowlands e.g., also some alluvial landforms. At Sogeri, the failure of the tomato plants to survive in the Ferrosol that had very low extractable P (Appendix 8) is evidence of the need for additional P input for this crop, which is known to be very susceptible to P deficiency. Not only did the low extractable P indicate P deficiency, but symptoms progression were consistent with P deficiency ie stunted plants, blue green leaves, appearance of red and purple pigments (presumably xanthocyanins) and ultimate plant death. There are significant implications for crop production in the Ferrosols of Sogeri – either crops that are comparatively tolerant of low P supply will need to be chosen, or significant P fertiliser inputs from either organic or mineral sources will be needed. Subsoil acidity and high subsoil exchangeable aluminium levels were also measured in the Upper Sogeri soil indicating liming or other pH amelioration will be needed for sensitive crops. The Ferrosols also had some of the lowest CECs and base cation levels in our study.

Also, at Sogeri, all broccoli varieties failed to produce marketable heads, and Marathon failed to produce many inflorescences. This may be due to relatively high temperatures and this cultivar and Summer King being most susceptible to high temperature in the controlled environment studies at the University of Tasmania, resulting in lack of flowering (Table 20). Clearly, cultivars that can tolerate high temperatures should be grown, even at the altitude of Sogeri. These findings emphasise the need for an integrated systems' approach to research and development projects', incorporating resource studies, value chain studies (to identify candidate crops) and agronomic work to address limitations and opportunities in both.

7.6 Agronomic Studies – Production Systems

The systems trials have only been running for a very short time, so results have to be treated as preliminary, as trials of the nature of those established here need to run for extended duration (10 years minimum and more than likely considerably longer in tropical environments) for trends to appear. However, early results indicate the highest marketable yield and lowest pest incidence in tomatoes at Laloki (2011-2013, Table 22) and English cabbage at Sogeri in (2013, 2014) (Table 23) occurred in LIS and/or HIS, which. The trials at Laloki and Sogeri so far indicate that low input improved system (LIS) is usually comparable to the high input system (HIS) in terms of yield, pest and disease incidence and quality. The traditional production system (TPS) has high incidence of pests and disease and has produced lower yields.

(i) Low altitude (Laloki) Production Systems Evaluation Trial

Summary of Production System study at Laloki

- Yield levels in three systems were low and almost comparable with each other in 2011; most likely because of faults/interruptions in drip irrigation system and logistics.
- HIS showed a low rate of pests & disease incidence, followed by LIS.
- 2012-2013, HIS and LIS both outperformed TPS
- As in 2011, HIS and LIS showed low incidence of pests and disease.
- Fruit quality of the LIS was comparable to that is HIS

Table 22: Yield, Yield Attributes and Pests and Disease Rating of Tomato, var. Money Maker as indicator crop for the Production Systems Evaluation Trial at Laloki

Production System	No. of fruits/plant			Market weight/fruit (kg/plant)			Potential Yield (tonne/ha)			[6] Pests & disease infestation			Quality
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013	
Traditional (TPS)	[4]DNC	32	18.3	0.08	0.05	0.04[B]	9	7.3	3.4[C]	4	3.3	3	3
Improved (LIS)	[4]DNC	44	24.7	0.09	0.06	0.06[A]	6	13.6	4.3[B]	3	2.3	2.3	2
Intensive (HIS)	[4]DNC	42	23.3	0.09	0.06	0.06[A]	6.3	11.3	6.8[A]	2	2	2	2
LSD		ns	ns	ns	ns	0.013	ns	ns	0.67	ns	ns	1.2	

(i) Mid altitude (Sogeri) Production Systems Evaluation Trial

Summary of Production System study at Sogeri

2013

- IPS was high yielding (19 t/ha) compared to HIS (14.8/t/ha), and had a comparatively low infestation by pests and diseases followed by the high input system and finally the traditional practice system.
- Head quality in IPS and HIS was comparable
- TPS performed poorly in the 2013 trial

2014

- HIS was high yielding (10t/ha) followed by LIS (8t/ha) and TPS the lowest (5.3t/ha).
- HIS had the lowest infestation by pests and disease followed by IPS while TPS was highly infested with pests and disease.
- Head quality in HIS and IPS were of very good market quality than that of TPS.

2015

- Trial will complete by October 2015

Table 23: Yield, Yield Attributes and Pests and Disease Rating of English Cabbage, var. Racer Drumhead as indicator crop for the Production Systems Evaluation Trial at Sogeri in 2013 and var. Tropical Delight in 2014.

Entries	Maturity	No. of marketable heads/plot		Market weight/head (kg)		Potential yield (tonne/ha)		Pests & disease infestation		Quality	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Traditional (TPS)	Mid	18	8	1.1b	0.33	12.5^{b}	5.3^{b}	3.3^{a}	2.2^{a}	3	3
Improved (IPS)	Early	20	11	1.3^{a}	0.5	19^{a}	8.3^{a}	2^{b}	1.8^{ab}	2	2
Intensive (HIS)	Early	20	12	1.1^{b}	0.7	14.8^{b}	10^{a}	2.3^{b}	1.4^{b}	2	1
SE		0.88	0.9	0.02	0.09	0.74	0.4	0.19	0.14		
LSD		ns	ns	0.09	ns	2.9	1.57	0.75	0.56		

Discussion – Production Systems

The production systems trials have only been running for a very short time, and can only be expected to provide some guidance to which may be the most appropriate in the longer term. They also need to be considered in relation to resource constraints and the economic opportunities. Given the nature of the environment and socio-economic realities, use of high intensity production systems on smallholdings is unlikely in the foreseeable future. However, low input improvements to traditional production systems appear to provide benefits that could be widely adopted within current technologies available to smallholders and their socio-cultural practices and preferences. It is highly desirable that the site be maintained over the longer term to gain the greatest scientific output and production impact.

7.7 Economic Analyses

The number of man-days used in vegetable production was highest in capsicum (225/ha), followed by tomato and watermelon, zucchini and French bean (which required less than one sixth of the labour of the other three crops (Figure 6). They were, though, comparatively low yielding. Figure 7 shows the distribution of labour among farm activities, for tomato, other crops had similar patterns though the relative proportions varied. Harvesting and packaging involved most labour in all crops, explained by multiple harvests (up to 5) in each crop, followed by transport to the roadside due to distance and that most transport is done manually over distances of up to 9km. Labour for pest control and fertilizer application is minimal as both are applied on an as needed basis, and individual applications take comparatively little time. Production costs of the vegetables were summarized in percentage terms in Figure 8. Labour cost exceeded 70% of all costs in all crops, when included at a notional PNGK1.43/hr, the rural minimum wage, for the unpaid labour time used on each crop. Unit costs of production varied, with capsicum (PGK3.24/kg excluding labour the most expensive to produce, and zucchini was the least. Zucchini also had a higher return than French beans, watermelon and capsicum, which showed negative margin after labour was included. Tomato had the highest margin of the crops assessed (Table 24).

Figure 6. Labour (man-days/ha) in the production of tomato, capsicum, watermelon, French beans and zucchini in Girabu village, Rigo District.

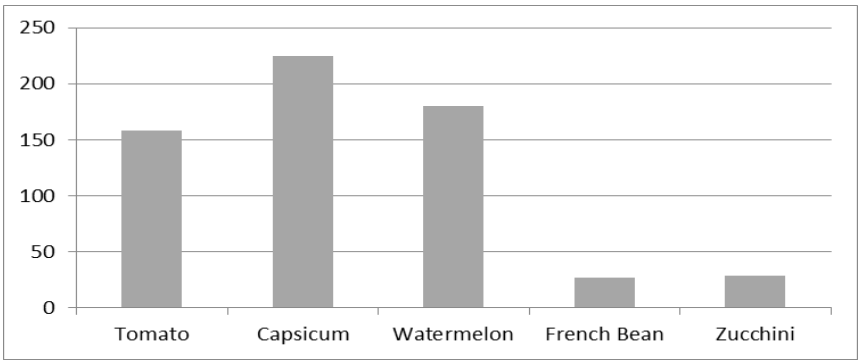


Figure 7: Labour (man-days) used in tomato production activities (minor activities excluded)

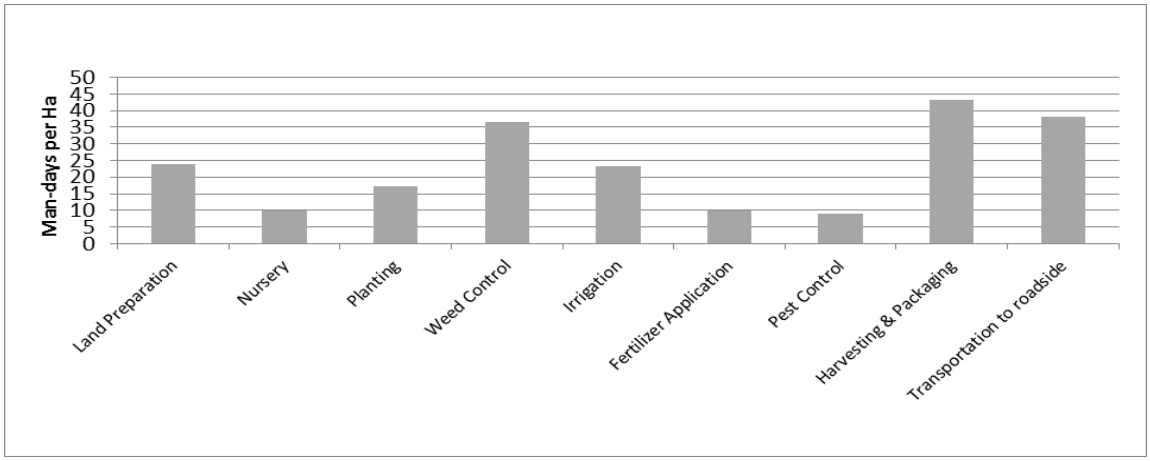
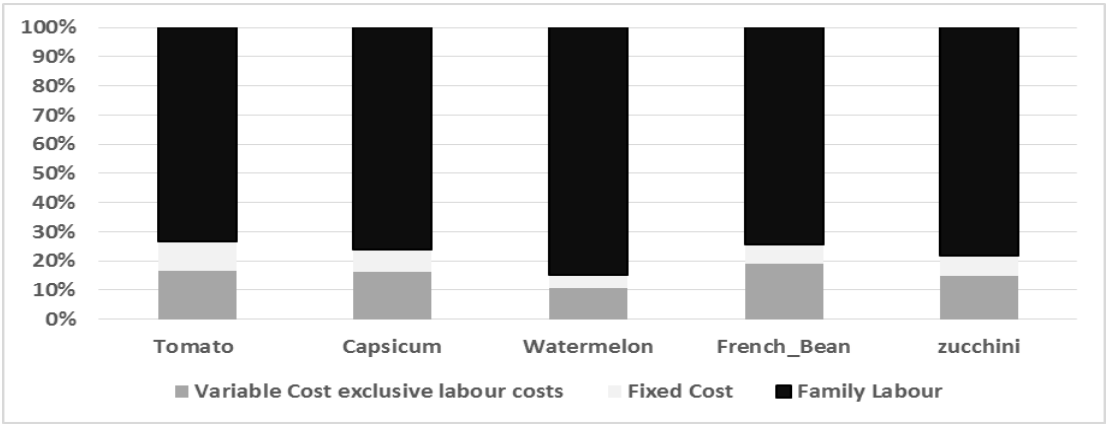


Figure 8 Variable, fixed and labour costs as proportions of total costs of production in tomatoes, capsicums, watermelons, French beans and zucchinis.



Discussion of economic analyses

The high cost of labour (>70% of all costs) means it is likely to overwhelm efficiencies introduced in other aspects of production, especially as expectations for improving capacity to meet living, education, medical and other costs rise (Palaniappan et al 2013). Loss of labour to cities to access improved opportunities and services (Bourke and Harwood 2009)

Table 24. Costs and returns for tomato, capsicum, watermelon, French beans and Zucchinis in Girabu village, Rigo district, PNG.

Crop	Tomato	Capsicum	Watermelon	French Bean	Zucchini
Price (PGK/kg)	8.50	10.00	5.00	12.00	12.00
Yield (kg/ha)	1420	500	940	140	470
Revenue (PGK/ha)	12070	500	4700	1680	5640
Variable cost (PGK/ha)	1060	1100	490	160	120
Fixed cost (PGK/ha)	660	1620	700	220	180
Total cost (PGK/ha)	1720	1620	700	220	180
Margin before labour (PGK/ha)	10350	3380	4000	1460	5460
Cost/kg before labour	1.21	3.24	0.75	1.57	0.38
Cost/kg inclusive labour	4.50	13.50	4.81	5.92	1.72
Labour (PGK/ha)	4670	5120	3880	610	620
Margin after labour (PGK/ha)	5680	-1740	120	850	4740

is also likely to increase pressure for higher wages for labour. The most labour intensive activities (harvesting, packaging and transporting) is due to the lack of mechanisation of these, and that the farms were distant (~9km) from the main highway. Addressing this accessibility constraint would save time and encourage increased production to benefit economically. It would also enhance competitiveness in the market. Labour requirements for harvesting and packaging may be reduced by availability of better materials and facilities for cleaning and storing of produce and improvements to packing practices to avoid double handling. High labour requirements for weeding can be attributed to environmental conditions, especially the distinct wet and dry seasons. For crops planted in the wet season, weeding is done four to five times, while dry season crops are normally weeded twice. Opportunities to reduce weeding include more appropriate timing of planting and use of herbicides, though the economics of alternative agronomic practices were studies here. To reduce labour requirements, training in more efficient methods and use of improved technology for weed control, irrigation and harvesting techniques are required.

Widespread lack of data on labour input in agricultural activities in developing countries contrasts with the detailed data in the manufacturing sector. In reality, most labour in the farming sector is not paid - farmers simply buy their needs from surplus funds after non-labour production costs are paid (Hansen et al, 2001). This study shows that improvement in labour productivity improve profitability of smallholder farmers. How this might be achieved was not an objective of this study, however, the adoption of technology, small scale mechanisation (micro-mechanisation) and staff training as reported in Palaniappan et al. (2011, 2014) would be appropriate strategies. Further, improvement in currently low crop yields would distribute labour costs over greater production, reducing per unit labour cost.

7.8 Socio – Economic Studies

Identification of broad social issues production and marketing:

The most benefitted vegetables in terms of income are watermelon and tomato during the dry season and aibica, pumpkin and corn during wet season in Bautama. In Rigo-Koiari, the vegetables they grow include cabbages, pakchoi, choisum, aibika, watermelon, tomatoes and cucumber. The most benefitted vegetables in terms of income are ripe banana, kaukau, and green peanut in Tapini. In all 3 selected communities they knew

what to produce and when to produce based on the season, income, yield and cultural activities. All 3 communities had no firm arrangement with the transporters, wholesalers, buyers. They fit into whatever opportunity is available in the market. To increase the yield the Bautama community stated that they are aiming for a good variety for tomato and also agronomic practices for pest and disease control. In future all the 3 communities are aiming for a more stable market. Also cooperative marketing will provide them better prices. The youths prefer to continue with farming as working in the farm helps them to get better income and freedom to make their own decisions in all 3 communities.

Understanding Value chain and relationship among players in the chain:

Value chain workshop was conducted for District Administrators of Central province, FPDA, NARI and PAU. 30 participants attended the workshop at PAU. 5 participants from FPDA, 2 participants from PAU, 8 participants from NARI and 15 participants from Central Province attended the workshop. The workshop resulted in understanding

- the expectations of the actors in the chain,
- the gap between the existing attributes for the produce and expected attributes for the produce
- the reason why the actors could not work together

In regards to what customers wanted from suppliers quality of the produce, regular supply and reasonable price were reported as expectations. In regards to what suppliers want from the customers feedback and better price for the produce were reported. Freshness and quality is regarded as the expected attributes of product by consumers. Price for the value of the produce, poor Quality and no Label (providing information to consumers) is largely practiced in the most commonly purchased markets. The 3 main factors that influence the actors working together are cultural factors, educational factors and lack of support. *Cultural factors (norms and values) like* the Wontok, Cultural variation, Attitude, Distrust, Land ownership. *Educational factors (knowledge, attitude, skill)* like Lack of vision, Education + awareness, Awareness and Training, Lack of information dissemination and networking, marketing knowledge, Leadership + coordination + Skills, Illiteracy, Fear of loss. *Facilities* like Rigid credit facilities, Lack of access to market, Poor transport infrastructure, Lack of Capital, Lack of finance and equipment resources

Identifying community capacities and problems in the marketing system through Need Analysis:

Horticultural roles in the value chain are often traditionally based on gender and therefore women or men may have rated a task as easy or difficult because they didn't have to do it, this should not imply that training should only reflect such gendered practices. Our results (Table 24) demonstrate that horticultural production activities like soil preparation and planting are undertaken by men and irrigation and crop management are undertaken by both men and women. This suggests that irrigation and crop-management techniques that might suit both genders need to be considered during gender-inclusive training. In regards to marketing activities, it was evident that harvesting is mostly done by women, whereas packaging and marketing are the responsibility of both men and women. Business activities, such as banking, bookkeeping and transport, are also undertaken by both women and men. While there are differences, especially between villages, the results confirm that both genders need to be considered in value-chain building, packaging techniques and business-management training.

7.9 Training Outcomes

These addressed Objective 3 using techniques described in items 5.1.4 and 5.1.4. On the basis of the training needs analysis reported in item 7.8, training workshops for women and men were conducted. Detailed reports of approach, presentation, content and outcomes are included in Appendix IV (Trip Reports) and Appendix V (Training Reports). Also, training manuals have been prepared and included in Appendix III (Publications). A perspective on the amount of training delivered during the project can be gained from

Table 25, which documents the training in which the principal local extension and training agency, FPDA participated, and Table 26 which lists farmer training and workshops and extension newsletters provided. The training is considered effective by participants and staff presenting it, however, there is a need to continue this work for it to be effective in continuing to support capacity building in rural communities in PNG. In addition to farmer training, staff training has been an integral part of the project, and includes attendance of workshops, conferences and specifically designed training visits to Tasmania. One project staff member has commenced PhD studies, while others have benefitted through mentoring by senior staff in PNG partner institutions and staff of TIA. Important to the scientific development of PNG scientists has been participation in publication of results in scientific conferences and journals. Training in GIS assessment of land capability was also included, and involved two training workshops. The latter of these in Lae was attended by staff of project partners and other institutions and businesses. These were well received, and post presentation surveys of the presentation and learning were positive. As a result of this training, there is a pool of trained staff who would fill essential roles in any project or business in which land capability assessment using GIS was needed.

Table 25. Training priorities of workshop participants separated by age into 'younger' and 'older' groups, by village

Workshop group	**Training priorities (where '1' is highest ranking)**		
Older women	*Bautama*	*Rigo-Koiari*	*Tapini*
	Crop management (1)	Bookkeeping (1)	Soil preparation, crop
	Banking (2)	Harvesting (2)	Marketing, Book Keeping (=2)
	Irrigation (3)	Soil preparation, crop	Banking (3)
	Planting (4)	Irrigation (4)	
		Marketing (5)	
		Packaging (6)	
Younger women	*Bautama*	*Rigo-Koiari*	*Tapini*
	Crop management (1)	Soil preparation, crop	Banking, Book Keeping (=1)
	Banking (2)	Bookkeeping (2)	Crop management (2)
	Planting, marketing (= 3)	Harvesting (3)	Communication with buyers (3)
		Packaging (4)	Soil Preparation (4)
		Banking (5)	Harvesting (5)
		Marketing (6)	
Older men	*Bautama*	*Rigo-Koiari & Sogeri*	*Tapini*
	Soil preparation (1)	Soil preparation (1)	B3 Transport (1)
	Bookkeeping (2)	Bookkeeping (2)	B2 Book keeping (2)
	Transport (3)	Transport (3)	H4 Crop Management (3)
	Crop management (4)	Crop management (4)	B1 Banking (4)
			H1 Soil Preparation (5)
			H3 Irrigation (6)
			M2 Packaging (7)
Younger men:	*Majority of participants were from Bautama*		*Tapini*
	Banking (1)		B3 Transport (1)
	Crop management (2)		H4 Crop Management (2)
	Bookkeeping (3)		H3 Irrigation (3)
	Transport (4)		M3 Marketing (4)
	Soil preparation (5)		M2 Packaging (5)
	Planting (6)		H1 Soil Preparation (6)

Table 26: Details of farmer trainings and workshops conducted and extension newsletters submitted during the project life.

Location	Date	No. of participants	Topics covered
NARI Laloki	14-18 May 2012	30 (all Females)	General to Post harvest
Rigo Koiari	August 2011	57 (15F, 42M)	Soil & Nursery preparation, field establishment, pest & disease, farm records & gross margin
Rigo Koiari	Oct/Nov 2011	56 (16F, 40M)	Financial literacy & gross margin
Laloki	Sept 2011	29 (6F, 23M)	Basics of vege production, farm records & gross margin
PAU	Sept 2011	30 (all females)	Identifying constraints to vegetable production
PAU	Feb 2011	All PC staff	Value Chain Management workshop
Koiloa (Tapini)	Aug 2010	40 (15F, 25M)	Basics on potato and broccoli production and PLB management
Aroma	August 2012	20	Vegetable production, financial literacy
PoM	June 2012	11	Crop husbandry & financial literacy
Tapini	Aug 2010	40	PLB management
Kerekadi	Nov 2012	24	Vegetable production
PAU	Sept 2012	24	Value chain & Training needs assessment
Tapini	March 2013	30	Value chain & training needs assessment
Fresh Produce Newsletter	March 2013		Tasmania trip document
	June 2013		Tapini training
	June 2013		Aroma trip, funded by Project
Various	Aug 2013	All males	General to Post harvest

Table 26. Training conducted for farmers and numbers trained from project communities; Rigo-Koirari, Bautama & Hiri (Tubuseria); Sogeri and Tapini-Goilala of Central Province.

Group	Date	Training location	No. of participants	Topics covered
1. Women of Rigo-Koiari, Bautama & Tubusereia	14-18 May 2012	NARI Laloki	30	Basic crop production, Post Harvest & Basic Financial Literacy
2. Men of Rigo-Koiari, Bautama, Sogeri, Tapini & Tubusereia	05-09th August 2013	NARI Laloki	28	Basic crop production, Post Harvest & Basic Financial Literacy
3. Women of Tapini	12-16th August	NARI Laloki	18	Basic crop production, Post Harvest & Basic Financial Literacy

8 Impacts

8.1 Scientific impacts – now and in 5 years

(i) Immediate impacts

This project was the first integrated and interdisciplinary study utilising a value chain approach to identification of research needs, and is, in many ways a model for future work of this nature in PNG. That is not to say improvements cannot be made, but that future change should aim to add value to the approach used. It integrated the collaborative problem solving methodology of Organic Research and Collaborative Development (ORCD) (Chambers and Spriggs (2009) with Appreciative Inquiry (AI) (Cooperrider, Whitney & Stavros 2003) and Rapid Supply Chain Appraisal (RSCA) described by Collins and Dunne (2008) into a new methodology, the Rapid Value Chain Research and Development Method. This provides for:

- Iterative visioning, planning, implementation and review;
- An affirmative, culturally appreciative and empowering;
- A focus on planning collaboration and coordinated implementation activity;
- Explicit capacity-building processes to develop participant and community knowledge of the value chain management process;

The utility of Rapid Value Chain Research and Development Method to identify community issues and training needs was clearly demonstrated and accepted by all project participants. The method provided a substantial body of knowledge on what is needed to improve vegetable chains in PNG, and follow up work during the project based on this resulted in further information that will be of use.

The project has provided more comprehensive soil description and analytical data than previously available, albeit for a limited number of sites and soil types, and much improved land resource assessment using advanced techniques, for a range of sites within the projects geographical area of activity. The approach reported and outcomes achieved provide guidance to and a model for future resource assessment activities. It would provide much improved information across the whole of PNG if applied either directly or with improvements, especially as remote sensing for land resource assessment improves. Nevertheless, there is a practical limit to the refinements needed and it is considered that the present techniques should be used in the foreseeable future.

Crop adaptation and identification of suitable cultivars is partially resolved – in a sense, this work is always needed, so a durable definitive outcome is not possible. Nevertheless, promising cultivars of several crops (tomatoes, sweet pepper, broccoli, French beans, carrots, English cabbage) have been identified. Not surprisingly, these differ among locations, and several questions remain unresolved eg the relative merit of local open pollinated cultivars and hybrid cultivars.

The production system trials are, in the early stages, and aside from setting them up and getting baseline data, long term impact cannot be assessed in a few years. However, those data which are available indicate that improvements to traditional (subsistence) systems of production by mulching, limited fertiliser application and use of drip irrigation will be beneficial to crop yield and quality, and moving to a highly intensive production system is not viable for individual smallholders, but could be for larger producers and cooperatives.

Crop production constraints, again unsurprisingly, were identified as water supply, nutrient supply and weeds, pests and diseases. Of particular importance was the failure of tomatoes at Sogeri, the progression of symptoms indicating severe phosphorus

deficiency. Soil analytical data supported this conclusion and indicate the need for substantial phosphorus input if tomatoes are to be grown successfully in the Ferrosol soils of the Sogeri plateau. This is no different from other areas where tomatoes are grown in soils with high P fixation capacity. Also, though not a treatment in the experiments, timing of planting and maturity in relation to market needs is clearly an important consideration.

All information and findings are available for wider use, there being a deliberate policy of project partners to publish findings and make them freely available in PNG and elsewhere.

(ii) Impacts in 5 years

The longevity of impacts depends on there being staff and operational budgets in place to support ongoing extension of existing findings and further research, and the information and data being freely available. Clearly, then, strategies for establishing sustainability of impacts (and change) is needed, and could involve both PNG and International professionals being involved in program/s to ensure the project's scientific legacy. This matter will be addressed in the Conclusions and Recommendations section.

8.2 Capacity impacts – now and in 5 years

There have been considerable impacts on the capacity of staff of lead and partner agencies, and community members (villagers and others who participated in any aspect of the research, training and extension activities). Some of the capacity enhancement has been assessed through post-evaluation surveys, but much of it could only be assessed experientially and anecdotally. Further assessment beyond the life of the project could be beneficial, provided appropriate tools, timing and funding were available. However, the key message is that the capacity impacts will best be sustained as a project legacy by future activities (research, training and extension) that enhance capacity improvement achieved to date and spread them further within partner institutions and the communities that benefited from the project and other communities. It would be appropriate to consider further investment, involving an 'engagement' model, to enhance the development of independence of participants. Comments are provided under specific capacity impacts that have been identified by the TIA team in consultation with PNG partners.

(i) Scientific capacity of staff involved

Scientific capacity incorporates a number of dimensions, including knowledge expansion, methodological knowledge, publication capacity/experience, co-learning by PNG and Australian participants, presentation skills, and the development of sound cross institutional relationships.

The project team recognises that capacity impacts have occurred in staff of PNG partner organisations and TIA, hence co-learning by PNG and Australian participants in the project. Further comment will be provided on this dimension later. Very importantly, positive cross institutional relationships and collaboration were much enhanced by the project.

PNG staff have experienced substantial expansion in their knowledge through project activities within PNG and from studies and travel outside PNG. Knowledge expansion has arisen from reading and skills development associated with project implementation, mentoring by TIA staff, training courses and from effective cross institutional arrangements that developed during the project. A particularly important aspect of knowledge expansion is the gaining of methodological knowledge in value chain analysis, biophysical and agronomic research and socio-economic research. While not all staff participated to the same level in all of these, most, if not all, were exposed to each of them and gained from the experience. Staff who participated predominantly in one area eg agronomic research or socio-economic research developed depth to their discipline knowledge and methodologies used in them, whether for research or training and training evaluation.

Especially gratifying is the award of a John Allwright Fellowship to one project staff member, Mr Japhet Nivi, to undertake PhD studies – this will have long term positive effects within PAU (his employer) and to agricultural research and education in PNG.

Travel outside PNG includes training courses in Thailand (31st International Vegetable Training Course, September- October 2011), Vanuatu (Capacity building for youths in the Pacific, TOT Training Workshop on Organic Vegetable Production, June 2013) , and attendance of the Australian and New Zealand Soils Conference, December 2012), and the International Horticultural Congress, Brisbane, August 2014, and approved attendance of the Australian Agronomy Conference, Hobart, September 2015. These conferences provided project staff with opportunities for networking, and to develop publication and presentation skills. Specific short term training in value chain analysis and vegetable crop agronomy was also undertaken by several project staff, this involving 2 weeks of study and field visits in Tasmania. Marketing training was also provided to FPDA staff who visited Brisbane Markets. These activities have provided some basic to advanced training, and form a sound basis for future staff development.

Co-learning by PNG and Australian staff has equipped the team with real understanding of research strategies and substantial awareness of local cultural mores and practices that influence how research is approached and implemented, and its ultimate adoption by producers in PNG. The latter was particularly important to the Australian members of the team and will benefit any future projects undertaken by any of them in PNG, as they will have the cultural awareness as well as scientific capacity to implement projects more effectively. Partnering implied by co-learning is also fundamental to publication of findings, in which staff of PNG partner institutions gain confidence in writing and increasing seniority on publications, while Australian scientists take on more of a mentoring role, especially of early career researchers. This is seen by the project team as a major scientific impact that should be nurtured and enhanced.

(ii) Capacity in Communication of Findings

In addition to writing scientific (journal and conference) publications, communication of findings through extension and training activities, the media (eg newspapers) and by oral presentation has been an integral part of the project, and contributed to its positive outcomes. Confidence in oral presentation has clearly developed, and has been particularly evident in project meetings, including the mid project review. There has also been considerably increased capacity to independently run workshops (some of these being research oriented), using communication (and analytical) skills acquired during the project.

(iii) Capacity in the Wider Community

Possibly the most important impact in what might be termed community capacity relates to skills training for both men and women farmers (and their sons and daughters) in production, management and business, post-harvest techniques and marketing. Similarly, learning at field days and the project Showcase (March 2012) add to knowledge and confidence. There was also incidental training, principally of project support and technical staff, who participated in gained learning informally during project implementation.

Impact in 5 years

Comments in the previous section (Scientific Impacts) are reiterated, and could include, as parts of a strategy to continue to enhance capacity, in-service and higher degree training, ongoing mentoring in publication and research methodology through strategically aligned projects. These approaches should lead to embedding of skills and capacity in institutions and their staff, leading to a goal and achievement oriented culture. Further, the substantial amount of data collected and publications arising from the project will provide a rich source of information for inclusion of educational programs in Universities, agricultural colleges and high schools, and would extend the impacts well into the future.

8.3 Community impacts – now and in 5 years

Some community impacts have already been identified, especially in the section on Capacity Impacts (previous item). However, others that have been identified over the course of the project are now outlined. Extension and training has provided enhanced knowledge and understanding to both individuals and groups/villages. Longevity of these impacts will depend on the leaders who have emerged and those who have undertaken 'train-the-trainer' workshops continuing to implement the changes. Motivation during the project has been strong, giving confidence of ongoing activities, especially at village level. Learning by farmers and villagers who have been involved in both the value chain and production aspects of the project has been significant, reflecting a very positive attitude held by them. However, the project team is aware of the changing population in many of the villages, and it is therefore difficult to predict the long term longevity of this learning within villages, or whether it will be transferred to other villages as people move from one to another. The availability of a low cost hydraulic pump and low cost irrigation system is expected to enhance production by reducing labour requirements and thus relieving people from the time consuming, laborious repetitive task of carrying water and hand watering.

Improved relationships between producers and retailers (and others) have also emerged, especially with increased community understanding of 'the way the system works' ie role of the various participants in the value chain. An example is the Rigo-Koiari villagers and others selling produce by engaging with PAU or CPL, rather than each approaching the market individually, one of a number of beneficial changes arising from the women's workshops. In addition to improved commercial relationships, those between individual farmers and NARI and FPDA have been improved and new ones established. This eases barriers of exchanging ideas and knowledge and problems faced by farmers in producing vegetables.

Possibly the single most important impact is on community confidence – assertions like ***'we can do this, but need the Government needs to help'***, by which the villagers are referring to the need for infrastructure such as roads, stores, and provision of advisory services.

Predicting the impact in 5 years' time is fraught, because of the many social and economic forces that will impact on communities over the period. Nevertheless, the knowledge held by both individuals and the communities should be relatively durable, though changes in village populations may dilute it. The most important agents of durability and longevity will be the district advisory staff, consequently institutional support of them is vital, and dependent on decisions made at higher organisational levels. Specifically, a district advisor is needed in Tapini, something that has been articulated by the villages there.

8.3.1 Economic impacts

Economic impacts have been limited to date, but findings of the project in relation to production and value chain understanding and activities provide the basis of enhancement of economic outcomes for communities involved and in the longer term other communities. Nevertheless, it is important to recognise that the changes to populations of the villages and also the availability or otherwise of advisory staff will impact on the motivation for and implementation of change, and hence the extent of economic impact will depend on these factors. Strong motivation will improve economic wellbeing of communities, but if motivation lapses, regression and reduction of economic benefit is inevitable. Improved financial and banking management by farmers and cooperatives has also been evident, particularly through the training workshops.

Quantification of economic impact at district or industry scale not realistic from the limited data available, but can be done at village scale, subject to the caveats above. The project has been able to quantify, and thus lead to enhanced understanding of costs of production and the relative importance of labour and other inputs. This is particularly important to

villagers and cooperatives, and a strong basis for price setting. A further finding is that unit prices for products are high relative to those in countries from which imports could be (and are being made), putting small holder producers at a competitive disadvantage with importers and local large producers eg the new hydroponics facility at the 9 Mile and the hydroponics facility at Sogeri.

Predicting the impact in 5 years' time is fraught, in much the same way as in the Community Impacts above, because of the many social and economic forces that will impact on economic activities in the communities over the period. However, it is clear that increased competition is inevitable. The new hydroponics facility which is expected to be very efficient could well be the first of several delivering high volumes of almost certainly lower priced high quality product to the market. Consequently, a different model of small holder production may need to emerge to accommodate price pressures likely to emerge. It would be expected that this would be a cooperative model to gain scale, as explored in this project, hence the work done here will be invaluable in supporting small holders through the challenge that appears inevitable. Increased production, improved farming practices and consistent production will provide evidence to policy makers and relevant governing bodies to support cases for improved rural infrastructure. Tis would then support production, transport and marketing, and basic community services and infrastructure as already evident in some parts of PNG that have benefitted from development investment.

8.3.2 Social impacts

Social impacts occur at various levels, and some have already been mentioned in 8.3.1 and 8.3.2, and will not be repeated here. Two major impacts have involved small holder women, who have returned to their villages after training workshops to take the lead in developing collaborative production enterprises, and the connection of men to the women's production activities in Rigo-Koiari, in a way described in World Bank (2012b). This project's strategy and activities were aligned to the processes and emerging trends identified in World Bank (2012b), and thus is timely in providing a model for future projects that include social dimensions related to women's place in industry and economic activities associated with value chains from farm to end user/consumer. Interestingly, World Bank (2012b) indicate that men are becoming increasingly supportive of women's involvement, while recognising that traditional gender roles remain a strong social norm.

Community engagement in and by the project has enhanced peoples' willingness to share, and to make the effort to access information and work together. Enthusiasm and desire to stay engaged in this and related projects (eg ASEM/2010/052 – Women's Business Acumen) are evidence of immediate impact that is expected to persist. Further, motivation of community members eg Rigo-Koiari has been evident, partly as a result of project participation and partly because of provision of machines (tractor, implements) by other programs. Effective working relationships across research projects (eg ACIAR) and development (eg AusAid, PNG Government initiatives) will lead to more rapid progress and adoption of new practices, assuming community engagement and 'community ownership' are central themes that produce clearly evident and attractive outcomes and benefits for communities. The higher level of awareness of potential for production and economic activities in rural communities, and especially small holders in the project, others who attended field days and training means that future intentions and expectations have been enhanced. While it is not possible to reliably quantify the impacts in the short term, anecdotal evidence is uniformly positive, and impact should be formally assessed several years after the project's completion. Also, favourable press treatment in the PNG Press eg The National and National Broadcasting Commission and by Radio Australia Pacific Beat provides evidence of immediate beneficial impact extending beyond the project area.

In the longer term, though, strategies to sustain the impacts are needed. Some impact is likely to remain, regardless of future interventions. However, initiative that support and

sustain community learning through, for instance, expanded extension programs to support adoption of project findings would appear appropriate.

8.3.3 Environmental impacts

The project encouraged adoption of soil and water management practices that optimise and sustain vegetable production in lowland areas with lower soil erosion and land resource degradation risk than nearby elevated areas. While moving production from drought-prone peri urban hill slopes to alluvial valleys with substantial water supplies for irrigation is critical to longer term food security for Port Moresby, the short time frame means there has been no relocation of production, and may not be in the foreseeable future for socio-cultural reasons, especially those associated with land tenure. Assessment of land resources in Central Province has identified areas beyond the Laloki area where sustainable production could be expanded, and provide a better platform for ongoing development, but more remains to be done. Low input fertiliser programs and mulching will help sustain surface and ground water quality in the long term. Baseline data on resource quality has been collected for a small proportion of Central Province, though the approach used will be relevant to future projects and land management. However, because of the 4 year timeframe and the tiny fraction of land involved in the project, measurement of environmental changes was not appropriate. Nevertheless, as production increases and projects covering a larger proportion of the landscape or even single valleys regular analysis of soils and water could be justified, but the intensity of sampling to detect small changes may lead to prohibitive cost.

8.4 Communication and dissemination activities

Communication and dissemination of results has been a priority of the project team, as it was recognised very early in the project that scientific outputs and outcomes should be delivered to the scientific and policy communities involved in agriculture and agricultural development in PNG, and that local farmers and communities should also receive data and information in a form that was accessible to them in a timely manner. The project has also benefitted from uniformly positive media coverage that has provided additional pathways of delivering findings to communities. However, one of the challenges has been to deliver information to low literacy groups – this has been achieved by use of pictorial representation and presentation in both English and Tok-Pisin languages. Favourable press treatment was received in both PNG (Press and NBC, PNG) and from Australia (Radio Australia Pacific Beat). Full details of publication and dissemination in written form is listed in Section 10.2 below, and a compendium of publications (in all forms) is provided as Appendix III. In addition to written dissemination, a number of oral presentations have been made to groups eg Project Showcase, March 2012, and in training activities eg Rigo-Kioari Womens Training, Mens Training.

In summary, communication and dissemination have been:

- Publication in scholarly journals
- Publication in and delivery at PNG, Australian and International conferences and workshops
- Press coverage in newspapers, and by radio and television in PNG and Australia
- Brochures and posters in English and Tok Pisin on crops selected in the project
- Training workshops
- Field days (formal and impromptu)
- Extension to farmers by project and Central Province Administration staff
- Promotion of project to other agencies
- NARI Policy Workshop in Port Moresby, May 2014

The volume of output has been substantial, and will provide a valuable resource for future reference.

9 Conclusions and recommendations

9.1 Conclusions

1. The project has provided improved data on resources, crop adaptation and substantial understanding of value chain function and socio-cultural influences on economic activity, and importantly a model for further similar work.
2. Future vegetable production systems that are culturally and economically appropriate in PNG, and which can be accommodated within resource constraints, are likely to incorporate irrigation, mulching and limited fertiliser inputs, intensified systems being unaffordable by smallholders, at least for the foreseeable future.
3. Co-learning by Australian and PNG partners, PNG farmers and others associated with the project was a major benefit.
4. There is a level of change in communities (people moving in and out) that can lead to enthusiasm and motivation or loss of capacity and competence, depending on highly dynamic socio-economic and socio-cultural factors.
5. Further research is needed in assessment of biophysical resources and agronomic practice, especially important being land resource surveys, quantification of land suitable for agriculture, and systems that would confer agricultural sustainability.
6. Social contextual research remains fundamental to understanding community aspirations and responses to change and opportunity.
7. Capacity building has been a major impact on those concerned. A strategy to enhance improvements in capacity and to extend it to other staff of partner institutions, businesses and farmers is required for long term improvements.
8. Resourcing, support and mentoring of scientific staff in research, publication and attainment of higher qualifications is imperative to ongoing capacity building, as there is a major shortage of professionals serving agriculture.
9. Confidence of producers needs supporting and developing through focused, just-in-time training, to contribute to value chain development and continuity of supply.
10. Smallholders are skilled in growing crops, and embrace suggested changes to production practices enthusiastically, however, market access, inadequate infrastructure (cooling, transport, roads) and lack of or inadequate support services (e.g. agricultural advisers) remain major concerns. There is an expectation that Government will act to improve these areas of the value chain, using suitable, effective, low cost, co-investment options in International Development literature.
11. Registered land-owner cooperatives are essential for coordinated marketing.
12. Impact of high-efficiency, large-scale production e.g. hydroponics enterprises such as Sogeri hydroponics, Port Moresby Hydroponics needs to be assessed
13. The development of sustainable cool temperate vegetable value chains from Tapini in Goilala District is feasible.
14. Use of GIS can rapidly assess land capability and identify areas for production expansion and industry development.
15. Community skills are necessary to govern business arrangements and resolve personal disputes. In particular, understanding cooperative constitutions and operating them accordingly, leadership, negotiation and conflict resolution are critical.

16. Permanent Government officers are necessary in isolated areas to administer the District and support development projects.
17. Central Province appears to have cultural differences, meaning social relationships are more dynamic and need to be considered during project design, with PNG partners having as many Central Province personnel as possible on the team.

9.2 Recommendations

1. That a sustainable program of research and development activities be developed for Central Province to sustain project outcomes and expand their applicability.
2. That future research projects link with cognate projects for value and effectives.
3. That additional resources be provided for land evaluation using and soil survey work to expand on findings here in land resource assessment
4. That new projects (as part of a program of research (ACIAR) and development activities (eg AusAid, NZAid, Governments in PNG) be conducted, and include:

   a. ***Research activities in Central Province including****:*
   i. Socio–cultural research be continued and expanded to other areas and activities eg cooperative leadership, conflict resolution;
   ii. Production systems trial/s be retained and operated as long term soil and water management and crop evaluation (eg high value crops) research site/s;
   iii. Land resource assessment (soil survey, GIS) over additional areas, collate and digitise soil resource data base;
   iv. Seed Systems – comparing open pollinated and hybrid cultivars, seed production;
   v. Pest management – IPM, cool storage;
   vi. Participatory Action Research and demonstration in production technologies
   vii. Economic and extension research be embedded in each of (1) to (v)i.

   b. ***Based on objective analysis, development activities be supported in***:
   i. Value chain function, finance, agribusiness performance and training
   ii. Road and other infrastructure construction to access markets
   iii. Post-harvest packaging, handling and cool chain facilities;
   iv. Marketing infrastructure
   v. Extension, Education and Training be supported in:
      a) Improving qualifications of PNG staff at various educational levels;
      b) Extension, education and training on crop production, soil and land resource management for production and sustainability, value chains, economic and business performance and socio-cultural developments, agribusiness and innovation be enhanced based on findings of this project and included in curricula at various levels of education;
      c) Research training be included in educational programs of PNG institutions as appropriate for the level concerned;
      d) Specific extension and training/mentoring activities be identified and implemented to meet local community needs.
5. As transition arrangement to support ongoing impact of the project be supported by 1 or 2 visits/yr funded by ACIAR over the ensuing 2-5 years by 1 or 2 project team members to undertake mentoring and support of PNG staff. A post – project impact assessment to be included 3 years after project completion.
6. Permanently station Government Officers in districts for good governance.
7. Governance training to ensure cooperatives are properly managed should be a priority in market development projects.
8. Government support for cooperative functioning is recommended.

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10.2 List of publications produced by project

,Please note: Manuscripts that have been submitted are included for completeness and noted as ‘In Review’.

Scholarly Journals

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Promising vegetables for Central Province

Celebrating the contribution of PNG agricultural researchers

SRC feature vegetable farming in Mini field day at Laloki

More training needed for efficient vegetable production

Researchers remembered

Women today – farmers improve crop management

Central women learn farm management

AVRDC seed on trial in Papua New Guinea
Promising vegetables for Central Province

Seta-Waken, P. NARI Toktok Series (in draft form, should be released by December 2015)

1. Basic tomato production guide
2. Common tomato pests & disease and how to control them
3. Basic capsicum production guide
4. Common capsicum pests & disease and how to control them
5. Basic French bean production guide
6. Common French bean pests & disease and how to control them
7. Basic carrot production guide
8. Common carrot pests & disease and how to control them
9. Basic cabbage production guide
10. Common cabbage pests & disease and how to control them
11. Basic broccoli production guide
12. Common broccoli pests & disease and how to control them

Pamphlets and Extension Material

Pamphlets and TokTok Series for Mini field day

Capsicum
Tomato
Egg Plant
Yard Long Bean (Snake Bean)
Pak Choi
Steps in extracting and saving crop seed

Producing and saving vegetable seed for sustainable production and improved livelihoods

Egg Plant
Yard Long Bean (Snake Bean)
Okra
Soybean

Introduction to Basic Crop Management Techniques

11 Appendices

Below is a list of appendices which are supplied separately from this report.

(i) Detail of crop cultivar and agricultural systems trials

(ii) (A) Detailed data on trials at Laloki, Tapini and Sogeri (experimental data) and (B) Labour and economic analysis of vegetable production

(iii) Publications

(iv) Trip Reports

(v) Training Reports

(vi) Value Chain Study, Broccoli, Tasmania

(vii) Detailed soils report - Soil Resources in Central Province, PNG - Report to ACIAR

(viii) Land Use Capability Report