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2 Executive summary

The development of an agri-food processing sector has the potential to speed up the process of rural development and industrialisation of an economy. Given that sweetpotato is the main staple crop in PNG and is grown by smallholder farmers across the country, the socio-economic impact on rural communities could be significant if an efficient sweetpotato processing sector can be established. The impact could be even greater when the associated technology spills over to other root and tuber crops (e.g. cassava, yam, taro, etc). The objectives of this study were to identify market diversification and processing opportunities for sweetpotato in PNG, and to make recommendations for a way forward.

In PNG, approximately 60% of sweetpotato is used for human consumption and 40% is used as pig feed. Almost none has been used for food processing, even for domestic consumption. Some attempt to promote food processing, especially through the Food Preservation and Processing Unit, from the early 1980s to late 2000s failed because of the lack of resources and support services for research, development and extension. The R&D capacity has improved in recent years due to capacity building and the purchase of processing equipment as a result of several externally funded projects. While previous processing research focused on product development, more recent work focuses on flour production.

The main finding is that although sweetpotato has many potential end uses, worldwide sweetpotato is used mainly in fresh form for human consumption and as stockfeed. A very small proportion (less than 1%) is processed into dried chips and flour mainly for home consumption. China is an exception where about 15% of total sweetpotato production is processed into starch/noodles and snack foods commercially and on an industrial scale. This is because sweetpotato, as a raw material for commercial food processing, is not as versatile functionally, and is not cost competitive with wheat and corn (for flour production), potato (for fries/chips production), and cassava (for starch production).

The main conclusion is that given current environment and levels of support and knowledge, promoting sweetpotato processing into commercial enterprises would be very difficult. Limited research resources may be better spent on improving the markets for fresh roots and for feedstock. However, if the PNG government is serious about developing a food processing industry, as indicated in the National Agricultural Development Plan 2007-2016 and the 2014 Budget White Paper, further research into sweetpotato flour processing, and related product development, can be used as pilot both to build capacity and to provide an opportunity to learn whether and how efficient food processing might be developed in PNG. If this is the case, flour processing will be the most promising food processing option for sweetpotato both for cottage and industrial uses. Furthermore, to develop an efficient sweetpotato processing sector, it will take time, it will require local ownership and it will need strong government support and international collaboration to build local capacity. And it must start small.

Main recommendations are:

1. That future processing research for sweetpotato focus on improving flour quality and processing efficiency.
2. That future processing research for sweetpotato focus on developing niche products from sweetpotato flour and local materials.
3. That processing research focus on adaption research and extension.
4. That a systems approach and interdisciplinary research program be considered to improve overall competitiveness of sweetpotato.
5. That stakeholders in the sweetpotato value chain lobby for government support in research, development and extension programs for food processing.

3 Introduction

Sweetpotato is the most important crop in Papua New Guinea, accounting for 43% of all food energy intakes. It is grown throughout the country, but production is highest in the highlands, where 75% of the crop is produced (Bourke and Vlassak, 2004). About 60 to 75% of highland sweetpotato is used for household consumption and 25 to 40% is used as pig feed.

As the major staple food crop, the national average consumption of sweetpotato is 260 kg/person/year. However, there are regional differences. The annual per capita consumption of sweetpotato in rural areas is 299 kg, whereas in urban centres it is 42 kg/person/year (Gibson, 2001a). By comparison, rice consumption is 66 kg/person/year in urban centres and 24 kg/person/year in rural areas, with a national average of 31 kg/person/year. Transport issues and availability of other staple foods (e.g., rice, bananas, taro, sago, yam, cassava), as well as socio-demographic differences, were thought to have contributed to the different consumption patterns for sweetpotato and rice (Gibson, 2001b).

These consumption patterns present opportunities for, and threats to, the long-term prospects of the sweetpotato sector and the many smallholder farmers who rely on it for their livelihood. On the one hand, the demand for starchy staple foods, such as sweetpotato, tends to decline as income increases and with urbanisation. On the other hand, economic development also tends to increase the demand for processed products and animal products for which sweetpotato is a potential input. In China, for example, over the past few decades sweetpotato has changed from being a main staple food in the 1950s (with nearly 60% of total production) to being used mainly as an input in pig feed (nearly 70%) and for starch/noodle/snack food manufacturing (nearly 15%) by the 1990s (Huang et al., 2004).

The objective of this project is to identify market diversification and processing opportunities for sweetpotato in PNG. It supports the PNG government policy to develop a food processing and preservation industry, as stated in the National Agricultural Development Plan 2007-2016. It is also consistent with the PNG National Food Security Policy 2000-2015 of improving food security in PNG by “improving production, downstream processing, marketing and utilisation of food”.

To achieve the project objective, we conducted an extensive literature review of sweetpotato processing research conducted in PNG, as well as in China and Africa where such research was most extensive, to learn from this vast amount of literature (that is available online free of charge) and their implications for PNG. Technical trials were conducted on-station to assess the processing cost and quality of sweetpotato flour, while sweetpotato products were developed out-station in collaboration with industry partners and community groups. We also conducted social mapping of collaborating communities to track the dissemination of sweetpotato processing technology and to assess the community impact of the project. In the following sections, we first present an overview of sweetpotato production and utilisation worldwide, and then the results and lessons learned from the literature review. This is followed by results of on-station technical trials of flour production and out-station product development. The report concludes with recommendations for a way forward and areas for further research.

4 Sweetpotato production

Sweetpotato as a food crop has several advantages. It requires fewer purchased inputs and less labour than other staple crops (wheat, rice, maize or cassava). It can adapt to a wide range of agro-climatic conditions, including marginal areas, dry periods and poor soil. It provides more edible energy per hectare than wheat, rice, maize or cassava. It has a reputation as a food security crop – the one that a family relies on when the maize or rice fails. In recent times, these attributes make it particularly suitable as a crop for households threatened by climate change, migration, civil disorder or diseases such as AIDS (CIP, n.d.). In addition, the ability of sweetpotato to establish ground cover very quickly enables suppression of weeds, control of soil erosion and maintenance of soil fertility (GTZ, 1998).

According to FAO, 115 countries produced close to 107 million tonnes (Mt) of sweetpotato in 2010 (Table 1). The production is concentrated is Asia (82.3% of global production) and in Africa (14%).

Table 1: World production of sweet potatoes (in Mt)

	2006	2007	2008	2009	2010
Total World	**106,641,705**	**100,943,340**	**104,578,294**	**102,323,748**	**106,569,572**
Asia, including:	**88,430,581**	**83,124,117**	**85,702,879**	**84,182,639**	**88,511,139**
China	81,039,000	75,600,000	78,830,000	76,772,593	81,175,660
Indonesia	1,854,238	1,886,852	1,876,944	2,057,913	2,050,810
Vietnam	1,460,900	1,437,600	1,325,600	1,207,600	1,317,060
India	1,066,500	1,067,200	1,094,000	1,119,700	1,094,700
Japan	988,900	968,400	1,011,000	1,026,000	863,600
Philippines	566,773	573,734	572,655	560,516	541,525
Africa, including	**14,712,718**	**14,098,182**	**15,275,678**	**14,353,091**	**14,213,680**
Uganda	2,628,000	2,602,000	2,707,000	2,766,000	2,838,800
Nigeria	3,462,000	2,432,000	3,318,000	2,746,817	2,838,000
Tanzania	1,396,400	1,322,000	1,379,000	1,381,120	1,400,000
Angola	684,756	949,104	819,772	982,588	986,563
Kenya	724,646	811,531	894,781	930,784	383,590
Madagascar	869,000	890,000	941,355	910,857	919,127
Mozambique	929,826	875,216	890,000	900,000	920,000
Rwanda	777,034	841,000	826,000	801,376	840,072
Ethiopia	388,814	388,814	526,487	450,763	401,600
Latin America, including:	**1,961,714**	**2,104,017**	**2,057,497**	**2,162,830**	**1,966,398**
Brazil	518,541	529,531	548,438	477,475	479,200
Cuba	303,000	414,000	375,000	437,000	384,700
North America, including:	**744,046**	**819,741**	**836,662**	**883,207**	**1,081,720**
United States	743,937	819,641	836,560	883,099	1,081,590
Oceania, including:	**719,410**	**763,716**	**641,861**	**680,177**	**742,554**

Papua New Guinea[1]	560,000	580,000	485,181	534,085	576,000

Source: UNCTAD, 2012. http://www.unctad.info/en/Infocomm/AACP-Products/COMMODITY-PROFILE---Sweet-potato/.

China is the world's largest sweetpotato producer, with 76.2% (81 Mt) of global production. This is followed by Uganda (2.84 Mt), Nigeria (2.84 Mt), Tanzania (1.4 Mt) Indonesia (2.05 Mt) and Vietnam (1.32 Mt). Together, Uganda, Nigeria and Tanzania represent half of the African production. Contrary to the declining trends observed in Asia in recent decades due to economic growth, sweetpotato production has increased in some African countries. The most significant increase occurs in Uganda, from around 2 Mt in 1999 to 2.83 Mt in 2010. This expansion in production in Africa was explained largely by an increased demand linked to a strong population growth (UNCTAD, 2012).

Latin America is a minor player in the global sweetpotato production, producing 1.97 Mt in 2010 (2% of global supply). Brazil, Cuba and Argentina are major producers. The United States produces relatively little (around 1.0 Mt in 2010) but production is increasing, linked to increased awareness of the health benefits associated with its use, particularly its low GI, high fibre and low fat. The United States is the leading global exporter, mainly to Europe. In Europe, only Spain, Portugal and Italy produce sweetpotato but quantities are small on a global scale.

[1] *These figures are much lower than the 3 Mt estimated by Bourke and Vlassak (2004).*

5 Sweetpotato utilisation

Sweetpotato has many potential uses. Main sweetpotato processing options are: starch, dried chips/flour, stockfeed, and new food products (Fuglie et al. 2006).

Changes in sweetpotato utilisation in developing countries from the 1960s to 2009 are presented in Table 2. It shows that sweetpotato use in fresh form declined from 77.6% of total production in the early 1960s to 52.4% in the late 1980s. The trend is reversed for sweetpotato used as feed, which increased from 11.7% of total production in the early 1960s to 36.1% in the late 1980s. By comparison, there was little change in sweetpotato used for processing into new food products, from 4.5% to 5.4% over the same period.

Table 2. SP utilisation in developing countries[2]

	1961-63	1973-75	1986-88	2009*	
				1000 Mt	%
Food	77.6	70.2	52.4	55,380	54.2
Feed	11.7	19.0	36.1	39,790	39.0
Processing	4.5	4.8	5.4	42[3]	0.04
Seed/replanting	0.3	0.2	0.2	294	0.3
Waste/others	5.9	5.8	5.8	6,637	6.5
Total	100	100	100	102,143	100

Source: Scott, 1991, except for 2009 (calculated by authors using FAOSTAT database)

Two decades later in 2009, the proportions of sweetpotato used for food, feed, processing were 54.2, 39.0 and 0.04%, respectively (Table 2, last two columns). Clearly, the most significant change in 2009 is the reduction in the proportion used in processing. This could be a result of sweetpotato losing competitiveness as a raw material for starch production, especially in China, as alluded to in Fuglie et al. (2006)

5.1 Sweetpotato as a staple food

Sweetpotato is the seventh most important food crop in the world, after maize, rice, wheat, potato, cassava and barley. This means it is normally not consumed as a main staple, with few exceptions such as Papua New Guinea (260kg/person/year) and Solomon Islands (180kg/person/year) (Table 3, in Appendix 1). Other major consumers of sweetpotato are: Rwanda (73kg/person/year), Burundi (89kg/person/year), and Uganda (73kg/person/year) (Table 4, in Appendix 2). Although not shown in Table 3 or 4, southern China, West Papua in Irian Jaya, the central coast of Vietnam, and northern islands of the Philippines also consume sweetpotato as the main staple (Prain, n.d.).

FAO Statistics shows that the use of cereals (wheat, rice, barley, maize, rye, oats, millet, and sorghum) and starchy roots (cassava, potato, sweetpotato, yam, eating banana, taro, and sago) as staple food varies widely between regions and between countries within the region because of differences in agro-climatic conditions and the stage of economic development. Data in 2009 indicate that the world average per capita consumption of cereals is 146.7kg

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[2] *Huang et al. (2004) pointed out that these figures, estimates at best, should be used and interpreted with caution as reliable data are hard to collect because of the involvement of smallholder farmers whose production is often unreported. The concentration of sweetpotato production (75-85% of world production) in China could also distort the overall picture.*

[3] *Based on FAO statistics, this 42 Mt was used in China mainly for starch production. No processing use was reported in other countries.*

per year, with wheat (66kg), rice (53.3kg) and maize (17.1kg) being the top three cereal crops (see Table 4, column 1, top half). The world average per capita consumption of starchy roots is 61.1kg per year, with potato (32.6kg), cassava (14.3kg) and sweetpotato (8.3kg) being the top three root crops (see Table 4, column 1, bottom half).

For subsistence economies in the developing countries, the consumption pattern is determined largely by agro-climatic conditions, as in the Solomon Islands (French, 2011). The minimum requirements for growing are as follows:
1. Sweetpotato must have a well-drained soil.
2. Swamp taro grows in swamps, while Colocasia taro can grow in damp soil, Xanthosoma taro needs dry soil and Giant taro is often grown in pits in coral atolls. Another taro, called Elephant foot yam, suits seasonally dry areas.
3. Yams are usually grown in places with a long dry season. Greater yam takes six months to grow and can be stored for six months. Lesser yam takes longer to grow and can be stored for a shorter time. Potato yam often grows near the edge of the rainforest.
4. Cassava can grow in poor soils and is easy to grow, more so than sweetpotato.
5. Bananas are usually more important in areas with a dry season.
6. Solomon's sago needs a slightly drier location than sago that suckers.
7. Rice is a popular food, but it is much better suited to a monsoon climate.

In the PNG highlands, sweetpotato is the main staple crop because it can be grown all year round (Bourke and Harwood, 2009, p.141). In the lowlands of PNG, sweetpotato is consumed along with rice, banana, cassava, yam, taro and sago. Similarly, in Sub-Saharan Africa (SSA), in countries with two rainy seasons (e.g. Rwanda, Burundi and Uganda) sweetpotato is available 11 months of the year and is a primary staple. Elsewhere in SSA, where there is only one main growing season, sweetpotato is available 4-8 months of the year and is a secondary staple (e.g. Guinea, Seirra Leone and Liberia) (Low et al., 2009).

As an economy develops, agriculture becomes more market-oriented. In more advanced economies, food consumption is largely determined by economic factors, such as income, relative prices, and quality/nutrition, and socio-demographic factors, such as age, gender, location (rural vs urban), occupation, ethnicity, prestige, etc. However, in general terms, as income rises, there is a tendency for food consumption to move away starchy roots and towards cereals, and within cereals and within starchy roots, there is a move towards more nutritious, more versatile and better tasting choices (Scott et al., 2000).

There are also tendencies towards diversity and more convenient and easy-to-prepare products. That is, rather than consuming a vast amount of cereals or starchy roots, a more diverse and balanced diet may consist of a variety of cereals (rice, wheat, oats) and starchy roots (potato, sweetpotato, taro, cooking banana, etc), as well as animal protein, vegetables and fruit. There is no doubt that as an economy develops, the demand for convenient and therefore more processed products increases. This is evident by the consumption patterns observed in developed countries both in the West (e.g. Australia, New Zealand and USA) (see Table 4), and in the East (Japan[4], Korea, Taiwan, Hong Kong, Singapore), where diets are much more diverse and made up of processed and pre-prepared products that are more convenient to use.

Another factor that influences the choice of staple food is quality and nutritional value. Nutritional content (energy, protein, fat, carbohydrates, fibre, sugar, vitamins, minerals, and

[4] Sweetpotato was a significant food item in Japan and Taiwan in the 1940s and 1950s, and it was associated with poverty (coined as a "poor man's food") and harsh wartime conditions (Bourke, n.d.). Consumption has declined along with industrialisation to become negligible in recent decades. China is following a similar trend.

other minor elements) of key cereal and root crops (on a fresh weight basis) are shown in Table 5 (in Appendix 3). As can be seen, cereal crops are high in protein, led by wheat, soybean and sorghum (> 10%) followed by rice (7.1%) and maize (3.2%). Root crops are low in protein, with potato (2.0%), cassava (1.4%), sweetpotato (1.6%), yam (0.17%), and plantain (1.3%). Cereal crops, (except maize and soybean) are also high in carbohydrates (> 70%), compared with root crops (17-38%). Crops with high dry matter (low moisture) content have an advantage in processing as they produce higher yields, which result in lower processing cost, as well as being easier to store and transport.

Sweetpotato may not be the most nutritious staple crop compared with cereal crops, but it has the highest nutritional value as a vegetable. Sweetpotato roots are high in carbohydrates and dietary fibre, and are rich in vitamin B and C and minerals like potassium, magnesium, phosphorus and zinc (WHfoods, n.d.). In addition, orange-fleshed varieties contain high levels of β-carotene, (a pre-cursor for vitamin A), and are heavily promoted to combat vitamin A deficiency in SSA. Sweetpotato is also a beneficial food for diabetics because it has a low GI, which helps in stabilizing blood sugar levels and in lowering insulin resistance. Sweetpotato has a high content of Vitamins A and C, powerful antioxidants that help the body remove free radicals that damage cells. Sweetpotato vines are also high in protein, vitamins and minerals (Islam, 2006) and widely consumed as a leafy vegetable.

This means sweetpotato consumption will decline as income rises because consumers are afforded a more diverse and more nutritious diet. The differing consumption patterns of sweetpotato and rice between PNG rural and urban areas, shown in Gibson (2001a), is a good illustration of such inevitable changes. Therefore, to compete and slow down such changes, sweetpotato producers must improve their cost competitiveness and promote the health benefits of sweetpotato in the short to medium term while preparing for the demand decline by diversifying their income sources, e.g. through processing, in the longer term.

5.2 Sweetpotato as stockfeed

Feeding sweetpotato to pigs is a common practice in many countries, especially China, northern and central Vietnam, the island of New Guinea (Papua New Guinea and West Papua), the Philippines, Cuba and Uganda (Peters, 2004). Pig raising serves three important functions: generating income for rural households; providing manure for maintaining and improving soil fertility; and adding value to sweetpotato by converting low value sweetpotato to high value pigs/pork. In addition, pigs have social-cultural significance and represent status and prestige in some societies, including Papua New Guinea and West Papua.

As stockfeed, sweetpotato roots are used fresh (cooked or uncooked), sun-dried, or fermented as silage, often to supplement other cereal feed ingredients, particularly corn. Sweetpotato tops (the vines and leaves) are also fed to animals and are especially important because their per unit dry matter provides substantially more protein than sweetpotato roots. Sweetpotato tops make up a significant proportion of total feed for small-scale hog producers in Asia.

Sweetpotato roots have several shortcomings as stockfeed. First, they contain little protein – crude protein content commonly ranges from 1.3 to 4% on a dry weight basis. Although this problem can be overcome by supplementing sweetpotato-based diet with rice bran, fishmeal, soybean cakes, sweetpotato vines, cassava leaves, or commercial feeds, farmers often lack sufficient resources to purchase these ingredients (Peters et al., 2002). Second, they contain trypsin inhibitors, which reduce protein digestibility in uncooked roots and slow growth. Third, digestibility of sweetpotato starch is also poor. Starch and protein digestibility can be improved by cooking sweetpotato roots. Small farmers in China and Vietnam cook sweetpotato roots daily to feed their pigs, but it is labour-intensive and costly. In PNG, roots are fed to pigs uncooked. Another inefficiency in the sweetpotato-pig system is wastage following harvest since sweetpotato roots and vines do not store well.

Ensilaging sweetpotato roots (and foliage) appears to provide a solution to overcoming these problems. Peters et al. (2002) showed that incorporating 10-30% of sweetpotato root silage into a pig diet can improve both feeding and economic efficiency. Liu et al. (2004) also showed that through ensilaging, sweetpotato can be stored as high quality feed for up to six months and significant gains in feed-to-meat conversion are possible on diets composed of 20% sweetpotato silage and 80% basal grains.

The importance of sweetpotato as an animal feed varies widely by scale of operation and by region. In Asia, more than 80 percent of pig production is by small-scale “backyard” producers using sweetpotato and other locally available feedstuffs. However, these farmers are generally less efficient and achieve lower levels of feed-to-meat conversion, compared with middle-and large-scale specialised producers who rely on commercially formulated feed. These findings indicate both a challenge and an opportunity. Fuglie et al. (2006) argued that while small-scale producers face increasingly stiff competition in animal production, improving the sweetpotato-pig production system, which appears to favour small-scale production, may be a way for policy makers and scientists to achieve “pro-poor” agricultural development.

5.3 Sweetpotato for dried chips/flour production

Dehydration of sweetpotato is the most common way of processing sweetpotato. It has been traditionally practiced in major sweetpotato producing regions of Asia and Africa (Woolfe, 1992). Sweetpotato is cleaned, sliced/chipped, and sun dried. Dried chips are stored and later used both for human and animal consumption. Processing dried sweetpotato chips into flour further improves the shelf life of dried chips and makes it easier to store and incorporate into food products. In India, sweetpotato flour is used as a supplement to cereal flours in bakery products, chapattis, and puddings; while in the Philippines it is used in the preparation of gruel. In Peru, sweetpotato flour has been used to prepare wheat/sweetpotato bread.

Besides permitting better preservation, the drying and processing of sweetpotato into chips and flours offers other opportunities such as:

- facilitating storage and transport;
- reducing bulkiness and losses due to high perishability of fresh roots (although roots can be left in the ground for some time, they risk weevil attacks and infestation by other pathogens);
- increased shelf life;
- greater nutritional value, as the nutrients are concentrated in the dried food products; Hagenimana et al. (1999) showed that sweetpotato flour proved to be the most effective way of increasing carotenoid content, compared with boiled and mashed sweetpotato and raw and grated sweetpotato.
- potential for use as an ingredient in many marketable products; and
- creating new income opportunities for farmers as new markets and new sources of income.

Drying is potentially the simplest and least costly process to reduce storage loss of sweetpotato (Martin, 1984). However, traditional processing/drying methods of sweetpotato present certain problems, including:

- high dependency on climatic conditions;
- high manual labour requirements for peeling, slicing, spreading out to dry, turning the product during drying, guarding product from livestock, moving product if weather changes, etc;

- difficulties in maintaining quality because chips may be milled when they are not properly dried;
- difficulties in maintaining hygienic conditions can lead to products becoming contaminated by micro-organisms and dust;
- lack of control of enzymatic oxidative browning and other reactions leading to discoloured and/or strong smelling sweetpotato flour; and
- lack of uniformity in terms of chip size.

Improved processing/drying methods, such as solar drying, may help overcome some of the problems associated with traditional methods (Green and Schwarz, 2001). However the cost of these methods is usually higher than that of the traditional methods. The decision on whether to adopt the improved methods must pass a benefit - cost comparison to justify any additional investment.

5.4 Sweetpotato for starch production

The major industrial use of sweetpotato is in starch production. Nearly 70 percent of world starch production was derived from maize, and from cassava (nearly 10%) and sweetpotato (nearly 9%), with the remaining 12% coming from potato and wheat (see bottom of Table 6).

Table 6. World production of starch, 2002 (in Mt)

Region or country	Maize	Wheat	Sweet Potato	Cassava	Potato	Other	Total
China	5.45	0.03	4.82	0.42	0.99		11.71
Japan	2.61	0.03	0.09		0.27		3.00
Taiwan	0.05	0.02	0.02				0.08
South Korea	1.07	0.00	0.03				1.10
Thailand				2.59			2.59
Indonesia	0.08			1.27		0.03	1.38
Vietnam				0.50			0.50
Philippines	0.08			0.02			0.09
Malaysia				0.07		0.03	0.10
India	0.20			0.35			0.55
Asia Total	**9.53**	**0.08**	**4.96**	**5.21**	**1.26**	**0.06**	**21.10**
US, Canada, Mexico	24.60	0.30					24.90
European Union (15)	3.90	2.80			1.80		8.50
Ex-USSR & E. Europe	0.30				0.30		0.60
Australia	0.05	0.03					0.35
Latin America	1.70	0.04		0.43			2.17
Africa				0.02			0.02
World Total	**40.08**	**3.52**	**4.96**	**5.66**	**3.36**	**0.06**	**57.64**
% of total starch	70.54	6.11	8.61	9.82	5.83	0.10	100

Sources: Fuglie et al., 2006

Starch has wide usage in the manufacture of many food and non-food products (Fuglie et al., 2006). In food industries, starch is used to impart "functional" properties to processed foods such as thickening, binding, filling, texture, and taste. Starch is also converted into sugars and sweeteners, especially important is the use of corn starch to produce high-fructose syrup for soft drinks. Uses of starch in non-food industries include the textile, paper, plywood, adhesive, and pharmaceutical. Starch is also used to make beverage and fuel alcohol. Worldwide, the biggest user of starch is the sweetener industry.

As shown in Table 6, in developing countries, root and tuber crops are relatively more important as sources of starch while in developed countries, maize and wheat are the main sources of starch. Asia accounted for about one-third of world starch production, nearly half of which is from cassava and sweetpotato. While Thailand is the major producer of cassava starch, China is the major producer of sweetpotato starch.

The most important factor explaining the global production patterns of starch (as shown in Table 6) is the relative prices of commodities in the region. In the North America, maize is by far the cheapest source of starch and accounts for 98 percent of starch produced. In Southeast and South Asia, cassava is the cheapest source of starch and accounts for over 90 percent of starch produced in that region (Fuglie, 2004). In Europe, maize, wheat, and potato are main sources of starch, not because they are cheaper but a result of the subsidies afforded to processors (LMC International, 2002).

Raw material cost is key to the competitiveness of starch because it accounts for 70-80 percent of total processing cost. Another key determinant of starch processing costs is the starch conversion rates. Starch conversion rates are around 60-65 percent for cereals (maize, wheat, and rice), 22-25 percent for cassava, 8-12% for potatoes and 10-15 percent for sweetpotato (Wheatley et al., 1995, p.42). This means it takes twice as much sweetpotato to produce the same amount of starch from cassava. Therefore, one way to improve cost competitiveness is to increase starch extraction rate by selecting high starch-yielding varieties (Fuglie et al., 2006). Another factor is processing efficiency, which depends on the technology used and the scale of production, which in turn affect capital and labour costs. Taking into account all these factors, Thai cassava starch at US$217.8/t is the cheapest of all the starches, compared with Indonesia cassava starch (US$273.3/t) and Chinese sweetpotato starch (US$280/t) (Fuglie et al., 2006). More than 85 percent of Thailand's starch is exported to other countries in East and Southeast Asia, especially Japan, Taiwan, Indonesia, China and Malaysia. Trade in starch among Asian countries is heavily dominated by cassava starch because of its cost advantage.

Another important factor is the functionality of the starch. In Northeast Asia (China, Japan, and Korea), there is a major demand for starch from sweetpotato despite its high price due to the special characteristics of the starch for making noodles and specialty snack foods.[5]

5.5 Potential industrial uses of sweetpotato

Research carried out at the International Potato Centre has shown that more than 100 industrial products could be produced from sweetpotato, such as lactic or polylactic acid used in the manufacture of biodegradable plastics, and bioethanol. To date, however, their application is yet to be developed. Overall, the industrial potential of sweet potato remains largely unknown and yet to be fully exploited (UNCTAD, 2012).

5.6 Country examples

In the following section, sweetpotato utilisation in Asia, Africa, and PNG is briefly reviewed, starting with China which has a long association with sweetpotato.

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[5] Technology that allows low-cost starches, such as cassava starch, to be modified to suit user requirements has gradually eroded this marketing advantage previously enjoyed by sweetpotato starch.

China. Sweetpotato is the fourth major food crop in China, after rice, wheat and maize. Over the past few decades, it has changed from being a major staple food in the 1950s to being a major source of animal feed and a raw material for food processing industries by the 1990s (Fuglie and Hermann, 2004). While direct food use of sweetpotato in China has declined dramatically due to economic growth and urbanisation, the decline has not had a negative impact on production as it was offset by an increase in its use as stockfeed and for food processing. In particular, advances in postharvest and processing technology have played an important role in maintaining stability of the sector. In China, most sweetpotato is processed into starch, which is used mainly for noodle production. The remaining is made into alcohol and candies, biscuits, and other snack foods.

This transformation of the sweetpotato sector in China is best illustrated with the changes in sweetpotato utilisation in Sichuan and Shandong, the two largest sweetpotato producing provinces in China (Fuglie et al., 2005). As can be seen in Table 7, in Sichuan province, direct food consumption declined from 65% in the 1950s to 11% in the 1990s while feed use increased from 14% to 60% and processing use increased from 3% to 19% during the same period (Huang et al., 2004). In Shandong province during the same period, direct food consumption declined from 50% to 10%, feed use increased from 20% to 30%, and processing use increased from 15% to 48%.

Table 7. Sweetpotato utilisation in Sichuan and Shandong provinces in China, 1950s-1990s

	1950s	1960s	1970s	1980s	1990s
Sichuan province					
Food	65	60	50	20	11
Feed	14	19	29	60	60
Processing	3	4	5	10	19
Seed/replanting	6	6	6	5	5
Waste/others	12	11	10	5	5
Shandong province					
Food	50	45	40	20	10
Feed	20	25	30	30	30
Processing	15	15	15	38	48
Seed/replanting	5	5	5	4	4
Waste/others	10	10	10	8	8

Source: Huang et al., 2004.

The significant increase in processing use in Shandong province was associated with rapid development of a large-scale sweetpotato-based food processing industry and the abundant supply of maize as feed. By contrast, food processing in Sichuan province remained small-scale and basically a cottage industry as farmers relied on home-grown sweetpotato as feed and hence less sweetpotato was available for processing. These observations are applicable to explain differences in sweetpotato utilisation in China, both across regions and over time.

Other Asian countries. Sweetpotato has long been important to Vietnam as a food security crop against famine, but in recent years as grain production increases, it has become an important source of feed for livestock, especially pigs. An estimated 70 to 80% of sweetpotato is utilized for pig feed by Vietnamese farmers, with the remaining used for sale and home consumption (Peters, 2004). In Vietnam, some varieties are selected and growing primarily for their vegetable tops, with little or no harvest of roots. Using vegetable tops as a leafy vegetable is common in other Asian countries, such as Taiwan, Malaysia and the Philippines, and in Africa, such as Guinea, Sierra Leone, Liberia, Uganda and East Africa. In Taiwan some varieties are bred specific for their desirable vine properties as a leafy vegetable (flavour, taste, crispness, tenderness, etc).[6] Sweetpotato vegetables tops and vines are high in protein, vitamins and minerals. This means the importance of the crop could be much greater if production data include both vines and roots (Fuglie, 2007).

Africa. Sweetpotato is the third most important food crop in East and Central Africa, after cassava and maize, fourth in South Africa and 8th in West Africa (CIP, n.d.). In Africa, sweetpotato is mainly consumed as fresh boiled roots. However, in some parts of East Africa sweetpotato is traditionally processed into dried chips and/or flour to preserve the roots for household food security and to a lesser extent for sale in rural markets. The main use of sweetpotato in Africa is 'amukeke', which is usually sun-dried slices of sweetpotato, and 'inginyo', which is the sun-dried crushed of sweetpotato (Engoru et al., 2005). They are the staple food for the people in northeastern Uganda, where amukeke is taken for breakfast, along with peanut sauce, or for tea break in the morning. Inginyo is mainly mixed with cassava flour and tamarind for making "atapa", which is taken with smoked fish cooked in peanut sauce.

In a farm survey, Engoru et al. (2005) found that about 46.1 % of the farmers processed their fresh sweet potato tubers. The processing generated two primarily products locally called *inginyo* and *amukeke*; it is from further processing of these that two secondary products (*amukeke* flour and *inginyo* flour) were derived. Bashaasha and Scott (2001) reported that it was very likely that the over-riding motive for processing sweet potato is not profit but rather a mixture of complex issues including household food security, emergency income security and the need to circumvent a limited and erratic fresh sweet potato market. The other 53.9% of the farmers who did not process any of their produce attributed it mostly to lack of the necessary processing knowledge (33% of the non-processors and 17.8% of all respondents) as shown in Table 2. About 4.9% of the non-processors claimed that land shortage limited their fresh tuber output denying them a surplus for processing.

PNG. Sweetpotato is the most important staple food crop in Papua New Guinea. About 60 to 75% of highland sweetpotato is used for household consumption and 25 to 40% is used as pig feed (Bourke and Vlassak, 2004). For home consumption, sweetpotato is boiled in water or with coconut milk, roasted in open fire, or cooked in the earth oven (dry mumu). At the restaurants and fast food outlets (*kai bars*), sweetpotato is deep-fried in whole, chips or scallops, but they are not as prevalent as potato. There is little awareness among the general public of alternative uses of sweetpotato as a vegetable, as in Western countries, or as an ingredient in the production of noodles and snack foods that are commonly known and practiced in Asia.

[6] In the 1940s and 1950s, sweetpotato vines were called "pig's vegetable" in Taiwan, suggesting its primary use and lower status. However, nowadays it is one of the most popular leafy vegetables after significant improvements in breeding and variety selection.

6 Sweetpotato processing research

6.1 Priorities for sweetpotato research – results from CIP global survey

CIP, as an international agricultural research centre for sweetpotato since 1984, conducts surveys of key informants to help it set priorities for its research and development programs (Fuglie, 2007). Such surveys were conducted in 1987, 1990, 2005 and more recently 2012/2013.

From the 2005 survey, the priority needs of sweetpotato farmers in developing countries were identified as follows:

1. control of viruses (through varietal resistance, quality planting material, and crop management);
2. small-enterprise development for sweetpotato processing;
3. improvement in availability and quality of sweetpotato planting material;
4. improved cultivars exhibiting high and stable yield potential;
5. early-bulking cultivars;
6. reform of agricultural and food policies; and
7. improvement of ware storage methods.

Priority needs for China and SSA were reported separately because they are two main centres of weetpotato production in the world. Together they accounted for 87% of the sweetpotato harvested area in developing countries and 95% of the poverty-weighted harvested area. More importantly, priority needs were different between these two regions, highlighting the unique environment facing them. In addition to the seven global needs listed above, respondents from SSA indicated a list of high-priority needs for sweetpotato, namely: i) improved control of the sweetpotato weevil; ii) cultivars with high β-carotene content to address vitamin A deficiency; iii) improvements to sweetpotato propagation systems and storage methods; iv) cultivars tolerant to drought and marginal soil conditions; v) cultivars providing high yield as animal fodder as well as food; vi) improved management of soil fertility and cropping systems; vii) harvesting methods for sweetpotato; and viii) better evidence on the economic rate of return to sweetpotato research and development.

Top-priority needs from respondents from China (in addition to the seven global needs listed above) include: i) conservation and characterisation of sweetpotato genetic resources; ii) pre-breeding; iii) cultivars with high starch yield; iv) new food products from sweetpotato; and v) improved capacity in using information and communication technologies.

These regional differences in priority needs for sweetpotato reflect not only differences in the role of sweetpotato in the rural economies but also different capacities of the agricultural research systems. China, with its relatively strong agricultural research system, put greater importance on long-term research strategies in improving utilisation of genetic resources and pre-breeding and meeting the growing market demand for industrial starch and diverse consumer food products. Africa, on the other hand, placed higher priority on more near-term applied and adaptive research to improve cultivars and crop management methods suitable to local environmental conditions and, importantly, propagation systems to disseminate new varieties and reduce crop losses from viruses.

Fuglie (2007) concluded that sweetpotato will continue to play an important role in meeting the food, fodder, and income needs of the world's poorest and fastest-growing population. Further research to address those priority needs, as part of a pro-poor development strategy, will help contribute to improving the livelihoods of farm households in developing countries.

6.2 Sweetpotato processing research in China

Public research on sweetpotato processing in China began in the early 1980s. It was part of the Chinese government's effort to increase farmers' income and create employment opportunities for the relatively underdeveloped provinces in mountainous regions that rely on sweetpotato as a staple food. Significant resources were devoted to finding new uses and developing postharvest technology for sweetpotato, which, unlike potato processing technology, could not be readily imported from overseas. Although some progress was made in product development and a small set of equipment for extracting starch from sweetpotato was developed, starch quality was poor and processing cost was high. Outside help was needed to progress further.

In 1987, the Sichuan Academy of Agricultural Sciences began to collaborate with the International Potato Centre (CIP) on postharvest utilisation (Fuglie and Hermann, 2004). The collaboration lasted nearly two decades. Initially, the collaboration focused on introducing and improving machinery for small-scale starch extraction and noodle making. In the mid-1990s, the improved technology was extended to, and adopted by, machinery manufacturers and sweetpotato processors. With the success in noodle making, research and development activities were expanded to include product development and processing of instant noodles, snack foods, and flour products (Wheatley and Song, 2002).

However, by the late 1990s the households and small enterprises that had adopted sweetpotato processing technology for starch/noodle processing faced growing competition from other food manufacturing in China's rapidly advancing market economy. As a result, research by Chinese and CIP researchers turned increasingly toward questions of scale and efficiency (Huang et al., 2003). In particular, scientists sought to develop technologies that would make small-scale sweetpotato processors more productive and competitive. As competition issues became more acute, CIP-supported research expanded from production to include aspects of organisation and management of processing enterprises and the marketing of sweetpotato processed products (Zhang, 1999).

In addition to international collaboration, the Chinese government also played a key role in the turn-around of the Chinese sweetpotato sector in the 1990s, in particular, its support for the sector through research on processing technologies and the implementation of the "one-dragon" policy. The one-dragon policy is the Chinese approach to supply chain coordination (Wei and Zhang, 2004) that links farmers' groups (rural associations) to well-established food manufacturers (the dragon head enterprises (DHEs)).

Under the one-dragon policy, DHEs were selected based on their size, financial profile, market position and technological leadership. Their main role (as the dragon head) was to lead the way for agricultural industrialisation through market development, technology innovation, and supply chain management (Lingohr, 2007) and to drag its tail (the rural associations and their farmer members) to prosperity. Rural associations, on the other hand, supplied raw materials to, and often performed primary processing (e.g. crude starch) as well for, DHEs. In return for their participation in the one-dragon policy, both DHEs and rural associations were rewarded with preferential tax, low-interest loans, subsidies, equipment, training, and technical advice. According to Lingohr (2007), there were four, six and 15 DHEs for sweetpotato alone at the national, provincial and county levels, respectively.

This development indicates an increasingly larger role large-scale modern food manufacturing companies are playing in sweetpotato processing. It also recognises the importance of a value chain approach to industry development.

6.3 Sweetpotato processing research in Africa

Sweetpotato is undergoing a re-surge in Africa, motivated by its ability to withstand climatic shocks and increasing rainfall variability, their food security value in emergencies and their buffering role under changing price relatives with cereal. Since the early 1990s, CIP and partner institutions have undertaken a range of research projects in SSA on sweetpotato utilisation and processing, with the overall aim of increasing the role of sweetpotato in urban and rural diets, maximizing nutritional benefits, as well as enhancing incomes of rural producers (Thiele et al., 2009). This involves research in the following areas:

- Varietal selection for different end uses.
- Inclusion of sweetpotato roots, and derived intermediate products, in a range of commonly consumed foods.
- Technical aspects of processing and product quality.
- Economics of production and processing.
- Consumer and market acceptability studies.
- Orange-fleshed sweetpotato (OFSP)
  - Varietal variation and selection.
  - Levels of β-carotene /Vitamin A in fresh roots and processed products.
  - Evaluation of public health/nutritional benefits of OFSP promotion at community level.
- Market chain and enterprise development action-research based on sweetpotato.

The Sweetpotato Action for Security and Health in Africa (SASHA), funded by the Bill & Melinda Gates Foundation, is a five-year initiative designed to improve the food security and livelihoods of poor families in SSA by exploiting the untapped potential of sweetpotato (CIP, n.d.).

African research has a strong focus on the orange-fleshed sweetpotato mainly because of its potential to combat vitamin A deficiency. According to CIP (n.d.), Vitamin A deficiency threatens an estimated 43 million children under age 5 in SSA and contributes to significant rates of blindness, disease, and premature death in children and pregnant women. It takes only 125 grams of most orange-fleshed sweetpotato varieties to meet the recommended daily allowance of vitamin A for children and non-lactating women.

Started in 2001, Vitamin A for Africa (VITAA) is a partnership promoting the increased production and utilisation of orange-fleshed sweetpotato (OFSP) to combat vitamin A deficiency in sub-Saharan Africa. The aim is to make OFSP available on a large-scale, demonstrating the potential of crop-based approaches in alleviating micronutrient deficiency (Kapinga et al., 2007). OFSP contains ß-carotenes that can be converted easily by the human body to vitamin A. VITAA recognizes OFSP as a promising solution to vitamin A deficiency in eastern and southern Africa not only because they are rich in ß-carotene, but also they are easy to grow and affordable to the average resource-poor consumer. The partnership targets young children and their mothers, who are the most vulnerable to vitamin A deficiency.

VITAA partners include national agricultural research institutes, health and nutrition agencies, NGOs, community-based organisations (CBOs) and private businesses. Also there are several networks working in eastern, central and southern Africa. Member countries include: Ethiopia, Tanzania, Kenya, Uganda, South Africa, Ghana, Nigeria, Rwanda, Zambia and Mozambique. The initial VITAA activities were supported by generous contributions from CIDA, CIP, DFID, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), the OPEC Fund for International Development, the Senior Family Fund, The Micronutrient Initiative, USAID-Africa Bureau, PRAPACE and SARRNET.

Wheatley and Loechl (2008) reviewed the research undertaken on sweetpotato postharvest utilisation and processing in East Africa in the past two decades to assess outcomes and identify future research and development priorities. Some of this research focused on fresh root quality and postharvest storage and the development of market chains. However, most attention was placed on processing fresh roots to more stable intermediate products (dried chips and flour) and their use in a range of locally important snack food such as mandazi and chapatti. In recent years, significant effort was given to assessing health benefits of orange-fleshed sweetpotato.

Their findings, which are very relevant to PNG, are summarised below.

- Fresh use: Sweetpotato is still predominantly used in fresh form as a supplementary food crop for on-farm or local consumption.
- Fresh root marketing: In the 1990s, only a small percentage of production was traded (5%) and urban markets did not appear to be growing because of strong demand constraints for sweetpotato roots. However, more recent studies found some growth in urban markets for sweetpotato in line with rapid urbanisation, 'supermarketisation' of agricultural production, and the advent of OFSP varieties. It is noted that promotional campaigns associated with OFSP is instrumental in driving the demand growth.
- Starch: Sweetpotato is widely used in Asia for starch extraction and animal feed. The potential for starch in East Africa is not high, based on the absence of any compelling functional advantages of sweetpotato starch and a high raw material cost.
- Animal feed: Its uses have some potential, especially for intensive cattle production (fodder including vines), pigs and small ruminants, but there is a lack of basic information on this option.
- Processing fresh roots into food products: Small-scale rural or urban processing enterprises were assessed to be technically and economically feasible. However, only very limited commercial development of these technologies has occurred to date, usually within the supportive environment of development projects.
- Orange-fleshed sweetpotato (OFSP) varieties: OFSP has been demonstrated to be capable of providing sufficient vitamin A to counteract nutritional deficiencies. Fresh roots and processed products made from OFSP have proven acceptable to consumers when accompanied with a nutritional promotion campaign. There are indications that without such an associated effort, uptake of OFSP varieties in non-intervention areas would have been more limited.
- The development of market chains: Linking sweetpotato producers to urban fresh markets (via wholesalers and supermarkets) and to the developing food industry (including the potential for flour and chip intermediate products) has a potential to improve demand for sweetpotato.

The main conclusion from the review is that improving cost-competitiveness of non-OFSP as a food industry raw material (flour, dried chips, and starch) will require significant investments in improving productivity and root dry matter content in the field. Furthermore, with limited research funds, any further investment in sweetpotato processing research must be weighed against the potential returns on R&D from improving on-farm productivity and postharvest, and other crops that are also requiring similar investments.

6.4 Sweetpotato processing research in PNG

Sweetpotato processing research and development was institutionalised with the establishment of the Food Processing and Preservation Unit (FPPU) in 1984, aimed at developing a food processing sector in PNG (Cegumalua, 2007). FPPU was managed jointly by the Department of Agriculture and Livestock (DAL) (and later passed on to FPDA in 1996) and the University of Technology (UniTech). During its operation, the unit was used by DAL/FPDA for product research and development and by UniTech for teaching food technology students.

Under FPDA, the work at FPPU was geared towards the development of successful products for downstream processing and assisting entrepreneurs in progressing further into commercial scale agro-enterprises. Several products were successfully developed and a number of entrepreneurs were trained. Many more received technical assistance over the counter. Products that were developed and promoted more successfully at FPPU included:

- Noni juice
- Fruit juice
- Fruit jam
- Cassava flour (constitute 30% of composite flour)
- Peanut butter & roasted peanut in shell
- Crispy chips from staples (banana, cassava, white potato, sweetpotato, yam)
- Coconut oil (crude)
- Spices (dried & ground)

FPPU was reviewed in 2007. The review found that although there was a potential for, and significant interest in, food processing in PNG, the program failed to achieve its objectives (Cegumalua 2007). First, there was little uptake of the processing technology by the entrepreneurs/trainees. For those few individuals who did take it on, most did not succeed due to the lack of sufficient technical know-how. For those who manage to remain in operation, they failed to develop into fully-fledged commercial operators due to the lack of necessary capital and management skills to expand. Most of them continue to operate as a cottage industry and sell their products at the informal market. Second, the building and processing equipment were not properly maintained due partly to poor management and partly to financial constraints.

In 2007, after having been in existence for more than 20 years, FPPU was shut down. Interestingly enough, while the FPPU was being shut down, the National Agricultural Development Plan 2007-2016 released in 2006 specifically identifies “Developing a food processing industry for staple food crops and vegetables” as one of PNG’s development priorities.

After the closure of FPPU, most processing research was conducted at NARI. Research conducted there focused on evaluating sweetpotato varieties and their suitability for producing sweetpotato flour and its derivatives (cakes, donuts, pancakes, biscuits, noodles, etc) using composite (sweetpotato/wheat) flour. The objective was to replace wheat flour sweetpotato flour as much as possible without affecting the integrity of the product. Deep-fried products, such as scallops, chips and curls, were also experimented.

Several observations were made on the processing work conducted in 2007-2009. First, there was almost no facility or processing equipment that enabled the scientists to do their jobs properly. Second, under a very basic working condition, neither the products nor the processes could be sufficiently developed to ensure quality outputs and processing efficiency. There was also an issue with focus. Despite a lack of success in developing one good product, similar activities were extended to other products and other root and tuber crops. In addition, the quality of the product and consumer acceptability was assessed by technicians who made the product, rather than by taste panels with necessary qualification and experience. As a result, consumer acceptability could not be correctly assessed and the technology could not be effectively promoted. Finally, most research focused on mimicking wheat-based products using Western recipes, with the objective to replace wheat flour with sweetpotato flour as much as possible but without adaptation to local conditions. Peters and Wheatley (1999) pointed out that most of the technical research on sweetpotato flour has focused on the development of new products using sweetpotato flour rather than on efficient methods to produce and store the flour. This is also the case in PNG.

There appeared to be a turn-around in 2010 in processing research at NARI. Rather than making flour derivatives, the focus was on producing high quality flour from roots and tubers. This was made possible by a number of externally funded projects, including

- A sweetpotato marketing/postharvest/processing project funded by ACIAR (Chang and Irving, 2012). Though this project, training was provided to women's leaders on how to produce sweetpotato dried chips/flour and baked products in Jiwaka province and two milling machines and two baking ovens were provided to selected community groups to encourage them to experiment with food processing.[7] Also, a sweetpotato fair aimed at raising awareness of sweetpotato processing was held in Minj in Jiwaka province and sweetpotato products made by NARI and local women's groups were show-cased to more than a thousand visitors from all over Highlands.

- A yam project funded by the University–Industry Cooperation Foundation of Kangwon National University of South Korean. A full set of flour making equipment (including weight scale, dryer/oven, chipper/slicer, milling machine, etc.) were purchased. There was success in producing high quality flours from yam, cassava, taro, and sweetpotato. However, no processing protocol was developed and no data were collected regarding yield, processing cost and nutrient contents. Moreover, the flours have not been used for new product development.

- A cassava flour project, funded by the Agricultural Incentive Grant Scheme (AIGS) under the Agricultural Research and Development Support Facility (ARDSF) funded by AusAid. This project has also produced good outcomes, with a farmers group in Domil, Jiwaka province producing cassava flour and starch for sale, as well as for poultry feed to raise chickens on-site. One problem with the project was the lack of business and management skills of the farmers group involved, putting the sustainability of the project in jeopardy. Regardless, this is potentially a good model for improving sweetpotato utilisation.

- The NARI-EU-ACP-S&T Program (Building Human Resource Capacity in Science and Technology for Agricultural Development in Western Pacific Countries) funded by the European Union.[8] Under the program, a 3-day processing training course was developed

[7] Over the years, food processing training was provided to 40 some women's groups in the rural areas of PNG highlands by a Catholic Church, but uptake of technology was poor. The training program was reviewed by the ACIAR project, and several constraints to adoption were identified, including labour intensity and the lack of access to equipment (milling machine, baking oven, kitchen utensils, etc), ingredients (milk, sugar, butter, egg, etc), and basic services (transport, clean water, electricity, credit, technical support, etc). A related issue is the lack of processing culture in PNG; there is little awareness of food preservation and processing. This is understandable as unlike rice- or wheat-based societies that face distinct seasonality in agricultural production, PNG relies on roots and tubers as their staple foods, which are either available all year round or are complementary for each other. The year-round availability eliminates the need for food processing and preservation for future use during off-season and lean times. However, it means that any training or awareness program must take into consideration this low level of knowledge and start small.

[8] The NARI-EU-ACP-S&T Programme (Building Human Resource Capacity in Science and Technology for Agricultural Development in Western Pacific Countries) is a capacity development initiative for research and development institutions in three Western Pacific countries – Papua New Guinea, Solomon Islands and Vanuatu. The programme was amied at addressing the lack of appropriate human resource capacity on science and technology for agricultural development in research, extension and development institutions in the Pacific. This capacity is essential for conducting and promoting agricultural research aimed at enhancing productivity, efficiency, and sustainability of the smallholder agriculture sector. Under the program, NARI provided expert training to agricultural researchers, research managers, disseminators and farmer innovators in nine institutions across the three Western Pacific countries.

and delivered to a number of scientists from PNG and the Pacific Islands (Vanuatu and the Solomon Islands), as well as numerous communities in PNG. This means a successful sweetpotato project in PNG would have spills-over effect to other root and tuber crops and to other South Pacific countries.

Given that processing research on flour has produced positive results and deemed appropriate to the PNG context, field research of this project built on what have been achieved thus far while focusing on improving the scientific rigour that was lacking in previous research, especially data collection and analysis, and new product development that is locally appropriate. Consultations with local food processors also confirmed sweetpotato flour processing as a promising processing option because of its abundant supply and health benefits, as well as the potential socio-economic impact on local farmers. Flour processing was also identified as most promising by Collins (1989) based on diagnostic assessments carried out in developing countries.

6.5 ACIAR sweetpotato research in PNG

ACIAR has funded several research projects in Papua New Guinea on sweetpotato research in past ten years. They include:

1. SMCN/2003/010: Farmer evaluation and multiplication of sweetpotato varieties on the North Coast of PNG.
2. SMCN/2004/071: Reducing pest and disease impact on yield in selected Papua New Guinea sweet potato production systems.
3. SMCN/2004/067: Soil fertility management in the Papua New Guinea highlands for sweet potato based cropping systems.
4. SMCN/2005/043: Analysis of biophysical and socio-economic constraints to soil fertility management in the PNG Highlands.
5. PC/2005/134: The use of pathogen tested planting materials to improve sustainable sweet potato production in Solomon Islands and Papua New Guinea.
6. ASEM/2005/126: Report on ACIAR Sweetpotato Workshop in Madang.
7. ASEM/2005/044: Towards a research agenda for improving consumer demand and marketing of sweetpotato in PNG.
8. ASEM/2006/035: Improving marketing efficiency, postharvest management and value addition of sweetpotato in Papua New Guinea.
9. ASEM/2010/053: Enhancing role of small scale feed milling in the development of the monogastric industries in Papua New Guinea.
10. PC/2010/026: Validating and documenting a strategy for producing virus-free sweetpotato planting material in Papua New Guinea.
11. PC/2011/053: Identifying appropriate strategies for reducing virus and weevil losses in sweetpotato production systems in Papua New Guinea and Australia.

Clearly, the focus has been to a greater extent on improving on-farm production through variety evaluation, composting and pest and disease control (viruses and weevils). However, there is an increasing attention on postharvest management, marketing and processing.

7 Sweetpotato flour processing

7.1 Quality characteristics of sweetpotato flour

The most important quality characteristics of sweetpotato flour are moisture content, protein and β-carotene content, microbiological quality, colour, taste, and odour.

The quality of sweetpotato flour is defined in the African Standard CD-ARS 827:2012(E) (ARSO, 2012). The Standard covers the requirements regarding the quality of raw material, the colour, odour and particle size of flour, nutritional contents and microbiological limits, and the presence of micro-organisms, food additives and contaminants (pesticide residues, heavy metals, mycotoxin, chemicals, and other contaminants), as well as packaging and labelling.

African nutrient composition and hygienic and food safety requirements are presented in Tables 8 and 9, respectively.

Table 8. Compositional requirements for sweetpotato flour in Africa

Parameter	Requirement (On dry matter basis)	Method of test
Total ash	< 3.0	ISO 2171
Moisture	< 12.0	ISO 712
Crude fibre	< 5.0	ISO 5498
Acid insoluble ash	< 0.15	
Total sugar (as sucrose)	> 6.0	ISO 2173
Starch	> 60.0	ISO 15914
pH of aqueous extract	4.5-7.0	ISO 1842
Cold water solubles	< 12.0	ISO 941

Source: African Organisation for Standardisation (ARSO), 2012.

Table 9. Microbiological limits for sweetpotato flour in Africa

Micro-organisms	Requirement	Method of test
Escherichia coli, cfu/g	< 1	ISO 7251
Salmonella, 25g	Absent	ISO 6579
Yeasts and moulds, cfu/g	$< 10^4$	ISO 21527-1

Source: African Organisation for Standardisation (ARSO), 2012.

A variety of data show that with existing technology flour with desirable quality can be made even at the household/village level. Table 10 shows the range of nutrient content associated with sweetpotato fresh root and flour (Wheatley et al., 1995; Van Hal, 2000).

Table 10. Nutrient contents of sweetpotato fresh root and flour

	Fresh roots*	Flour**	
	On fresh weight basis	On dry weight basis	
		Range	Average**
Moisture	65-81	4.4-13.2	8
Dry matter	19-35	86.8-95.6	92
Total carbohydrates		85-95	90
• Total starch	18-28	57-85	70
• Reducing sugar		1.18-12.03	4.94
• Total sugar	1.5-5.0	6.7-22.7	11.3
Ash	1.0	1.28-2.53	1.89
Protein	1.0-2.5	1.0-8.5	3.90

Lipids	0.5-6.5	0.06-1.90	0.60
Fibre	1.0	2.3-19.3	10.3
pH	--	5.79-5.85	5.8

Source: *Wheatley et al., 1995, p.42 and **Van Hal 2000, p.5.

Moisture content. As can be seen from Table 9, the moisture content of sweetpotato flour ranges between 4.4 and 13.2%. Moisture content is directly related to drying method, drying time, and period and conditions of storage. Moisture at around 8% can be obtained using solar drying and moisture at as low as 2– 3% can be obtained using artificial dryers (Peters and Wheatley, n.d. cited in Van Hal, 2000). Although the moisture content of sweetpotato flour is important where storage is concerned (because water can accelerate chemical or microbiological deterioration), there is a trade-off between moisture content and processing cost. This is because a lower moisture content means a lower flour yield and a higher drying time or temperature. Therefore, the optimal moisture content must be carefully assessed based on intended use and storage period and conditions. Zhao and Jia (1985) found that when flour is stored at 6–10°C ambient temperatures, a level of up to 17% moisture content is acceptable while when stored at 27–29°C, a level of up to 12.5% is acceptable. They recommended drying to a maximum of 10% moisture content for long-term storage. These results suggest that the average moisture content of 8% commonly observed may be lower than necessary, and hence increasing processing cost unnecessarily (Peters and Wheatley, n.d. cited in Van Hal, 2000).

Carbohydrates. Carbohydrates account for the bulk of sweetpotato flour, ranging between 85% and 95 on a dry weight basis, with an average of 90% (see Table 10). The total starch content varies between 57–85% on a dry weight basis, with an average of 70%. In sweetpotato roots, total carbohydrates are comprised of approximately 80% starch and 20% total sugar (Ulm, 1988). And there are large varietal variations, from 18 to 28% for total starch and from 1.5 to 5.0% for total sugar. Varieties that are high in dry matter are also high in carbohydrates hence producing higher flour yields.

Proteins. The protein content of sweetpotato flour is generally low, ranging between 1.0 and 8.5% and with an average of 3.9%. Although regarded as a high-energy, low-protein food, sweetpotato serves as a fairly important protein source for low-income consumers who have limited access to proteins of animal origin. In the short term, using sweetpotato flour in combination with other protein-rich ingredients can overcome this deficiency in sweetpotato flour. In the longer term, the alternative is to breed and select varieties with high protein content.

Carotenoids. Orange-freshed sweetpotato roots are one of the major food sources of carotenoids, along with apricots, carrots, and peaches (Hagenimana et al., 1999). The significance of carotenoids is that some are converted into vitamin A in the digestive system. Among the carotenoids, β-carotene has the highest pro-vitamin A activity (100%), compared with α- and ϒ-carotenes (50%). Orange-fleshed sweetpotato obtain their colour through the presence of carotenoid pigments and the intensity of the flesh colour of sweetpotato root reflects largely the concentration of β-carotene. Carotenoid content decreases over time during storage in both fresh and processed forms. In sweetpotato flour, carotenoid content can vary greatly among different varieties and within varieties, as well as with the type of processing especially during heat treatment. White sweetpotato cultivars are not a source of vitamin A because of the lack of carotenoids.

Colour. An important quality attribute of sweetpotato flour is appearance, primarily colour, which affects the acceptability of flour and the food products made from it. Colour is especially important if sweetpotato flour is used mainly as a substitute for wheat flour. Depending on the variety and processing methods, flour colour ranges from whitish or cream coloured, different shades of yellow, orange (pale or light), to pale purple. The colour of sweetpotato flour is due to a variety of complex biochemical factors (Collado et al., 1997). One is the presence of natural pigments, which affects the redness and yellowness of the flour. The other one is the levels and reactions of substrate, natural inhibitors, and enzyme, which affect whiteness of the flour.

Discolouration can also occur during sweetpotato processing and storage. Peters and Wheatley (n.d. cited in Van Hal, 2000) found that some varieties showed a clear downward trend of whiteness with each day of storage before processing while others did not. Browning occurs during processing as polyphenolic compounds in roots are oxidised in the presence of enzymes called polyphenol oxidases (PPO). Apart from selecting a suitable variety (with low concentration of phenolic compounds and high level of natural inhibitors of PPO), browning can be prevented by soaking chips in acidic solutions.

Microbiological Quality. To reduce problems of microbiological contamination during processing, one should improve hygiene practice and avoid contamination through disinfection of water and equipment using chlorine or sodium hypochlorite.

Organoleptic Quality. The perception of taste, aroma, and texture are all crucially important in determining consumer acceptance of a food product. Physical–chemical and functional analysis of sweetpotato flour can give some indication on the organoleptic quality desired. However, only sensory tests carried out with trained panels can assess if the more subjective aspects of quality are satisfactory. Lizado and Guzman (1982) showed that through subjective evaluation, the most important sensory characteristic of sweetpotato flour was odour, followed by smooth mouth feel with no lumps. Organoleptic quality of sweetpotato flour should be evaluated through the organoleptic quality of products made from it.

Peters and Wheatley (1997) found that partial substitution with sweetpotato flour changed the taste, smell, and texture of the product enough to have them marketed as a different product. This means using sweetpotato flour as a substitute for wheat or other flour may be restricted. For example, sweetpotato flour was found to have a negative effect on loaf volume, flavour, colour, and texture of bread, with a substitution level of 10–15% on a dry weight basis as the most acceptable. Research also showed that although the potential for sweetpotato flour to substitute for wheat flour for bread is limited, other baked goods can be made with higher proportions (10–100%) of sweetpotato flour. For example, in India, pancakes, puddings, and chapattis are made with 50% sweetpotato flour (Nair et al., 1987).

In East Africa sweetpotato flour was less acceptable for making into the traditional staples, such as ugali, because of its sweet taste (Omosa, 1997). However, it was more acceptable when it was used in the production of traditionally wheat-based snack foods, such as chapattis (flat unleavened bread) and mandazi (doughnuts) and porridge, where sweetness is not an issue. This is also true for a much wider range of products, mostly with a sweet taste, including donuts, biscuits, muffins, cookies, brownies, noodles, pies, breakfast foods, and baby foods (Woolfe, 1992; Peters and Wheatley, 1997).

These results suggested that functionally sweetpotato flour is very different from all-purpose flour and should not be treated as such. Therefore, it is unreasonable to expect sweetpotato products using composite flour to appear and taste the same or similar to the original products (made with 100% wheat flour).

Hagenimana and Owori (1997) found that bread and some snack products made from boiled and mashed sweetpotato, rather than using flour, gain the highest consumer acceptability and out-perform those products made solely from wheat flour. Products made with mashed sweetpotato also absorbs considerably less oil (an expensive ingredient) than those made with wheat flour alone (Hagenimana et al., 1998). A potential problem is that washing, peeling and boiling sweetpotato required too much labour time and may not be acceptable to bakers and food processors, who are used to managing and storing dried ingredients.

7.2 Factors affecting flour quality

Sweetpotato flour processing involves the selection of fresh roots, trimming, washing, peeling, slicing/shredding, soaking, pressing, spreading, drying, grinding, sifting, and packaging (see Figure 1).

Figure 1. Flowchart of sweetpotato flour processing process

Source: Van Hal (2000).

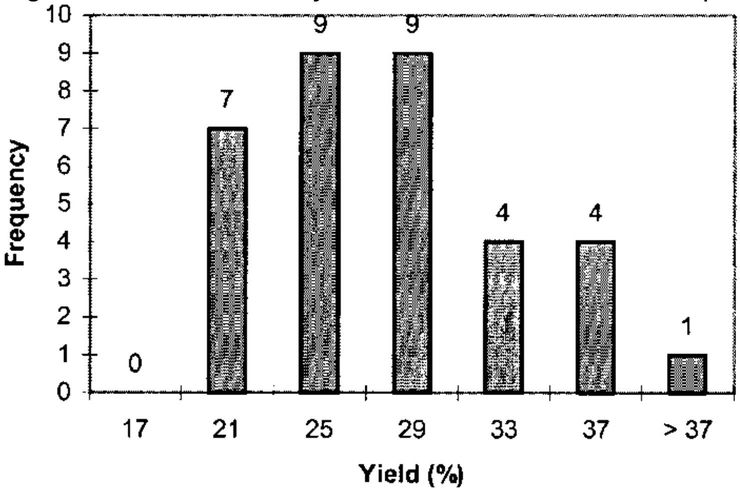
This is not a complex process and can be done without sophisticated equipment or significant capital investment. However, each of these steps has some bearing on the quality and the processing cost of the flour, especially the selection of fresh roots, peeling, soaking, drying, and packaging.

7.2.1 Selection of fresh sweetpotato roots

Sweetpotato roots are classified into two general types in terms of dry matter content and colour: dry-fleshed cultivars with mealy, light yellow or white flesh and the moist-type cultivars with soft, gelatinous, bright orange flesh. Variety has the most significant effect on the conversion rate of root to flour, i.e. flour yields. Gakonyo (1993) estimated the maximum flour yield to be 37.7%, assuming a moisture content of 70% for fresh roots, a desired moisture content of 12% for flour, and a 10% wastage rate. At a conversion rate of 37.7%, it takes 2.65 kg of unpeeled roots to produce one kg of flour. At 20%, it takes 5 kg of unpeeled roots to produce one kg of flour. Yields reported in the literature range from 17 to 38%, but they are most likely to be between 25-29% (see Figure 2). Dry matter content and flour yield are the most important factors influencing processing cost. Therefore, careful consideration must be given to the selection of the raw sweetpotato roots as dry matter content can vary from 65-81%, depending on varieties.

To achieve white colour they should be low in total sugar, reducing sugar (not exceed 2% on a dry weight basis), amylase activity, and polyphenol oxidase to limit discolouration during processing (Lizado and Guzman, 1982).

Figure 2. Distribution of yield of flour of different sweetpotato varieties



Source: Van Hal (2000).

In addition to choosing the right variety, physical characteristics of fresh roots are also important. For any given variety, sweetpotato roots must be selected based on the size and shape of the roots and freedom from rotting, insect damage, excessive mechanical damage and excessive soil or other foreign materials. Peeling takes more time when the roots are too big, too small, or with irregular shapes while excessive culling and trimming to remove undesirable parts of roots will increase wastage and reduce yield, as well as increase labour costs (Gakonyo, 1993). For industrial production, sorting and grading are essential and must be done on farm, rather than at the processing site, to reduce transport cost and avoid disease transmission during transit.

After the selection of good quality roots, critical points during sweetpotato flour processing are the peeling, the soaking, and the drying, as they can cause significant changes to the nutritional value of the sweetpotato roots.

7.2.2 Peeling

Peeling removes the skin from the root and can be carried out manually or mechanically. Peeling the roots is sometimes included in the process to increase the quality of the flour but it causes losses and reduces flour yields (Gakonyo, 1993). Wastage rate from peeling depends on the form and irregularity of the roots, but an average wastage rate of 10% of root weight is common. In addition, peeled sweetpotato roots must be submerged in water to avoid browning. Since the peel of the root is thin, it does not pose problems if it is not removed before processing. Elimination of the peeling step cuts down the processing time, since peeling is time-consuming work, although using unpeeled roots requires the washing step to be especially thorough. Flours from peeled and unpeeled roots were found to be different in composition since flour from the latter was higher in ash and crude fibre. This makes the decision not to peel dependent largely on consumer acceptance of a slightly browner flour colour caused by the colour of the skin.

7.2.3 Soaking (Bleaching/Blanching)

Discolouration of sweetpotato slices/shreds produces a brown flour, due to the action of oxidase enzymes and is enhanced by mechanical or heat treatment (Silva,1990). Soaking or dipping sweetpotato slices/shreds in water (cold/boiling) or in solutions (which contain sodium sulphite, sodium meta-bisulphite, citric acid, acetic acid or potassium) for 3 to 10 minutes decreases oxidase activity and thus prevents browning. Soaking serves several purposes. It prevents browning, whitens the final product, preserves the natural flavour of the sweetpotato, and/or prevents microbiological contamination (Lizado and Guzman, 1982; Gakonyo, 1993). However, it also results in a decrease of yield due to losses of some solubles, higher final moisture content of the flour due to reduction of evaporation by the solute sodium bisulphite, a decrease of total sugar content, starch and amylose content and ash content, as well as shrinkage of the slices due to plasmolysis (Widowati and Damardjati, 1992).

7.2.4 Drying

Drying is the most critical step in processing sweetpotato flour in terms of the final flour quality and processing cost. Drying more than necessary reduces yield and increase cost. Different drying methods exist. Solar drying is the cheapest since it uses free and non-polluting energy with a minimum investment in equipment. However, solar drying has a number of disadvantages. They include: i) poor control of energy input and product quality; ii) the interruption of drying caused by cloud, rain, and nightfall; and iii) frequent contamination of food by microorganisms, dust, and insects.

Drying of sweetpotato root slices in direct sunlight or in a solar dryer is frequently carried out. Drying times of 4, 6–7, 8, or 12–15 hours and 1, 2, and 5 days have been recorded, depending on climatic conditions. Slices were dried until they reached a moisture content of about 6–10% (Winarno, 1982). Both white and coloured varieties have been found suitable for solar drying. In many countries, solar-drying can be used as a simple and cheap method. It requires very few purchased inputs and is suitable for home and small-scale use as well as industrialisation. Lizado and Guzman (1992) observed that the point at which the sweetpotato slices become brittle corresponds to reaching constant moisture content and as such could be used as an empirical criterion to finish the drying process. However, the quality of foods dried in direct sunlight is often considered inferior to that of foods dried by other methods, such as drum or spray drying (Woolfe, 1992).

Drum or spray drying is often used in large-scale enterprises and these are highly technical processes which use large amounts of energy. Therefore, they may not be suitable for many developing countries (Martin, 1984). The final flour obtained drum or spray drying is different from that produced using solar drying, since the flour leaves the drum dryer or sprayer pre-cooked. Heat processing treatments have a negative influence on protein quantity and quality depending on the period and the intensity (temperature) of heat exposure.

7.2.5 Packaging/storage

Sweetpotato flour can be packaged and sealed in different forms of packaging material, which includes porcelain and glass jars, tin cans, paper ‘‘craft’’ bags, polypropylene bags, polyethylene bags, cotton bags, or a combination of two different materials, for example polyethylene and cotton bags together. Although flour is less vulnerable to spoilage during storage than the fresh roots, it has a capacity for absorbing moisture. Orbase and Autos (1995) studied the effect of different packaging materials (polyethylene, muslin cloth, and polyethylene/muslin cloth) on the microbiological quality of sweetpotato flour. They found that microbial count (bacteria, molds, and yeasts) did not change over time or with different packaging materials.

Dried sweetpotato products have a higher sugar content, which favours the growth of microorganisms and attracts insects (Woolfe, 1992). For prolonged storage, sweetpotato flour must be put in sealed containers or packaging with a low initial moisture content (not more than 10%). In addition, the packaging material must be impermeable to vapour and gas, resist tearing, protect against contamination from the environment, be easy to handle, and preferably be inexpensive. Flour can maintain its quality for 5 to 7 months provided that it is stored in cool, dry, dark places using appropriate packaging, for example in polypropylene or polyethylene bags.

In summary, to produce good quality sweetpotato flour, due considerations must be given to the quality of raw material, the processing process, and storage. First, ideally the roots should be high in dry matter content and low in polyphenolic compounds. Second, if a white colour is required, peeling is necessary. But not peeling increases yield. Third, soaking, with or without sodium meta-bisulphite or citric acids can prevent browning and discolouration, and microbial contamination. Fourth, Heat treatment with high heat intensity during drying can cause damage to the protein and the β-carotene. Fifth, the use of solar drying is cheap, but it requires much attention to hygiene practices. Finally, for storing sweetpotato flour, the initial moisture content should be low (< 10%) and levels of moisture uptake can be limited using appropriate packaging.

Angue and Inocencio (1992) observed that studies on sweetpotato processing tended to focus on chemical analysis of the flour while improvement of sweetpotato processing technologies was rarely carried out. This is an oversight as processing costs depend on the type of technology used and processing costs can be lowered by using inexpensive technology. In addition, for technology to benefit smallholder farmers and rural processors, it must be easy to use, provided by local artisans at a low price, and have multiple uses for those periods when sweetpotato processing is not possible. They recommended that more emphasis is needed to raise awareness and interest in improving flour processing technologies and processes.

8 Results from field research

The empirical work of this project included on-station sweetpotato flour production trials and on-farm and off-farm sweetpotato product development trials with collaborators. On-station technical trials focused on developing processing protocols and collecting and analysing technical and cost data and quality composition of the flour to identify areas for improvement. On-farm/off-farm product development was done in collaboration with an industry partner (Paradise Foods) and three communities in Lae and 2 communities in Minj. While Paradise Foods was supplied with sweetpotato flour only, participating communities were provided with flour, as well as recipes, training, necessary inputs (flour or milling machines/baking ovens) and technical support. In this section, the results from on-station flour production trials are presented. First, we present results from on-station flour processing, followed by on-farm/off-farm product development in collaboration with local communities and social mapping.

8.1 On-station flour production trials

Altogether six batches of sweetpotato flour in different volumes and using three different varieties were produced. Data collected included: (1) the time taken from weighing, sorting, washing, peeling, chipping, drying, milling, sieving, to packaging of flour (as shown in Figure 1); (2) input costs; (3) extraction rate; and (4) proximate contents of flour.

Key results are:

- Raw material: one bag of fresh sweetpotato roots (80-100kg/bag).
- Time consumption: on average, it took 28 hours from start to finish, including 20 hours of drying time.
- Total variable costs: sweetpotato (K88/bag) + water use (K5) + electricity use (K12) + labour (K50) = K158.
- Extraction rate: 17-20%.
- Proximate analysis: average readings from 4 samples tested: protein, 3.26%; moisture, 6.34%; fat, 1.67%; ash, 1.93%; and fibre 1.82%.
- Average variable cost of flour: K158/20kg = K7.80.

Yield. An extraction rate of 17-20% is within the range of 17 to 38% reported by Van Hal (2000), but is on the low side. Flour yield depends on the raw material (variety and quality of fresh roots) and the processing processes, especially peeling, soaking and drying) employed. Roots with higher dry matter produce higher yield. Drying more than necessary reduces yield. Losses due to peeling and trimming are particularly important.

Proximate composition. Proximate analyses showed that the nutrient contents from four samples are within the ranges reported in other studies and meet the African standard presented in Table 8.

Table 10. Proximate analysis results from 4 samples (in %)

SP Sample	Milled	Tested	Protein	Moisture	Fat	Ash	Fibre
One-moon	04.10.12	23.10.12	2.58	8.25	3.75	1.00	2.00
Wahgi Besta	29.11.12	9.12.12	3.24	7.50	0.75	2.50	1.50
Wahgi Besta	11.12.12	18.12.12	*4.22*	2.85	0.67	2.48	3.26
Kerot	22.04.13	29.04.13	3.00	6.75	1.5	1.75	0.50
Average			3.26	6.34	1.67	1.93	1.82

Results from other studies			1.0-8.5	4.4-13.2	0.06-1.90	1.28-2.53	2.3-19.3
African standard			--	< 12%	--	< 3%	< 5%

Source: sweetpotato flour analysed by Unitech.

Moisture content, ranging from 2.85% to 8.25%, appears low compared to the minimum requirement of less than 12% indicated in the African standard. This suggests that drying procedures (temperature and drying time mix) can be adjusted to achieve the acceptable moisture content of 10-12%. This will not only improve yield, but also save on energy cost.

Another observation is that the results are quite varied from sample to sample. It is not clear how much they reflect the real difference across samples and how much is due to the unreliability of the test. [9]

Costs. An extraction rate of 20% means that it takes 5kg of fresh roots to produce 1kg of flour. At the retail price of K0.88/kg for fresh roots at the Lae market, raw material cost alone is K4.4/kg. This is close to the retail price of wheat flour at K3.8-4.5/kg and rice price at K3.45-4.0/kg at the Lae supermarkets (Table 11).

Table 11. Flour prices at Food Mart, Lae, September 2012

Product	Manufacturer	Price
Plain wheat flour	Goodman Fielders	K3.8/kg
Self-raising wheat flour	Goodman Fielders	K4.0/kg
Scone wheat flour	Goodman Fielders	K4.40/kg
Plain wheat flour	3 Roses	K4.40/kg
Self-raising wheat flour	3 Roses	K4.50/kg
Rice	EZY Cook	K3.45/kg
Rice (10kg)	Various brands	K2.2-2.95/kg
Buckwheat flour (500g)	EGE Fine Foods (Australia)	K15.90/kg
Wheat flour (enriched Vit B1-B2, folic acid, iron and zinc)	Cakra Kembar (Indonesia) (For bread)	K7.15/kg
Wheat flour (enriched with Vit A, B1-B3, D3, folic acid, iron and zinc)	Kunci Biru (Indonesia) (For biscuits/cookies)	K6.50/kg
Atta flour (400g)	Alagapas (Malaysia)	K6.50/kg
Arrowroot flour (500g)	Nguan Soon (Thailand)	K9.40/kg
Sago starch	PNG Local	K7.00/kg
Wheat starch (450g)	Foo Lung (Belgium)	K10.70/kg
Corn starch (500g)	Nguan Soon (Thailand)	K8.20/kg

When other variable costs (labour, water use, and electricity use) are taken into account, sweetpotato flour would cost twice as much as wheat flour. However, if sweetpotato were sourced locally, the cost of sweetpotato could be reduced by at least half to around K0.40/kg.[10] At K5.3/kg (K2.0/kg for sweetpotato and K3.3/kg for other variable costs),

[9] *Previous studies found that the service provided by Unitech was unreliable and expensive. There was also no guarantee when the results would be received. It seems it would be beneficial if these tests can be done on-site to ensure timely, reliable results are obtained.*

[10] *Processing near the production areas will also improve the quality of roots significantly. In one of the trials, we found that the quality was extremely poor, with nearly 50% of the roots already sprouted.*

sweetpotato flour would become more competitive. Similar results were found in other studies (e.g. Peters and Wheatley, 1997; Omosa, 1997; Amano, 1996). It was suggested that sweetpotato flour has to be 50%–90% lower in order to replace wheat flour in any significant volume. Omosa (1997) also found sweetpotato flour uncompetitive with cassava and maize flour because of high raw material cost.

These results suggest that only by inexpensive raw materials and by very efficient processing can sweetpotato flour be competitive with wheat flour. In terms of reducing raw material cost, considerations must be given to improving yields to lower cost of production, selecting variety of high dry matter, identifying processing sites that are near the source of supply and potential markets, and improving postharvest management to reduce product losses during transit and storage. More research is also required to determine the desirable moisture content and the optimal combination of temperature and drying time and the effect of unpeeling on the quality of flour and its derivatives.

8.2 Off-farm industry-level sweetpotato product development trials

Four local food processors were consulted in September 2012, including Lae Biscuits, Nestle, and Paradise Foods in Lae and POM. All appreciated the idea and saw the market advantages of using sweetpotato as an input because sweetpotato is locally available and organically grown, and with significant health benefits (high in β-carotene, anti-oxidants, and fibre, and with low GI). High sugar content was seen as a potential problem, but also as a positive for making semi-sweet biscuits. Another strong message received was that they were only interested in sourcing flour directly, rather than producing flour on-site because it would require a significant investment in equipment and storage. Common concerns for food processors were flour quality and consistency of supply of flour. Another thing we learned from consultation with major food processors was that for proximate analysis, samples were sent to either Australia or Singapore either because such services were not available or unreliable –something that we experience ourselves. A well-equipped national food lab was suggested as a solution.

After careful consideration, we decided to work with Paradise Foods in POM as it has a R&D division and is keen to collaborate on developing sweetpotato products seeing it as a way to help local farmers.

Four batches of sweetpotato flour samples were sent to Paradise Foods in POM, but two batches were lost in transit between Lae and POM for unknown reasons. The required flour specifications for making biscuits from Paradise Foods are shown in Table 12 below.

Table 12. Flour compositional requirements of Paradise Foods

Parameters	Requirements
Protein	6-8%
Moisture	5-7%
Fibre	4-6%
Ash	3-5%
Colour	Varies, depending on sample

Based on the two samples received, five small-scale trials were conducted to produce cracker biscuits from composite flour using different proportions of sweetpotato and wheat flour. Three small scale trials were conducted in January (using white-fleshed Wahgi Besta variety) and two trials in May (using orange-freshed Kerot variety). In the first and second lots of trials, products were developed with 100% and 50% of sweetpotato flour, respectively. The resulting doughs were not of the quality expected and were rejected. In the third lot of trials, the proportions of sweet potato flour in the composite flour were reduced to 5-30% and they produced reasonably good products. Two more trials were conducted using Kerot variety using 5-30% of sweetpotato flour. Preliminary results also showed that white flour (Wahgi Besta variety) produced slightly better results compared to the yellowish flour (Kerot variety).

These products were evaluated by the new product development team at Paradise Foods. The initial assessment was that high percentages of sweetpotato flour (50-00%) were not suitable for cracker biscuit development, while small proportions (5-30%) was deemed having some potential. It was recommended that more experiments be conducted on biscuits to improve product quality, as well as testing on cookies and shortbreads.

Five packets of sweetpotato cracker biscuits, as well a box of traditional wheat-based biscuits, were received from Paradise Foods and evaluated by the NARI team. The consensus was that it was a good start, but much is yet to be done to improve the quality of sweetpotato cracker biscuits.

8.3 On-farm village-level sweetpotato product development trials

Several flour samples were distributed to three communities, including Gebansis, Sibi and NARI.[11] Each recipient was given 500g or 1kg of sweetpotato flour to "make something out of it", along with recipes and basic training on flour processing and baking. With the Gebansis group, the products they came up with were cakes, cookies, and sweetpotato balls. For the Sibi group, more than a dozen interesting new products were developed using ingredients that were available in the village. Some of these products were show-cased at the NARI Agricultural Innovation show in June 2013. They were well-received and generated significant awareness and interest in sweetpotato processing.

Flour was also provided to several NARI staff to test the hypothesis that it is easier for urban households to get involved in processing than rural households because of ready access to basic services and baking facilities. However, nothing was done with the free samples provided t urban household, mainly because of time constraint and the potentially very high opportunity cost of home baking. This may appear to be a trivial result. However, it has significant implications for where and how sweetpotato processing is to be promoted. It suggests that households whether they are in the village or in the city are not potential users of sweetpotato processing technology. While rural households lack access to necessary equipment and ingredients for home baking, urban households lack time and motivation.

This means potential target market for future training and education is most likely to be commercial operators, be it entrepreneurs, micro-enterprises, local bakeries, and food processors, rather households. If commercial operators are the target market, the training must include both technical and business training if they are to succeed in a commercial environment.

8.4 Social mapping

In this project social mapping, a participatory rural appraisal (PRA) method, was used to track the spread of the postharvest technology on sweetpotato flour processing in two village communities 6-8 months after they received training and sweetpotato flour from the project (Sar et al., 2013). The two collaborating communities were from two Local Level

[11] *More information about Gebansis and Sibi villages are provided in social mapping discussed in the following section.*

Governments (LLGs), Wain-Erap and Wampar, in Morobe province. Participants from the Wain-Erap LLG were members of the Kasuka Cooperative Group from seven villages located in the Middle Erap: Kwerebo, Kawalang, Barawang, Bayang, Sibi, Sawana and Kwaleng. This group has a population of approximately 5000 people. The second group of smallholder farmers were from Gebansis village, Wampar LLG with a population of approximately 7000 people -- this is a large village compared to most villages in PNG. Sibi village is an hour's drive away from Lae in a mountainous area 600 meters above sea level, while Gebansis is more conveniently located near the main road to Bulolo.

8.4.1 Social mapping in Middle Erap community

The mapping exercise was done at the community resource centre in Sibi village, with 30 participants. Two maps were made: one for the whole community and one for Sibi village. Participants were formed into two groups and each group concentrated on drawing one map after receiving general instructions on what to do.

The Sibi village mapping began with a description of the location of the resource centre, main roads, mountains and rivers, and any other relevant geographic features (Figure 3).

Figure 3. Sibi village map

The group working on the community map was asked to include the locations and names of the villages in the community and any information on development projects occurring in each of the village, such as cash cropping. They were also asked to identify villages where sweetpotato flour knowledge was disseminated and to indicate the number of households who used the sweetpotato flour distributed and the location of drum oven.

Key features included on the community map were: the location of community resources such as schools, health clinics, churches, and development intervention projects, such as fish ponds, rice fields, and pineapple fields. One the map, Chinese taro (*Xanthosoma sagittifolium*) was identified as the major food crop, and coffee and cocoa as major cash crops. These crops were widespread in the community. The only drum oven in the community was located in Sibi village and owned by a community leader. As in most rural communities in PNG, there is no rural electricity service in Sibi village although few households were using generators and solar power. From the map, out of the initial 7 villages identified as project villages, only Sibi was actively utilising the sweetpotato flour to develop new products.

The Sibi village map identified the location of four groups, including (1) households who had attended postharvest training, but did nothing, (2) those who attended the training and used the sweetpotato flour distributed, (3) those who attended the training, used the sweetpotato flour distributed, and had shared the sweetpotato knowledge with others, and (4) those who did not attend training but were given the flour and used the flour. Households that used the sweetpotato flour also showed recipes that they used and the modifications made. The results showed that 16 households had used the flour. Baking was done in groups, mostly by women members, using the only drum oven in the community. On average, Sibi participants modified each recipe six times in order to get satisfactory results.

A major enabling factor in the Middle Erap community was the presence of the PNG Volunteer Service officer (VSO), Ms Priscilla Lillih, employed to facilitate and keep records of development interventions in the community and to ensure the community benefited from the various projects. Priscilla resides in the Sibi village where the resource centre is located and works closely with the community leaders and outside R&D organisations. The R&D organisations that had presence in the community were NARI (inland aquaculture, rice growing, and sweetpotato processing), Trukai (rice production), ADRA (Healthy Island Concept), FPDA (fresh produce production), and district office (cash crops – coffee and cocoa). The community also has a link with urban supermarkets in Lae supplying fresh fruit and vegetables to Papindo, Anderson, and Foodmart on a weekly basis. The Evangelical Lutheran Church is also a major player in the community with several activities to improve livelihoods. Over time Priscilla had developed strong rapport with the community and outside development organisations.

8.4.2 Social mapping in Gebansis village

In Gebansis village, mapping was done on the village community day -- a day reserved for meetings and discussions of community affairs in the village between the villagers with their leaders. The attendance was very good. There were 70 people participating, with equal representation of male, female, youth and the elderly. Maps were first done on the ground, and then transferred to large sheets of paper (see Figure 4).

Figure 4. Participatory ground mapping at Gebansis village

On the maps participants identified those who attended the training in food processing, those who proceeded to bake using the recipes provided, those who shared the knowledge on sweetpotato recipes, and those with whom knowledge was shared.

Gebansis village is structured into 8 sections with nominated section leaders coordinating development activities under the leadership of the overall village committee chairperson. There was plenty of potential for more households to use sweetpotato flour based on the interest shown by women living around the centre of the village. Two of these women own drum ovens. Another drum oven was owned by the coordinator of the agro-tourism project**.**[12] In one section, the population is higher than the seven other villages put together. Therefore if sweetpotato flour innovation is successful in this section, the impact could be greater.

The coordinator of the Agro-tourism Eco-lodge, Sam Ifid, is an overall community leader who works with other section leaders to ensure efficient management of community resources and maintain harmony in the village, He is the main contact with outside organisations. The village has easy access to Lae urban centre and electricity is available for those who can afford it. Gebansis village has a cocoa cooperative and there is a strong presence from the Niugini Tablebirds Poultry as most households are engaged in raising chickens for the company as contract growers. In Gebansis, banana is the staple crop so sweetpotato for processing was purchased from the Lae market.

8.4.3 Spread of sweetpotato postharvest technologies

GIS technology was introduced after ground and paper maps were cross-checked and participants had identified points of local significance and are relevant to their community development projects, including sweetpotato processing. The local maps were juxtaposed with Google Satellite Maps to show the exact position of those focal points.

The spread of knowledge, and village resources, are shown in Figure 5 (Sibi village) and Figure 6 (Gebansis village). Notice that in Sibi village, the paper map was juxtaposed with the Google Satellite Maps, whereas the one for Gebansis is not. The circles on the maps showed where the groups who took on sweetpotao processing were located. The more circles there are, the more people were involved, and the bigger the circle, the more the technology had spread in that location. The large (purple) circle at the bottom of Figure 5 shows where the resource centre and Priscilla are located in Sibi village.

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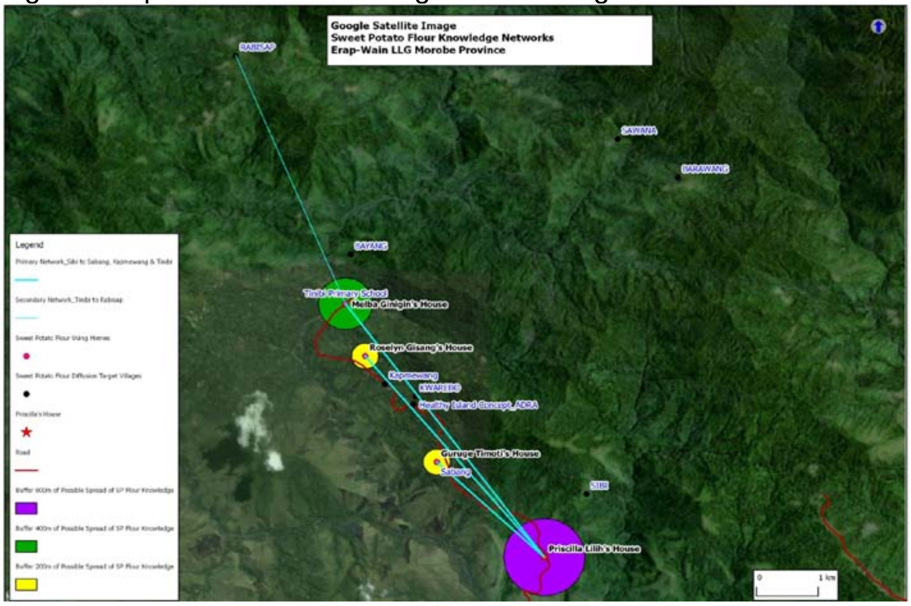
12 The agro-tourism project was a two-year project funded by a Korean University, with NARI and Gebansis village as collaborators. The objective was to build an eco-lodge to promote agro-tourism for the area. The eco-lodge was to be supplied and managed by the local people. The main activity was to train the community on the production and processing of African yam with an aim to supply the eco-lodge, along with local produce. The agro-tourism project did not eventuate as African yam was introduced into a banana-based farming system. The Eco-lodge has not been in operation since its completion in 2011 because of issues over land ownership where the Agro-tourism Eco-lodge was located.

Figure 5. Spread of SP knowledge in Sibi village



By comparion, in Gebansis village (Figure 6), there are two big circles and they represented where the school and the community leader are located.

Figure 6. Spread of SP processing knowledge in Gebansis village

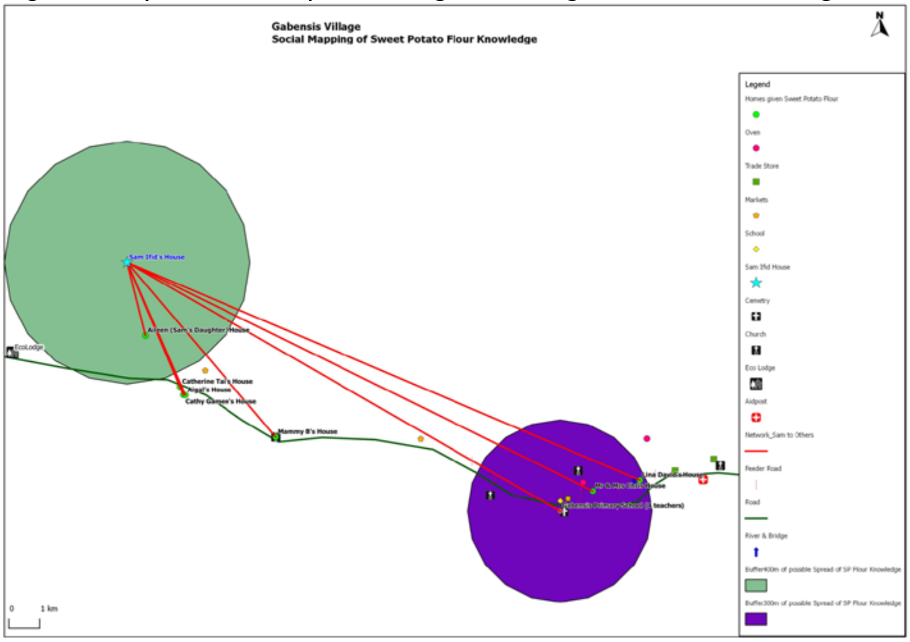


Table 14 shows the type of products that have been made and the number of people involved in Sibi and Gebansis villages, based on the 30 some products displayed at the NARI Innovations Show (AIS) in June 2013.

Table 14. Sweetpotato products displayed at the NARI Innovations Show, June 2013

Village	Sibi	Gebansis
Sweetpotato products	Donut, Pastry (Pumpkin, Potato – popular recipe), Scone, Fried flour, SP cookies, Banana cake, Peanut cookies, Ukoi – (pumpkin, pawpaw), Strawberry	SP strips, Cassava SP cake, Fried SP balls, Sago SP fried, Donut, Cookies – (pumpkin, banana), Boiled SP flour, Fried SP flour & Rice balls.

	flavoured cookies, Steamed banana cake, bun, bread, Cassava donut with locally made desiccated coconut, pizza base, bun – various flavours	
No. of households involved	15	7
Average no. of modification made to recipes	6	2

Figure 7. Sweetpotato products from Sibi village at NARI AIS

From the mapping exercise, we identified the social networks through which sweetpotato knowledge was disseminated, the change agents, and the individuals who used the knowledge and their relations to the change agents. In particular, we found that in Gebansis social networks are based mainly on kinship while in Sibi village, social networks extend to include neighbouring villages who are members of the co-operative. The coordinator for Sibi village, being a full-time volunteer from outside, appears to be more objective and inclusive in her decision making. Given that rural communities are diverse and their social structure, complex, the people-oriented participatory multi-layered methodology employed in this project helped gain significant insights into the working and power relationships of rural communities that has significant bearing on knowledge dissemination aimed at improving livelihood. Further research is needed to address the socioeconomic constraints to technology dissemination and adoption, and to identify appropriate technology (equipment and tools) for rural households with limited resource. Given that leadership is the most significant enabling factor in the spread of technology and initiating change, it is crucial to identify individuals who have the social capital and commitment to broaden the existing networks to include wider communities.

8.5 Impact assessment

In August 2013, the research team went to Sibi village to assess the impact of the training on them, and their experience with sweetpotato processing, as well as to find out more about constraints and opportunities for village-level processing. First we spoke with the village as a whole (with nearly 100 people) and later with half a dozen people who have taken on sweetpotato processing.

A few issues were identified in regards to sweetpotato processing, including

- Product development – development costs were high because it took time and several experiments to get it right. Using local ingredients reduced costs and encouraged creativity.
- Equipment – availability of equipment and tools are a serious issue for the community and they were looking at other ways to bake/cook, such as dish oven, steaming and frying, as there was only one drum oven in this community. More research was needed on identifying food processing equipment that is relevant to community use.
- Costs of ingredients – availability and cost of sweetpotato and other ingredients, such as oil, sugar, egg, wheat flour, etc, were also an issue.
- Labour intensity – it was time-consuming to make flour.
- Access to sweetpotato processing training and flour – some participants complained about not having access to training or flour because they were not part of the networks.

Overall, the most significant impact of the project was the increased community awareness of sweetpotato processing. This was achieved through the following activities:

- Processing training provided to communities in Jiwaka and Morobe provinces;
- Participation in the NARI Innovations Show, which show-cased more than 30 sweetpotato products made by collaborating Sibi and Gebansis communities;
- Processing training provided by Priscilla Lilih to women leaders from 15 parishes of Lutheran Church in Morobe province;
- Sweetpotato products provided to visitors to Sibi village and neighbouring villages; and
- In September 2014, the Kasuka Co-op will be preparing sweetpotato products to entertain more than 1000 people at the Lutheran Church conference. NARI team will help prepare sweetpotato flour for the group and disseminate extension materials at the venue.

In addition, sweetpotato products have been sold by several farmers at both Gebansis and Sibi villages with great success (they were sold very fast). Profitability from the sales is yet to be assessed.

8.6 Stakeholder consultation and workshop

The sweetpotato product development stakeholder workshop was held at the NARI's AQ Conference Centre, 21-22 November 2013. There was equal participation from each group that had been actively involved in the project, including NARI, Unitech, Gebansis village, and Sibi village. A total of 30 participants attended the workshop.
Seven presentations were made, covering the main activities of the project. They included:

1. literature review on enabling environment: the necessary conditions for fostering private agro-enterprise development in sweetpotato processing at the household/village level and in the food manufacturing industry;
2. review of sweetpotato processing work at NARI and future research directions;
3. the process of flour production;
4. results from on-station sweetpotato flour processing trials and costing;
5. off-farm product development trials conducted at Paradise Foods
6. on-farm product development trials conducted at Sibi village; and
7. social mapping conducted at Gebansis and Sibi villages.

All presentations were of high quality with useful and interesting information; they were well-received. Key issues raised and discussed at the workshop included: the role of food processing (vs increasing production) in achieving food security; the role of government (subsidies and the provision of basic services); who is responsible for ensuring the sustainability of the project when the project ends; is the project promoting household, village or industry level processing; scale of production (own labour versus labour-saving equipment); variety selection; where processing should take place (lowland vs highland); and how to make unique sweetpotato products using locally appropriate recipes and locally available materials. These issues were addressed in this report.

9 Policy and business environment for sweetpotato processing in PNG

The “development of food processing and preservation industry” (Program Area 2) is listed in the Priority Program Areas for Food and Horticulture Crops Development in the National Agricultural Development Plan 2007-2016, with the objective “to develop food processing and preservation for commercial and cottage industries” (Ministry of Agriculture and Livestock, 2006). The other two program areas are: Program Area 1: Improved food production and Program Area 3: Market development and promotion. The first strategy listed under Program Area 2 is “Conduct feasibility study” to “establish guidelines for product development, the demand, volume, quality and price”, “provide the development plan and a business plan for establishing the food processing and preservation industry in the country”, and “determine upstream requirements for the raw materials and supply to the processing industry”.

NARI was mentioned in the Strategy 2: Long term research and development, and are responsible for “research on development of local staples, introduced vegetables and nuts into marketable food and industrial products”. FPDA was mentioned in Strategy 3: Development of new products. New products when developed were expected to “increase farm profitability through new enterprises, create employment, reduce the freight cost and increase the shelf life”. Clearly, food processing is considered as a key element to agricultural development in PNG.

In the 2014 Budget Strategy Paper (Government of PNG, 2013), “Improving the enabling business environment for the agriculture sector as well as small to medium enterprises” through microeconomic (or structural) reform is listed as one of six key priorities[13]. The microeconomic reform agenda encompasses:

- encouraging state-owned enterprises (SOEs) to be efficient, with a particular focus on the telecommunication, electricity and transport sectors;
- enforcing the competition and consumer protection law so that markets operate competitively and fairly;
- build the productivity of tourism and agriculture sectors especially in rural and remote areas of PNG;
- reduce the cost of doing business and remove regulatory impediments to private sector growth;
- facilitate the development of the small and medium enterprise sector; and
- encourage the operation of the informal economy and the transition of informal economy participants to the formal economy.

These two documents suggest that the policy environment is favourable to small-scale food processing. Although they are not directed specifically at sweetpotato processing, or any other crops, there is an opportunity for such a proposal. This is because sweetpotato is the main staple crop in PNG and is grown by smallholder farmers across the country, the socio-economic impact on rural communities could be significant if an efficient sweetpotato

[13] The other five key priorities are:
1. Maintain Papua New Guinea’s macroeconomic stability;
2. Implement major infrastructure projects;
3. Ensure an appropriate alignment between the construction of new roads, health or education buildings and the provision of money;
4. Continue to expand funding in the education sector; and
5. Continue to expand funding in the health sector.

processing sector can be established. The impact could be even greater when the associated technology is spilt over to other root and tuber crops (e.g. cassava, yam, taro).

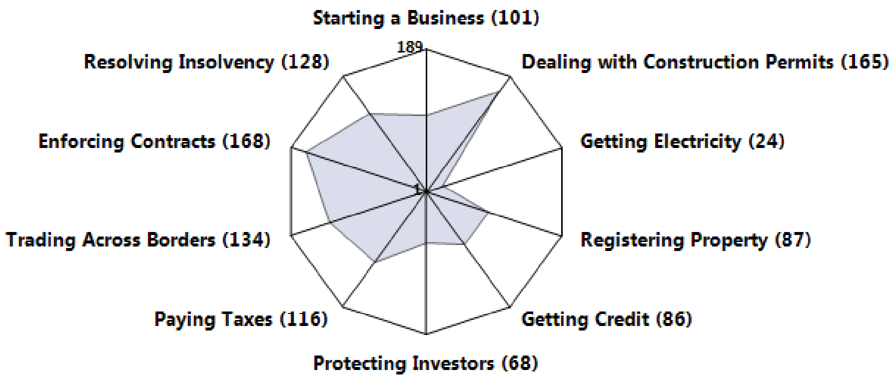
GTZ (2003) identified ten preconditions that are necessary for successful intervention in rural development through agro-enterprise development:

- An enabling environment that provides for an attractive investment climate and fosters dynamic entrepreneurship;
- Adequate mechanisms and structures that address local needs;
- Active private sector institutions and linkages;
- Functioning and effective infrastructure (hard and soft);
- Access to integrated and open markets;
- Access to effective and efficient support services and resources;
- Adaptive management capacity and entrepreneurial competence within business and enterprises;
- Local organisations, groups and associations (representing the poor) as building blocks;
- Active participation in and ownership of development processes by well-linked stakeholders; and
- Ongoing learning from success and failure by all stakeholders.

This means the current business environment is not as favourable. Some of the well-acknowledged problems are: law and order, lack of basic infrastructure (roads and transport, and water and electricity supplies), high costs of doing business, and unskilled labour force.

The business environment in which domestic small to medium-size businesses operate can be assessed using the *Doing Business Index which* ranked economies from 1 to 189.

Figure 8. Papua New Guinea's ranks on Doing Business



Source: World Bank Group, 2013.

PNG's rankings on Doing Business is presented in Figure 8.[14] As shown, PNG is ranked 101/189 for starting a business and 168/189 for enforcing contracts. Interestingly enough, PNG is ranked 24/189 for getting electricity even though it requires 4 procedures, takes 66 days and costs 57.5% of income per capita to get connected, and there are frequent blackouts.

Clearly, there is a significant role for the PNG government to play in providing an enabling environment for developing an efficient food processing sector.

[14] For each economy the index is calculated as the ranking on the simple average of its percentile rankings on each of the 10 topics included in the index in *Doing Business 2014*: starting a business, dealing with construction permits, getting electricity, registering property, getting credit, protecting investors, paying taxes, trading across borders, enforcing contracts and resolving insolvency. The ranking on each topic is the simple average of the percentile rankings on its component indicators.

10 Future prospects for market diversification and sweetpotato processing

Sweetpotato is a "wonder crop" and is widely grown in the world. It requires few purchased inputs and relatively little labour and can be grown from sea level up to 2500 latitude. It tolerates dry periods and yields well even on marginal soils. It has a flexible growing season which allows piecemeal harvesting over a 3-10 months period and a tremendous capacity for producing high yields (up to 80 Mt/ha).

Sweetpotato has many potential end uses: roots can be used as fresh food, stockfeed, and raw material for processing into starch, dried chips/flour, and new food products, while vines (from the right varieties) can be used as a vegetable and stockfeed. Worldwide, sweetpotato is used mainly in fresh form for human consumption and as stockfeed.

As fresh food, sweetpotato is an excellent crop (Woolfe, 1992). Both roots and vines are highly nutritious. In recent years, it is also recognised as a functional food with anti-carcinogenic, anti-oxidant, anti-inflammatory, and cardiovascular disease preventing properties; its low Glycemic Index helps stabilise blood sugar and reduce insulin resistance; and OFSP with high beta-carotene is used to combat Vitamin A deficiency for children in Africa (WHfoods, n.d.). Despite its many nutritional and health benefits as fresh food, sweetpotato is consumed mainly by the poor in developing countries of Asia and Africa as a supplementary or food security crop.

PNG is an exception, where sweetpotato remains the main staple food, with an average annual consumption of 260 kg per person – the highest in the world. The world average is 8.3 kg. Worldwide, per capita sweetpotato consumption tends to decline with income growth and urbanisation as consumers are afforded choices in price, quality, convenience, and diversity. The current high level of sweetpotato consumption in PNG will change, and has changed in urban centres (Gibson, 2001b). Markets for fresh roots will continue to exist in PNG in the short to medium term, but the demand for quality will increase. In the longer term, sweetpotato will become less important as a staple food.

As stockfeed, sweetpotato has some shortcomings, such as a lower dry matter and relatively indigestible roots (due to the presence of trypsin inhibitors). However, these problems can be addressed through ensilaging, especially for smallholder farmers, and genetic improvement. During economic transition, while fresh use is declining, more sweetpotato will be used as stockfeed but may be replaced eventually by commercially formulated feed, as happened in China and several other Asian countries (Japan, Taiwan, Vietnam, etc) in the past few decades. In PNG, sweetpotato as stockfeed has good potential because it is already widely practiced. It is also complementary to the development of a high quality fresh market, utilising rejects and seconds from sorting and grading.

Several arguments have been put forward for promoting sweetpotato processing in PNG and elsewhere, including:

- Fresh sweetpotato roots are bulky and perishable, processing (e.g. into dried chips and flour) allow them to be transported further and store longer.
- Processing into new food products (e.g. chips, cake, bread, donuts, candies, snacks) can create new uses for a crop that traditionally is boiled or roasted as a staple food.
- Processing into flour can reduce reliance on imported wheat flour.
- Processing provides an opportunity for farmers to diversify their income sources.
- Processing provides opportunities for generating off-farm employment and speeding up rural development.

Sweetpotato processing may have some potential in PNG. However, it is non-existent right now.

For sweetpotato processing to succeed on a commercial basis, the price and quality of sweetpotato products must be competitive with other competing products. Small-scale trials conducted in this project showed that it is not currently competitive and is unlikely to become competitive without removing significant obstacles it faces. Research conducted in Asia and Africa in the past few decades also showed that sweetpotato, as a raw material for commercial food processing, is not as versatile functionally or cost competitive when compared with wheat and corn (for flour production), potato (for fries/chips production), and cassava (for starch production). This is the main reason why there is little sweetpotato processing in the world. Only a very small proportion (less than 1%) is processed into dried chips and flour. They are practiced in regions where sweetpotato cannot be gown all year round and used mainly for home consumption (humans and pigs).

China is an exception where about 10-15% of sweetpotato production is processed into starch noodles and snack foods on a commercial basis and industrial scale. However, this is a result of decades-long dedication and international collaboration with CIP on building capacity in research, development and extension, and strong government support in industry development. The recent success in Africa with orange-fleshed sweetpotato and processing is also a direct result of substantial external funding and international collaboration in research and product development and promotion. Without such high levels of support, sweetpotato processing would either be non-existent or remain, at best, as a cottage industry.

Given the current levels of support and knowledge, promoting sweetpotato processing into commercial enterprises would be very difficult. However, if the PNG government is determined to develop a food processing industry, as indicated in the National Agricultural Development Plan 2007-1016 and the 2014 Budget White Paper, further research into sweetpotato flour processing, and related product development, can be used a pilot to not only build capacity but also provide an opportunity to investigate whether and how an efficient food processing can be developed in PNG.

11 Conclusions and recommendations

11.1 Conclusions

Sweetpotato has many uses: as fresh food, stockfeed, and raw material for flour and starch production. The global sweetpotato utilisation pattern in 2009 shows that nearly half of global production was consumed fresh, nearly 40% was used as stockfeed, nearly 7% was wasted, and less than 1% was used for processing. This utilisation pattern has been determined by market forces. The main reason for the low level of processing is that sweetpotato as a raw material for food processing is not competitive with its main rivals, e.g. cassava for starch and wheat for flour. China is an exception. Sweetpotato processing in China focuses on traditional Chinese starch noodles – a niche market, and its industrialisation owed much to the strong push from the national government and international collaboration in capacity building. Much can be learned from China's and Africa's experiences in sweetpotato product and process technologies and in research priority setting, and they can serve as a starting point for adaptation to conditions in PNG.

The main conclusion is that given the current environment, promoting sweetpotato processing into commercial enterprises would be very difficult. Limited research resources may be better spent on improving the markets for fresh roots and for feedstock. However, if the PNG government is determined to develop a food processing industry, as indicated in the National Agricultural Development Plan 2007-1016 and the 2014 Budget White Paper, further research into sweetpotato flour processing, and related product development, can be used as pilot both to build capacity and to learn whether and how an efficient food processing sector can be developed in PNG. If this is the case, flour processing will be the most promising food processing option for sweetpotato both for cottage and industrial uses. Furthermore, developing an efficient sweetpotato processing sector will take time, will require local ownership and will need strong government support and international collaboration to build local capacity. And it must start small.

11.2 Recommendations

- That future processing research for sweetpotato focus on improving flour quality and processing efficiency.

  This will include: (1) evaluating and selecting varieties that possess desirable processing traits (e.g. high dry matter). Due to the number of sweetpotato varieties available in PNG, it is necessary to determine what varieties are most suitable, as well as whether and how mixing varieties affect flour quality and consistency; (2) improving flour processing efficiency and paying special attention to the selection of fresh roots, peeling, soaking and drying; and (3) identifying locally appropriate systems for grading and storage to maintain the quality of fresh sweetpotato roots and intermediary and final products.

- That future processing research for sweetpotato focus on developing niche products from sweetpotato flour and local materials.

  Previous research into sweetpotato product development has focused on mimicking wheat products. This is not a winning strategy, according to Peters and Wheatley (1997). This is because functionally sweetpotato flour is very different from all-purpose flour. Even partial substitution of wheat flour with sweetpotato flour will change the taste, smell, and texture of the product enough to have it appear as a different product. Moreover, if sweetpotato flour is to be used as a substitute for wheat flour to mimic the original products (made with 100% wheat flour), then low substitution levels can be expected. Substitution at low levels will add costs and produce little economic benefits, which defeats the purpose of substitution.

On the other hand, opportunities exist for sweetpotato products to be marketed to a niche market as new products in their own right. However, it will require a different mindset (that is the market is likely to be small), and a different approach to product development (that is, more experimenting than following existing recipes designed for wheat products). Small-scale trials conducted in this project showed that sweetpotato products made of locally available materials such as coconut, banana, peanuts, cassava flour, etc are of good quality and have unique local flavour. The fact that sweetpotato flour cannot compete with wheat flour both in price and functional properties indicates clearly that efforts in trying to imitate wheat flour has not worked and will not work. Rather, the focus should be on developing sweetpotato products that accentuate the unique characteristics of sweetpotato, and use as much as locally available materials and traditional cooking methods as possible.

- That processing research focus on adaption research and extension

  Sweetpotato is a very important crop, especially for the poor. Significant processing research has been done in Asia and Africa since the 1980s as a pro-poor development strategy to assist smallholder farmers. A large volume of research papers is available online. There will be great savings in time and resources, and gains in efficiency if more research effort is devoted to review existing literature, learn from it and build on it. Furthermore, the aim of processing research should be eventually passing the information and technology to entrepreneurs and commercial operators. Therefore, more resources should be allocated to extension and capacity building of potential operators.

- That a systems approach and interdisciplinary research program be considered to improve overall competitiveness of sweetpotato.

  Regardless of use, sweetpotato must compete well in price and quality in the market. However, currently it is not competitive as fresh food, as stockfeed or as raw material into processing. Many factors contribute to its un-competitiveness, including low input-low yield production systems, poor postharvest management (no sorting/grading, poor packaging and handling), and inconsistency in supply and resulting variable prices. This means processing research designed to diversify use or increase market demand must be supported by research designed to increase on-farm productivity (through improved varieties and planting materials, pest and disease control, soil fertility, etc) and postharvest management research to maintain quality. Similarly, linkages between different uses must be recognised and managed, e.g., potential competition for quality roots between fresh and food processing use and the potential use of seconds and by-products from the fresh market and processing as stockfeed.

- That stakeholders in the sweetpotato value chain lobby for government support in research, development and extension programs for food processing

  One key lesson learned from the Chinese and African experiences is that developing a sweetpotato processing sector will require significant investments from the national government, national agricultural research organisations and the food industry. The policy environment appears favourable given the strategy statements made in the National Agricultural Development plan 2007-2016 (the development of a food processing sector) and the 2014 Budget Strategy Paper (the development of a small to medium private business sector). An industry forum comprising of key stakeholders will help identify research priorities for key crops of interest. Such initiatives must come from the stakeholders to ensure local ownership and participation. One possible source of government funding for an industry forum and a pilot study, and possibly a national food laboratory, is the Public Investment Projects.

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13 Appendixes

13.1 Appendix 1: Table 3. Annual per capita food supply/consumption in the world and the Pacific, 2009

(In kg)	World	Australia	NZ	USA	PNG*	Fuji	Solomon Islands	New Caledonia	Samoa	Vanuatu
Total Cereals	**146.7**	**96.9**	**95.4**	**108.2**	**51**	**147.1**	**86.7**	**108.1**	**66**	**99.5**
Wheat	66	79.1	75.6	81.1	20*	102.7	22.8	86.4	53.9	46
Rice (Milled Equivalent)	53.3	11.5	9.5	8.3	31	42.8	63.7	20.1	12	48.5
Barley	0.9		0.3	0.5	0	0.2	0	0	0	1.1
Maize	17.1	5.1	3.3	12.7	0	0.2	0.1	0.9	0	0.1
Rye	0.9	0.4	0.1	0.3	0	0	0	0.2	0	0
Oats	0.5	0.8	2.7	3.7	0	0.6	0	0	0	0
Millet	3.3		0	0	0	0	0	0.4	0	0
Sorghum	3.8		0	1	0	0	0	0	0	0
Cereals, Other	0.9		3.9	0.5	0	0.7	0	0.2	0	3.8
Total Starchy	**61.1**	**55.3**	**57.7**	**56.9**	**401**	**87.6**	**340.2**	**64.4**	**142.3**	**206.5**
Cassava	14.3	0.2	1	0.1	25	20.3	5.1	5.1	2	0
Potatoes	32.6	53.3	54	53.7	3	23.8	0.3	32.7	5.8	35.5
Sweetpotato	8.3	1.7	2.6	2.4	260	5.6	179.5	5.3	0	0
Yams	3.8	0	0	0.1	28	1.4	65.5	20.9	14.6	0
Roots, Other	2	0.1	0	0.6	85**	36.5	89.8	0.6	119	171
TOTAL	**207.8**	**152.2**	**153.1**	**165.1**	**452**	**234.7**	**426.9**	**172.5**	**208.3**	**306**
SP/Starchy (in %)	13.58	3.07	4.51	4.22	64.84	6.39	52.76	8.23	0.00	0.00
SP/Total (in %)	3.99	1.12	1.70	1.45	57.52	2.39	42.05	3.07	0.00	0.00

Source: FAOSTAT database, FAO, http://faostat.fao.org; except PNG (Gibson, 2001a).
*Wheat = (7kg of flour + 4kg of bread + 3kg of biscuits) /0.70 (the average extraction rate) = 20kg (wheat equivalent).
**Other roots = 62kg of taro + 23 kg of sago = 85kg.

13.2 Appendix 2: Table 4. Annual per capita food supply/consumption in Asia and Africa, 2009

(in kg)	China	Indonesia	India	Philippines	Vietnam	Rwanda	Burundi	Kenya	Ghana	Uganda
Total Cereals	**151.4**	**186.7**	**143.7**	**153.9**	**166.3**	**49.3**	**34.7**	**113.8**	**87.9**	**62.6**
Wheat	66.4	21	57.7	23.5	14.2	10.2	4.5	25	17.3	12.9
Rice (Milled equiv.)	76.3	127.4	68.2	123.3	141.2	9.6	6.4	8	26.9	4.6
Barley	0.2	0	1	0.1	0	0.1	0	0.1	0	0
Maize	6.8	38.3	5.1	6.6	10.9	16.7	22	77.2	26.1	22.4
Rye	0.3	0	0	0	0	0	0	0	0	0
Oats	0.1	0	0	0.2	0	0	0	0.1	0.1	0
Millet	0.3	0	6.4	0	0	0.7	0.3	1	7.8	18
Sorghum	0.6	0	5.3	0	0	12	1.3	2.1	9.7	4.7
Cereals, Other	0.3	0	0	0.1	0	0.1	0	0.3	0	0
Total Roots	**65.2**	**57.9**	**29.6**	**30.8**	**16.6**	**283.5**	**172.1**	**48.7**	**421.3**	**183.5**
Cassava	1.9	44.6	7.6	20.9	7.5	94.2	76.6	20.2	219.5	96.3
Potatoes	36.8	4.7	21.1	2.6	4.5	103.1	0.5	6.6	0.2	14.5
Sweetpotato	25.5	6.8	0.9	5.5	4.6	73	88.9	21.2	5.1	72.6
Yams	0	0	0	0.2	0	1.3	0.7	0.1	146	0
Roots, Other	1	1.7	0	1.6	0	11.9	5.4	0.5	50.5	0
TOTAL	**216.6**	**244.6**	**173.3**	**184.7**	**182.9**	**332.8**	**206.8**	**162.5**	**509.2**	**246.1**
SP/ Roots (in %)	39.11	11.74	3.04	17.86	27.71	25.75	51.66	43.53	1.21	39.56
SP/Total (in %)	11.77	2.78	0.52	2.98	2.52	21.94	42.99	13.05	1.00	29.50

Source: FAOSTAT database, FAO, http://faostat.fao.org.

13.3 Appendix 3: Table 5. Nutrient contents of major staple foods

	Maize	Rice	Wheat	Potato	Cassava	Soybean	Sweet potato	Sorghum	Yam
Water (%)	76	12	11	79	60	68	77	9	70
Protein (%)	3.2	7.1	13.7	2.0	1.4	13.0	1.6	11.3	1.5
Fat (%)	1.18	0.66	2.47	0.09	0.28	6.8	0.05	3.3	0.17
Carbohydrates(%)	19	80	71	17	38	11	20	75	28
Fiber (%)	2.7	1.3	10.7	2.2	1.8	4.2	3	6.3	4.1
Sugar (%)	3.22	0.12	0	0.78	1.7	0	4.18	0	0.5
Nutrient value per 100 grams									
Energy (kJ)	360	1528	1419	322	670	615	360	1419	494
Calcium (mg)	2	28	34	12	16	197	30	28	17
Iron (mg)	0.52	4.31	3.52	0.78	0.27	3.55	0.61	4.4	0.54
Magnesium (mg)	37	25	144	23	21	65	25	0	21
Phosphorus (mg)	89	115	508	57	27	194	47	287	55
Potassium (mg)	270	115	431	421	271	620	337	350	816
Sodium (mg)	15	5	2	6	14	15	55	6	9
Zinc (mg)	0.45	1.09	4.16	0.29	0.34	0.99	0.3	0	0.24
Copper (mg)	0.05	0.22	0.55	0.11	0.10	0.13	0.15	-	0.18
Manganese (mg)	0.16	1.09	3.01	0.15	0.38	0.55	0.26	-	0.40
Selenium (mcg)	0.6	15.1	89.4	0.3	0.7	1.5	0.6	0	0.7
Vitamin C (mg)	6.8	0	0	1Ω9.7	20.6	29	2.4	0	17.1
Thiamin (mg)	0.20	0.58	0.42	0.08	0.09	0.44	0.08	0.24	0.11
Riboflavin (mg)	0.06	0.05	0.12	0.03	0.05	0.18	0.06	0.14	0.03
Niacin (mg)	1.70	4.19	6.74	1.05	0.85	1.65	0.56	2.93	0.55

Vitamin B6 (mg)	0.06	0.16	0.42	0.30	0.09	0.07	0.21	-	0.29
Vitamin A (IU)	208	0	0	2	13	180	14187	0	138
Vitamin E, alpha-tocopherol (mg)	0.07	0.11	0	0.01	0.19	0	0.26	0	0.39
Vitamin K (mcg)	0.3	0.1	0	1.9	1.9	0	1.8	0	2.6
B-carotene (mcg)	52	0	0	1	8	0	8509	0	83
Lutein+zeazanthin (mcg)	764	0	0	8	0	0	0	0	0
Saturated fatty acids (g)	0.18	0.18	0.45	0.03	0.07	0.79	0.02	0.46	0.04
Monounsaturated fatty acids (g)	0.35	0.21	0.34	0.00	0.08	1.28	0.00	0.99	0.01
Polyunsaturated fatty acids (g)	0.56	0.18	0.98	0.04	0.05	3.20	0.01	1.37	0.08

Source: Nutrient Data Laboratory, United States Department of Agriculture, n.d. http://www.nal.usda.gov/fnic/foodcomp/data/SR18/sr18.html.