# Novel Strategies for the Control of Planthoppers of Rice and Taro

**K.S. Powell,* F. Pau† and S. Nake‡**

*Abstract*

Taro and rice form a major part of the staple diet of Papua New Guineans but the sustainability of these crops in the Pacific region is constrained by insect pests. A novel approach to control pests of taro and rice would be to develop genetically modified plants expressing foreign genes with insecticidal properties.

Insect feeding trials were conducted *in vitro* to determine the effects of plant lectins against planthopper pests of taro and rice. Lectins were incorporated into an artificial diet at 0.1% concentration (wt/vol). The lectins *Galanthus nivalis* agglutinin and concanavalin A had significant antimetabolic effects on third instar nymphs of taro planthopper (*Tarophagous proserpina* Kirkaldy), whilst *Pisum sativum* agglutinin showed no significant effects against the insect. *Psophocarpus tetragonolobus* agglutinin (PTA) showed significant antimetabolic effects on third instar nymphs of rice brown planthopper (*Nilaparvata lugens* Stål) when incorporated into an artificial diet at 0.1% concentration. PTA also reduced levels of honeydew excretion by rice brown planthopper over a 24-hour period, demonstrating the antifeedant properties of the protein.

THE insect family Delphacidae contains a large group of sap-sucking planthoppers that affect a wide range of economically important crops including taro and rice. Taro (*Colocasia esculenta* (L.) Schott) is a root crop that is grown throughout the tropics and subtropics. It forms part of the staple diet of many Pacific islanders and is also grown commercially. In the South Pacific region, taro is affected by the economically important insect pest, taro planthopper (TPH, *Tarophagous proserpina* Kirkaldy). In Southeast Asia and the Pacific nations of PNG and the Solomon Islands, one of the most economically important rice pests is the rice brown planthopper (BPH, *Nilaparvata lugens* Stål). Both BPH and TPH are monophagous and cause direct damage, including yellowing (hopperburn) and stunting, due to adult and nymphal feeding and ovipositor damage to stems (Mitchell and Maddison 1983). Both insects also act as vectors of economically important viruses. TPH acts as a vector for two rhabdovirus diseases, Alomae and Bobone, which are found exclusively in PNG and the Solomon Islands (Rodoni et al. 1994) and can cause yield losses of up to 100% and 25%, respectively (Gollifer and Jackson 1978). Neighbouring islands are major exporters of taro, and virus-carrying TPH represent a significant quarantine risk to the region. The lack of suitable pest management strategies to control pests and diseases of taro has resulted in a decline in traditional taro-farming practices. This has also contributed to successive failures to develop wide-scale rice production in PNG and the Solomon Islands.

Genetic engineering, as part of integrated pest management, could be used to develop a novel control option of homopteran-resistant root and cereal crops for developing countries that rely on low-input subsistence

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agriculture. A number of lectins, in particular those exhibiting mannose or mannose/glucose-binding affinity, when incorporated into artificial diets, exhibit antimetabolic effects towards a range of Homoptera including aphids, leafhoppers (Habibi et al. 1993; Powell et al. 1993; Rahbe et al. 1995) and one species of delphacid planthopper, BPH (Powell et al. 1993; 1995a). To date, none of these lectins have been screened against other insect pests belonging to the planthopper family Delphacidae. One of the more widely studied lectins, *Galanthus nivalis* agglutinin, has been transferred successfully to both cereal and tuber crops (Gatehouse et al. 1995; Down et al. 1996; Rao et al. 1998).

This study describes assays to identify potential insecticidal proteins whose encoding genes could be included in the taro genome to target the economically important insect pest *Tarophagous proserpina*. It also provides evidence of the antimetabolic and antifeedant effects of an *N*-acetyl galactosamine-binding lectin against *Nilaparvata lugens*.

# Materials and Methods

## Insect cultures

A culture of *Tarophagous proserpina* Kirkaldy, originally obtained from a taro garden at the University of Technology Agriculture Farm, Lae, PNG was reared and maintained on 30–50-day-old taro (*Colocasia esculenta* (L.) Schott. var. *esculenta*) local cultivar Nomkoi. A culture of *Nilaparvata lugens* Stål obtained from a rice demonstration site at Bugandi High School, Lae, PNG, was reared and maintained on 30–50-day-old rice (*Oryza sativa* L.) plants of the susceptible local variety finschafen. All insect stock cultures were maintained in a controlled environment glasshouse, with 80–90% relative humidity, 25°C ± 5°C, and a light–dark cycle of 16 hours light/ 8 hours dark (L16:D8).

## Chemicals and materials

*Galanthus nivalis* agglutinin (GNA), *Concanaralia ensiformis* agglutinin (Con A), *Pisum sativum* agglutinin (PSA) and *Psophocarpus tetragonolobus* agglutinin (PTA) were obtained from Vector Laboratories, Peterborough, England. Bovine serum albumin (BSA) and all dietary components were obtained from the Sigma Chemical Company, Sydney, Australia. Taro planting material was obtained from local market sources and Trukai Industries, Lae, PNG, kindly supplied rice seed. Artificial diet (MMD-1) was prepared according to Mitsuhashi (1974), filtered and maintained as described by Powell et al. (1993).

## Feeding trials

Five third instar nymphs of the test insect, either *N. lugens* or *T. proserpina*, were removed from the host plant (using a camel hair paintbrush to minimise physical damage) and placed into a plastic feeding chamber as described by Powell et al. (1993). A single layer of stretched Parafilm-M membrane was placed over the feeding chamber and 200 microlitres of MMD-1 diet was added. The diet was then covered with a second stretched Parafilm-M layer to form a feeding sachet. Test proteins were incorporated into the artificial diet at 0.1% (wt/vol). Two controls, diet-alone and no diet, were used in all bioassays and ten replicates were used for each treatment and control.

## Determination of antimetabolic activity

To determine treatment effects, the increase in mortality compared with the diet-fed controls was corrected according to Abbot (1925). The corrected mortality was calculated on the day when all nymphs in the no-diet control had died, as described by Powell et al. (1993). Insect survival frequencies on treatment and control diets were subjected to statistical analysis by a *z*-test for determining proportions of independence as described by Snedecor and Cochran (1971). Yates correction was applied to data where appropriate. The null hypothesis under test was that survival was independent of treatment.

## Semiquantitative honeydew analysis

Two three-day old brachypterous female BPH were removed from the host plant and transferred to a filter paper-lined petri dish. A Parafilm feeding sachet, containing 200 microlitres of 0.1% (wt/vol) test protein in MMD-1 diet, was placed over the petri dish to form a feeding chamber. The feeding chamber was then incubated for 24 hours in an illuminated incubator (25 ± 2°C, light regime L16:D8). Two feeding chambers were placed into a floating humidity chamber (Powell et al. 1995b) and five replicates were prepared for each treatment and control ($n = 10$). After 24 hours, insects were removed from the chambers and filter papers sprayed with 0.1% ninhydrin reagent to detect the presence of amino acids excreted in the insect honeydew, which appear as purple stained areas.

# Results

## Taro planthopper feeding trials

Of the three lectins that were tested against third instar TPH nymphs (Table 1), GNA and Con A showed significant antimetabolic effects ($P < 0.001$), when incorporated at 0.1% concentration, with corrected mortality values of 72 and 93%, respectively. The nymphal survival period was significantly reduced when fed either GNA or Con A (Fig. 1, Table 1). The lectin PSA showed no significant antimetabolic effect towards TPH.

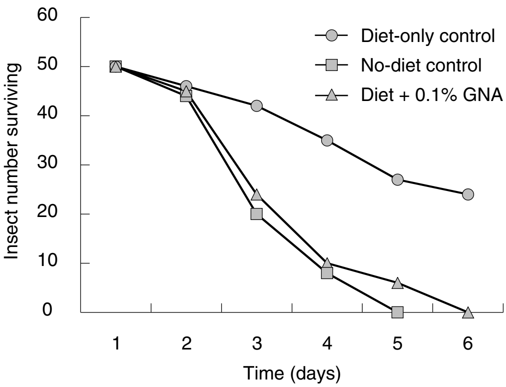


**Figure 1.** The effect on third instar taro planthopper survival of *Galanthus nivalis* agglutinin (GNA) incorporated at 0.1% concentration into artificial diet MMD-1.

## Rice brown planthopper feeding trials

When tested against third instar BPH nymphs, PTA showed significant antimetabolic effects ($P < 0.001$) when incorporated at 0.1% concentration (wt/vol), with a corrected mortality value of 72% (Table 1). The nymphal survival period was significantly reduced when fed PTA (Fig. 2).

## Ninhydrin analysis of excreted BPH honeydew

A visual semiquantitative assessment of the relative total amino acid content present in honeydew excreta of adult insects feeding on control and protein incorporated diet (and thus the relative quantity of diet imbibed) was determined. When insects were fed on the diet containing PTA, far less of the filter paper was stained by the ninhydrin reagent than with insects fed the control diet (Fig. 3), indicating a reduced volume of excreted honeydew. In contrast, insects fed on the inert protein bovine serum albumin (BSA) excreted similar amounts of honeydew to control diet-fed insects.

# Discussion

Lectins with a range of specific carbohydrate-binding affinities have been isolated from a variety of plants and tissue sites and the toxic effects of these compounds towards insects, over a range of orders, is widely documented (Gatehouse et al. 1995). Many lectins with either mannose or mannose/glucose-

**Table 1.** Mortalities of third instar nymphs of *Tarophagous proserpina* and *Nilaparvata lugens* when fed on artificial diet, MMD-1, with a plant lectin incorporated at 0.1% concentration.[a]

| Target pest | Lectin[b] | Sugar-binding specificity | Corrected mortality (%) | *z*-test | *P* |
|---|---|---|---|---|---|
| *Tarophagous proserpina* | GNA | mannose | 72 | 4.645 | < 0.001 |
| | Con A | mannose/glucose | 93 | 3.819 | < 0.001 |
| | PSA | mannose/glucose | 54 | 1.784 | > 0.05 |
| *Nilaparvata lugens* | PTA | *N*-acetyl-*D*-galactosamine | 72 | 4.67 | < 0.001 |

[a]Five nymphs per replicate, 10 replicates per treatment
[b]For details of lectins, see Materials and Methods section

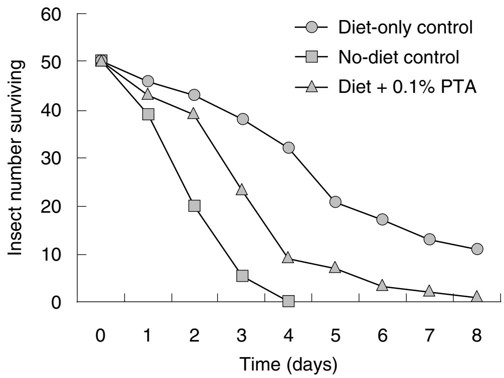


**Figure 2.** The effect on third instar rice brown plant-hopper survival of *Psophocarpus tetra-gonolobus* agglutinin (PTA) incorporated at 0.1% concentration into artificial diet MMD-1.

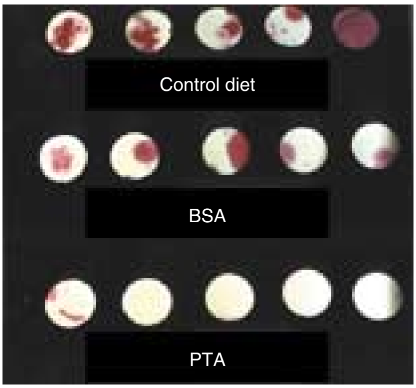


**Figure 3.** Relative quantities of amino acid-rich honeydew produced, as determined by areas stained purple with ninhydrin reagent, by adult BPH feeding on *Psophocarpus tetra-gonolobus* agglutinin (PTA) or bovine serum albumin (BSA) incorporated into artificial diet MMD-1 at 0.1% concentration.

binding affinity, including GNA, Con A and PSA, exhibit toxic effects towards members of the homopteran families Aphididae and Cicadellidae, both in vitro (Habibi et al. 1993; Powell et al. 1993; Rahbe et al. 1995) and in planta (Gatehouse et al. 1996). The insecticidal properties of plant lectins towards the family Delphacidae were first described by Powell et al. (1993) when *Galanthus nivalis* agglutinin was found to exhibit antimetabolic effects on BPH. Further investigations showed that GNA exhibited a multi-mechanistic mode of action having both antifeedant (Powell et al. 1995b) and systemic toxic effects (Powell et al. 1998) against BPH.

The antimetabolic effects of GNA towards TPH described in this study are similar to those observed against BPH in earlier studies (Powell et al. 1993), which indicates that GNA may be a suitable candidate protein to screen against other pest genera within the family Delphacidae. Preliminary observations also show that GNA exhibits antifeedant properties towards TPH when fed in diet at 0.1% (wt/vol) concentration and honeydew excretion is significantly reduced over a 24-hour period (K. Powell, unpublished). Similar antifeedant properties have been reported against BPH (Powell et al. 1995b).

Although PSA and Con A have similar binding specificities toward mannose and glucose, only Con A exhibited significant antimetabolic effects towards TPH. This is in contrast to an earlier study where both PSA and Con A showed no significant effect on BPH nymph mortality (Powell et al. 1993). Whilst PSA has been shown to be effective against some lepidopteran and coleopteran species (Boulter et al. 1990), it is ineffective against others (Czapla and Lang 1990). Thus, there is potential for broadening the range of action of mannose and mannose/glucose-binding lectins towards homopteran pests of taro, as GNA and Con A also exhibit insecticidal properties towards *Myzus persicae* and *Aphis gossypii* respectively (Rahbe et al. 1995; Gatehouse et al. 1996). Previously, lectins with either mannose or *N*-acetyl glucosamine-binding properties have shown toxicity towards BPH. The winged bean lectin, PTA, which binds to *N*-acetyl galactosamine carbohydrate moieties, is toxic towards insects in the order Coleoptera (Gatehouse et al. 1991) but has not been screened against other insect orders. This is the first report demonstrating that PTA exhibits toxic effects towards BPH. These findings extend the range of plant lectin families that could be used to develop control strategies for homopteran insect pests.

An important consideration when selecting potential primary gene products for control of insect pests is the potential effect of these products on natural enemies and predatory species present in the natural ecosystem. The level of proteolysis of plant lectins in the target insect's digestive system is likely to determine the degree of toxicity of the lectin consumed by a predatory species. There are different levels of lectin processing in the digestive system of Homoptera. When ingested in artificial diet by the pea aphid *Acyrthosiphon pisum,* Con A was not detectable in the insect honeydew, whereas GNA was detectable (Rahbe et al. 1995). No significant GNA proteolytic activity has been observed in the gut or honeydew of BPH fed on GNA-containing diet (Powell et al. 1995b). Therefore, GNA could potentially be consumed by natural predators. Recent studies have shown that when GNA was inserted into the genome of transgenic potato plants to control aphids, the fecundity of predatory ladybirds was adversely affected (Birch et al. 1999). One of the most important groups of natural enemies of planthoppers are the mirid bugs (order Hemiptera). In PNG, where this study was carried out, the most abundant natural enemies of BPH and TPH are *Cyrtorhinus lividipennis* and *C. fulvus* respectively, which are predominantly egg predators. Further investigations should be carried out to determine whether plant lectins can be ovarially transmitted to the target insect eggs and subsequently affect mirid bug and other predatory insects.

Assessing the level of toxicity of plant lectins or agglutinins to nontarget species, particularly crop consumers such as mammals, is also an important consideration. Whilst there is clear evidence of the antinutritive effects of some *N*-acetyl glucosamine-specific lectins (Pusztai et al. 1993), the evidence regarding mammalian toxicity of the mannose-binding lectin GNA is currently inconclusive (Pusztai et al. 1996; Ewen and Pusztai 1999) and further studies are required. When fed to rats, Con A causes some intestinal allergic reactions affecting both gut ultrastructure and permeability (Sjölander et al. 1984). Little is known of the mammalian toxicity of PTA; however, all parts of the winged bean crop, with the exception of the stems and fine roots, can be eaten. Winged bean is widely used for human consumption in the Central Highlands and Sepik regions of PNG and is a rich source of dietary protein, oils, vitamins and antioxidants in other developing countries (Anon. 1975). Winged bean lectin is probably destroyed during the cooking process (Cerney et al. 1971).

Although the development of insect-resistant crops is still in its infancy in developing countries as a whole, and is nonexistent in PNG, the potential exists to develop this technology within PNG. This study has shown that it is possible to screen for potential insecticidal transgenes against target insect pests using the artificial diet system. The artificial diet technique could also be used for screening other plant-derived compounds for use in more conventional control strategies.

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# The Effect of Planting Density on the Marketable Corm Yield of Taro (*Colocasia esculenta* (L.) Schott)

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*Abstract*

Taro (*Colocasia esculenta* (L.) Schott) of the Numkowec variety was planted in six different spatial arrangements with five planting densities: 10,000, 20,000, 40,000, 80,000 and 160,000 plants per hectare (plants/ha) at the Bubia Research Station in Morobe Province, PNG. Total yield increased with increasing planting density while the mean corm weight decreased at higher densities. Total marketable yield increased with increasing planting density up to 80,000 plants/ha, but decreased at 160,000 plants/ha. The two highest marketable first-grade corm yields (16.4 and 15.9 tonnes/ha) were obtained at 40,000 plants/ha with spatial arrangements of 1 metre × 0.25 metre and 0.5 metre × 0.5 metre, respectively. The 1 × 0.25-metre arrangement gave higher mean corm weight, taller mean plant height and an average of three basal suckers. Thus, a plant population of about 40,000 plants/ha can be used for semicommercial and commercial taro production in locations with similar environmental conditions to those at Bubia.

TARO (*Colocasia esculenta* (L.) Schott) is a staple crop in many parts of PNG and is a major food crop in most lowland areas of the country. The plant is commonly grown for consumption of its corms; other parts such as leaves, petioles and rhizomes are used as vegetables. Taro can be grown upland or under irrigation depending on the variety. Most taro in PNG is grown as an upland crop while farmers in a few areas like Rabaraba in Milne Bay Province and Sialum in Morobe Province grow irrigated taro.

Growth and yield of upland taro is dependent on many factors including sett size, planting-hole size, soil fertility, variety, weed control, leaf area, suckering, spacing and many more, as reported by Berwick et al. (1972), Bourke and Perry (1976), De la Pena (1978), Ezumah and Plucknett (1981), and Cable and Asghar (1983). However, in the major taro-growing areas in the lowlands of PNG, taro is planted at different planting densities depending on the variety, type of planting material, soil type and fertility, cropping systems and cultural associations.

Taro is a traditional staple crop normally grown by subsistence farmers and more recently by semicommercial farmers who place an increasing emphasis on the cash income the crop can earn, especially from urban markets like Lae. It is therefore important for farmers to use their land and other inputs efficiently in order to maximise their food supply and cash income from a taro crop. This increased productivity would have a positive impact on their overall food security and income-creating efforts. The objective of this trial was to determine a planting density that would give an optimum yield with good marketable corm weight and

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allow mechanised weed control, effective weed suppression by canopy cover and good sucker production to provide planting materials.

# Materials and Method

## The site

The trial was conducted at the Wet Lowlands Mainland Program of the National Agricultural Research Institute (NARI) at Bubia Research Station in Morobe Province. Bubia (147°4′E, 6°41′S) is on an alluvial plain with small patches of sandy clay loam 15 kilometres northwest of Lae at an altitude of 16 metres above sea level (Akus, no date). The experimental site has a mean annual rainfall of 4952 millimetres and the rain is evenly distributed throughout the year. Average daily temperature is 26.8°C with a daily minimum of 20.4°C and a maximum of 31.1°C. The site has been cultivated continuously for research activities with short, intermittent fallow periods.

## Experimental design

The area was slashed, ploughed and disc harrowed by tractor before the plots were marked out. Six treatments (spacing arrangements) with four replicates were laid out in a randomised complete block design. The six spacing arrangements (treatments) used are presented in Table 1.

**Table 1.** Spacing and plant population.

| Spacing (metres) | Plant population density (plants/hectare) |
|---|---|
| 1 × 1 | 10,000 |
| 1 × 0.5 | 20,000 |
| 0.5 × 0.5 | 40,000 |
| 1 × 0.25 | 40,000 |
| 0.5 × 0.25 | 80,000 |
| 0.25 × 0.25 | 160,000 |

Side suckers of the locally preferred taro variety Numkowec were planted using wood and iron digging sticks. One sucker was planted in each 20–30-centimetre hole in the land that had been ploughed and harrowed a week earlier. The total land area used was 805 square metres (35 m × 23 m). The trial was planted on 3 May 1995 and harvested on 21 November 1995, the cropping period spanning approximately 202 days after planting.

Weed control was achieved with hand-weeding and supplemented by hand tractor inter-row cultivation. Nitrogen fertiliser in the form of urea was applied in two split applications, at one and three months after planting, at a nitrogen rate of 30 kilograms per hectare (kg/ha).

A major insect pest, taro hawkmoth (*Hippotion celerio*) was controlled twice during the cropping season by using a spraying regime of orthene (acephate) alternating with Karate (iamda—cyhalothrin).

At harvest, the plant height (measured from ground level to the sinus of the tallest leaf) and the number of suckers per plant for the 10 sample plants in each plot were recorded. The harvested corms were counted, weighed and grouped into four categories according to different marketable weight and taro beetle (*Papuana* spp.) damage assessment. The four different marketing categories were:

- marketable first grade—corms weighing 250 grams and above, with no taro beetle damage;
- marketable second grade—corms weighing 250 grams and above, with one or two taro beetle shot holes at depths of 1 centimetre or less;
- not marketable third grade—corms weighing 250 grams and above, with extensive taro beetle damage; and
- not marketable by size—corms weighing less than 250 grams.

The above parameters relating to taro beetle damage were assessed by visual observation when categorising the respective marketing groups.

Data collected on the mean corm weight, total yield, different marketable yield components, the plant height and the number of suckers per plant were analysed statistically using Minitab statistical software and the treatment means were compared by Duncan's multiple range tests.

# Results

The yields obtained from the various plant densities are shown in Table 2. The total yield of taro increased with plant density, showing significant increases at 40,000, 80,000 and 160,000 plants/ha over the base population. The mean corm weight, on the other hand, was reduced significantly at all planting densities above 10,000 plants/ha. There was no significant difference between the means of the different grades of marketable corms from the standard 1-square metre (1 m × 1 m) spacing. The two highest marketable first-grade corm yields of 16.4 and 15.9 tonnes per hectare (t/ha) were obtained at 40,000 plants/ha, under spatial arrangements of 1 m × 0.25 m and 0.5 m × 0.5 m, respectively.

The third highest marketable first-grade corm yields and the highest marketable second-grade corm yields were obtained at 80,000 plants/ha. However, under this density more than 15% of the produce was not marketable and at 160,000 plants/ha more than 43% of the produce was not marketable. All treatments except the 160,000 plants/ha gave percentages of marketable yield above 84%.

Spatial arrangements with 1-metre row spacing gave higher mean plant height at harvest than spacing arrangements with row spacing lower than 1 metre. The number of suckers per plant decreased significantly with increased planting densities (Table 3). Weed growth and ground cover were greater in low-density taro plots than in high-density plots.

## Discussion

Before this study, the standard spacing normally used at Bubia for growing taro was 1 square metre (1 m × 1 m). Therefore, the other five spacing arrangements used in this study were compared with this standard. There was a significant difference in total yield from plots using the new spacing arrangements compared to the standard spacing (1 m × 1 m). However, when considering the separation of different grades based on taro beetle damage, the amount of different grades of marketable yield was not significantly different between the new and standard spacing arrangements. In this trial, the highest yield of first-grade marketable size corms was 16.4 t/ha, obtained at a plant density of 40,000 plants/ha. Under the same density (40,000 plants/hectare) but with a different spacing arrangement (0.5 m × 0.5 m), the yield was 15.9 t/ha. The 80,000 plants/ha density performed better in both the first and second-grade marketable corm yields, with 15.2 and 7.5 t/ha, respectively.

**Table 3.** Mean plant height and average number of suckers per treatment.

| Spacing (metres) | Plant height (cm) | Number of suckers |
|---|---|---|
| 1 × 1 | 107.7 | 7.0 |
| 1 × 0.5 | 104.3 ns | 3.6* |
| 0.5 × 0.5 | 95.2* | 2.1* |
| 1 × 0.25 | 104.7 ns | 2.7* |
| 0.5 × 0.25 | 95.1* | 1.0* |
| 0.25 × 0.25 | 88.4* | 0.2* |
| LSD ($P$ = 0.05) | 9.9 | 1.2 |

LSD = least significant difference;
* = statistically significant; ns = not statistically significant

**Table 2.** Summary of mean corm weight and marketable corm yield.

| Spacing (metres) | Plants/ hectare ('000) | Mean corm weight (grams) | Yield (tonnes/hectare) | | | | | % yield NM |
|---|---|---|---|---|---|---|---|---|
| | | | Total | First grade | Second grade | Third grade (NM) | NM by size | |
| 1 × 1 | 10 | 839 | 14.9 | 9.3 | 4.0 | 0.8 | 0.8 | 10.2 |
| 1 × 0.5 | 20 | 576* | 16.3 ns | 9.2 | 5.0 | 2.0 | 0.1 ns | 13.0 ns |
| 0.5 × 0.5 | 40 | 445* | 23.3* | 15.9 | 5.4 | 1.7 | 0.3 ns | 8.7 ns |
| 1 × 0.25 | 40 | 479* | 24.6* | 16.4 | 5.0 | 2.0 | 1.2 ns | 13.0 ns |
| 0.5 × 0.25 | 80 | 340* | 26.8* | 15.2 | 7.5 | 2.3 | 1.8 ns | 15.3 ns |
| 0.25 × 0.25 | 160 | 295* | 33.6* | 13.8 | 5.3 | 4.1 | 10.5* | 43.3* |
| LSD ($P$ = 0.05) | | 82.4 | 4.0 | | | | 2.4 | 14.8 |

NM = not marketable; LSD = least significant difference;
* = statistically significant ($P < 0.05$); ns = not statistically significant

These results are similar to those obtained elsewhere. Sivan (1981) obtained the highest marketable yield at spacing of 60 square centimetres (60 cm × 60 cm) or 26,900 plants/ha. Mohan and Sadandan (1990) obtained their highest marketable yield at 60 cm × 45 cm (37,000 plants/ha). Berwick et al. (1972) reported that a plant population of about 27,000 plants/ha gave greater yield than others at wider spacing. Our results suggest that more plants per hectare might be better still, although above 80,000 plants/ha up to 15% of the produce was unmarketably small, and this figure rose to 43% for 160,000 plants/ha. De la Pena (1978) obtained fresh corm weights of 606 grams at about 49,000 plants/ha and 535 grams at 55,000 plants/ha after applying 70 kg nitrogen/ha as urea and 200 kg phosphate/ha as triple superphosphate. A good marketable corm size would be 400–600 grams along with the typical taro corm shape.

Since yield depends on many factors, including interplant competition and weed suppression, the 1-metre row spacing has reduced interplant competition thus giving higher mean plant height and an average of three suckers per plant; it also allowed for mechanised weed control. The wider inter-row space leaves the intercropping option open, which allows for better efficiency in use of land and time.

## Conclusions

The results and observations obtained from this and other studies suggest that plant densities between 20,000 and 60,000 plants/ha give optimum yields in terms of marketable individual corm sizes. Yield components include a high percentage of corms in the marketable range. It appears that a wide enough inter-row spacing is required to produce bigger corm sizes with the typical taro corm shape and adequate suckers for planting material. This should be complemented by an optimum intra-row or inter-plant spacing to avoid having too many small corms. Further research is required to establish suitable spatial arrangements under varying environments, cropping systems and levels of management.

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# Yams and Food Security in the Lowlands of PNG

**J.B. Risimeri***

*Abstract*

Yam is an important staple food and ceremonial crop in the lowlands of PNG, ranking fifth after sweet potato, banana, sago and taro as a staple crop. Two species, *Dioscorea esculenta* (lesser yam) and *D. alata* (greater yam) stand out under smallholder production. Lesser yam is the more important food species but greater yam still has a strong ceremonial attachment in yam-growing societies. *D. esculenta* is affected by fewer problems, while *D. alata* is constrained by shortage of adequate clean planting material and is attacked by anthracnose (a leaf disease) and several species of nematodes that degrade eating and planting material quality. In the last two decades, semicommercial producers have been increasingly hampered by irregular weather patterns and increases in natural disasters, exacerbating declining soil fertility problems that are caused by population pressure on the land. Farmers are now using the long storage life of yam tubers and opting to plant off-season crops to increase food security. Although past research attention to this crop has been minimal, current research should be strengthened and continue to address constraints and opportunities.

OUT of more than 600 species in the genus *Dioscorea* worldwide, six are important in PNG: *Dioscorea alata*, *D. bulbifera*, *D. esculenta*, *D. hispida*, *D. nummularia* and *D. pentaphylla* (King 1984). Considerable diversity exists within these species, making PNG a major centre of diversity (Martin 1977).

Another important species in West Africa and the Caribbean is *D. rotundata*, commonly known as 'white yam' or 'white Guinea yam'. It was introduced to PNG in 1986 and *D. rotundata* varieties are now in most provinces of the country. There has been no assessment of its spread and degree of acceptance into different farming systems, although it is still much less significant than the existing two main species.

Only two species, *D. alata* and *D. esculenta,* contribute significantly to the diet of yam growers and other consumers. In 1990, the yam production estimate for PNG was 201,000 tonnes (Britannica World Data 1993). The two species also carry ceremonial prestige in some yam growing areas like Maprik in East Sepik Province and the Trobriand Islands in Milne Bay Province. The greater yam *D. alata*, having a wider distribution, is ceremonially of greater significance (Malinowski 1935; Lea 1966). *D. nummularia* appears to have a stronger presence in the highlands and the high-altitude areas of Morobe Province, as evident in recent collection trips (Tony Gunua, National Agricultural Research Institute, pers. comm.).

Despite their dietary and cultural importance, yams remain underresearched in PNG. Bourke (1982) and King (1986a) reviewed the little research on yams up to that time.

The intention of this paper is to discuss yam crop ecology, highlight identified production and storage constraints, and discuss possible areas of research inputs. In view of the 1997 drought and frost, the paper also discusses the role of yam in ensuring food security and the possibility of doing adaptive onfarm research in our yam areas, based on research carried out in countries such as Nigeria (Hahn et al. 1987; Kalu and Erhabor 1992; Kang et al. 1984). The need for socioeconomic research is also raised.

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# Current Production

## Agroecology

The PNG lowland yam-growing areas are Maprik–Bogia, the southern half of Western Province, the coastal area of Central Province; Dogura–Safia and Bulolo–Markham. These areas have a distinctly seasonal rainfall distribution (Bourke 1982), receiving less than 2000 millimetres of rain per year and account for a total of approximately 65,000 square kilometres, or about 20%, of the total lowland area (King 1986a). Yams are also grown on the main islands, for example the Namatanai area of New Ireland Province (Kesavan 1983), and on smaller offshore islands, such as the most islands in Milne Bay Province.

## Cropping pattern

Yams are either grown in mixed cropping systems or as pure stands, separate or occupying part of a mixed garden, and are consumed as a costaple. The lesser yam, *D. esculenta,* is the most important food species in many lowland areas. The Wosera people regard *D. alata* highly, but there are not sufficient clean planting setts for its cultivation so their yam farming system is based on *D. esculenta* (Quin 1985).

Malinowski (1935), Lea (1966) and Allen (1985), an anthropologist and two geographers, respectively, described the yam-based systems of the Trobriand Islands and the Maprik and Drekikir areas of East Sepik Province. Allen (1985) and Quin (1985) noted that fallows in the shifting cultivation systems were getting shorter, resulting in low natural soil fertility and therefore lower yields.

Consumer preferences, particularly of tuber size (Hahn et al. 1987), dictate many aspects of production. Subsistence yam growers in areas where cultural values are attached to yams prefer large tubers (King and Risimeri 1992). Inputs may vary in different production environments, but production of large tubers requires planting low densities, tall stakes and large setts, with deep holes and large mounds at planting. Harvesting also requires slow and careful digging. The high labour requirement of yam production is a serious problem (Onwueme and Fadayomi 1980). A shift in consumer preference in favour of smaller tubers is desirable but planting densities in the PNG lowlands are likely to remain low under predominantly mixed cropping systems intended to produce large individual tubers.

## Planting density

King (1986b) observed *D. alata* and *D. esculenta* planting densities at 10,000 plants per hectare in farmers' fields in Central Province. Allen (1985), however, reported 2300 plants per hectare for *D. esculenta* in the Drekikir area of East Sepik Province. Lea (1966) reported a ceremonial *D. alata* planting density in Abelam gardens at about 839 plants per hectare. *D. alata* farmers on silt levee banks along the Sepik River use planting densities of about 27,000 plants per hectare. Quin (1985) reported a density of 2500 plants per hectare for *D. esculenta* in the Wosera area of East Sepik Province. King and Risimeri (1992) reported harvesting large tubers from a low density planting (2500 plants per hectare, with tall 3-metre stakes); increasing the height of staking from 1 to 3 metres at a density of 4444 plants per hectare did not give a yield advantage.

## Staking

Staking methods and heights differ between major yam-growing areas. In village gardens of the Central Province coast surveyed by King (1986b), staking height ranged from 1.5 metres (more common) to 2 metres and there were also unstaked plots. Staking material appeared to be a constraint in some of these villages.

In East Sepik Province, staking using taller poles is more common. Stake heights along the Sepik River range from 1.5 to 2 metres. In the forest fallow foothills and mountain gardens of Maprik and Wewak districts, 3–5-metre long poles and pollard trees serve as stakes (King and Risimeri 1992). In these farmers' fields, vines from one or two mounds are normally guided onto a single cut and erected stake. However, pollard trees support vines from a minimum of about six mounds planted at varying distances around the base of the in situ tree stake.

King and Risimeri (1992) obtained up to 36% yield increases from staking with 1.5-metre stakes over unstaked yams. Similarly, Ndegwe et al. (1990) reported that staking six stands of yams onto one pole gave the highest cash returns per hectare, representing an increase of 136% over unstaked yams. Their research was done in a high rainfall area of Nigeria.

Apart from planting density and staking, the size, phytosanitary conditions and physiological state of the planting sett are important determinants of yam tuber yield.

### Planting setts

Selected sett tubers from a preceding crop may amount to about 25–35% of the total harvest (Quin 1985; Ng 1988). Fully matured and undamaged tubers weighing 300–1500 grams are stored separately as planting material. Generally, high sett weights give higher tuber yields (Nwoke et al. 1984). In East Sepik Province, a considerable proportion of the stored sett tubers may be degraded by nematodes, pests or diseases during storage.

## Pests and Diseases

### Nematodes

Nematodes can cause serious losses, both in the field and in storage (Bridge and Page 1982). Two genera, *Pratylenchus coffeae* and *Radopholus* sp., were found in yams in several locations throughout PNG. Nematode infestation occurs in the field, but the damage becomes evident several months later during storage of the tubers. The nematode damage, coupled with other pest and disease losses, degrades eating quality and severely reduces the viability of sett tubers.

### Pests

Recorded pests of major importance in yam production in PNG include *Blastobasis* sp., *Planococcus dioscorea*, *Tagiades nestus* and *Senoclidia purpurata.* Other insect pests of medium and low priority are listed by King (1986a). Quin (1985) identified *Blastobasis* as a serious pest, especially on *D. alata*, against which no control measures were tested. The mealy bug *Planococcus dioscoreae* has been found in storage facilities with poor ventilation. Under these conditions the bug spreads rapidly and heavy infestations can severely retard newly emerged sprouts.

Minor pests are leaf-eating insects, including the taro hawkmoth *Hippotion celerio*, and tuber pests such as the taro beetle *Papuana* spp.

### Diseases

Shaw (1984) describes diseases of yam in PNG. A major disease is anthracnose, caused by the fungus *Colletotrichum gloeosporoides*. It affects *D. alata* more severely than *D. esculenta*. The yam crop is usually unaffected by anthracnose, but prolonged rainy weather can lead to premature vine death. Quin (1985) encountered a tuber rot during storage; although no pathogens were isolated, she reported similar symptoms to those caused by the fungus *Rhizopus nodusus*.

### Weeds

Rural yam producers in PNG use hand-weeding, intercropping and shifting cultivation to reduce weed competition in their crops. Weed control in yams may require up to 30% of the total yam labour allocation (Lyonga and Ayuk-Takem 1979). Chemical methods like those reported by Onwueme and Fadayomi (1980) may be available for adaptation and adoption; however, semicommercial yam growers may supplement hand-weeding by combining cultural control measures such as thorough land preparation, staking methods, and selective intercropping, which are less expensive and are environmentally friendly.

### Yield

It is evident from the above discussion that yield is affected by many factors and is difficult to predict. FAO (1991) gave a generalised small farmer yield of 10 tonnes per hectare (t/ha); whilst Rhem and Espig (1991) indicate commercial yields of 20–40 t/ha and experimental yields of 60 t/ha. Table 1 shows some yield data from Central and East Sepik provinces.

### Postharvest

Of the traditional root and tuber crops in PNG, only yams are storable for prolonged periods, remaining dormant for the first 10–15 weeks after harvesting (Hahn et al. 1987) and having a total storage life of up to 6 months (Allen et al. 1993). Careful harvesting (inflicting only minimum damage to tubers during harvest), careful handling during transportation, and curing for 2–3 days before storage can greatly reduce storage losses. Proper timing of the harvest also determines the moisture content and the physiological state in which tubers enter storage. Premature harvesting may lead to tubers entering storage with high (70–80%) moisture content. This may attract pests and diseases during storage (Hahn et al. 1987). Most PNG traditional storage systems seem to allow for good ventilation, and protection from direct sunlight and rain.

## Future Research Constraints

Although the severity and importance of each constraint may vary between locations, the following affect yam production in PNG:

- shortage of clean planting material, especially for *D. alata,* at any planting season;
- degradation of tuber quality by nematodes, pests and diseases;
- anthracnose leaf diseases;
- generally high labour requirements; and
- inadequate supply of staking materials.

## Opportunities

- Increasing the availability of planting material through the mini-sett rapid multiplication technique.
- Overcoming periods of yam scarcity through bimonthly planting.
- Introducing leguminous trees under alley cropping systems with in situ live mulch, for weed management, soil nutrient enhancement and staking material.

The NARI Research Station at Laloki used to maintain the National Yam Collection, while Bubia

**Table 1.** Yields of *Dioscorea esculenta* and *D. alata* from Central and East Sepik provinces obtained from village gardens, onfarm research plots and on-station research plots for comparison.

| Location | Yield (tonnes/hectare) | | Plot type | Source |
|---|---|---|---|---|
| | *D. esculenta* | *D. alata* | | |
| Central Province | 20.3 | 14.4 | VG | King (1986b) |
| Wosera, ESP | 13.6 | | OFRP | Quin (1985) |
| Amuk, ESP | 13.3 | | OFRP | Quin (1985) |
| Sepik River, ESP | | 25.0 | OFRP | Risimeri (unpublished data) |
| | | 22.4 | OFRP | Quin (1985) |
| Drekikir, ESP | 10.0–20.0 | 16.0 | VG | Allen (1985) |
| Saramandi, ESP | 16.3–36.7 | | OSRP | King and Risimeri (1992) |
| Saramandi, ESP | 12.0–28.0 | 11.0–28.0 | OSRP | Quin (1985) |

ESP = East Sepik Province; VG = village gardens; OFRP = onfarm research plots; OSRP = on station research plots

**Table 2.** The number of accessions of different species held in Laloki, Bubia and Saramandi Research Stations.

| Yam species | Number of accessions | | |
|---|---|---|---|
| | Laloki | Bubia | Saramandi |
| *Dioscorea alata* | 212 | 115 | 13 |
| *D. bulbifera* | 9 | 5 | – |
| *D. esculenta* | 206 | 61 | 10 |
| *D. nummularia* | 4 | 25 | – |
| *D. pentaphylla* | 12 | – | – |
| *D. rotundata* | 4 | 18 | 22 |
| Total | 447 | 224 | 45 |

– = species not maintained at that location

Note: the Laloki accessions are now lost, and the Saramundi ones have been transferred to Bubia.

Research Station and Saramandi Research Station maintained working collections. Table 2 shows the number of accessions for different species and varieties held at each location.

Kambuou and Ivahupa (1990) studied the effect of staking, mulching and fertiliser application on the yield of 104 accessions of *D. esculenta* at Laloki. Ivahupa et al. (1990) carried out some onfarm crop rotation trials using legumes and root crops, including yams. Onfarm studies were carried out in East Sepik and Madang provinces. There is a need to continue such researcher–extension worker–farmer studies in farmers' fields to address constraints and opportunities in different yam-growing areas of PNG.

### Production of clean planting material

Quin (1985) attempted to develop a package for producing clean seed yams. The procedure involved hot water treatment of mother sett tubers by boiling them at 55°C for 30 minutes. These heat-treated mother setts were cut and prepared according to the 'mini-sett rapid multiplication technique' developed at the International Institute of Tropical Agriculture (IITA 1984).

Observations on the mini-sett technique using *D. alata and D. rotundata* are so far very encouraging. Further work is required to assess cropping patterns and systems for each agroecosystem.

### Cropping systems options

Alley cropping can restore soil fertility to a higher level within a fallow period of two to three years compared with the bush fallow system. In parts of coastal Central Province, where staking materials are in short supply, byproducts from the system, such as firewood and staking poles, make alley cropping an attractive proposition. Alternatively, farmers can plant stake-lots using fast-growing pole species such as *Leucaena* spp. and *Gliricidia sepium* near garden fringes or on marginal land (Kang et al. 1984).

Since the late 1980s, farmers from the coastal area between Gilagil River and Bogia in Madang Province have been planting *Gliricidia sepium* to shade out and suppress *Imperata cylindrica*. After about two years they cut the *Gliricidia* back and use the fields for food and cash crops. Clearly, some onfarm adaptive work is required to introduce fallow management options. Farmers can then develop sustainable fallow management systems.

Kalu and Erhabor (1992) compared the mini-sett production of *D. rotundata* under ridge planting with a bed system, and found the bed system to be more productive and more economical than the ridge system.

### Pest and disease loss assessment and documentation

Further observations and investigations to study control measures for pests and diseases will allow the documentation of the distribution, severity and prevalence of *Blastobasis* sp. and *Planococcus dioscoreae* in village storage systems.

Additional observations and field trials in major *D. alata* growing areas will help to quantify yield losses caused by anthracnose. Research strategies could be formulated to address the problem if the situation warranted it. IITA is now distributing materials of anthracnose-resistant lines of both *D. rotundata* and *D. alata* (Hahn et al. 1987). These improved varieties could be imported into PNG.

### Continuous production

Ongoing research at Bubia Research Station promises the possibility of continuous year-round production of yam in environments where rainfall is evenly distributed or where irrigation facilities are available.

Farmers in the Bogia area of Madang Province have started to plant off-season crops of yam, because rainfall patterns have been irregular in the last 20 years.

## Food and Social Security

During the 1997 drought, many rural populations tended to gather wild yams, indicating the need for this crop in difficult times. The cultivation of yams should be encouraged in suitable environments where yams are not currently grown in gardens. Even in areas where other staple food crops are dominant, the presentation of yams at a feast or funeral is a dignified gesture of great significance.

### Technology adaptation and packaging

The mini-sett rapid multiplication technique could be used to assemble a more economical and resource-efficient yam production package. Advantages include increased production of clean setts, elimination of staking, conservation of soil moisture and nutrients, suppression of weeds and production of 1–3-kilogram table yams. Observations in Lae market during 1998 and 1999 have indicated that many PNG consumers prefer small tubers (2 kilograms and less). This increases the possibility of mechanised planting and harvesting (Hahn et al. 1987). Kalu et al. (1989) found that 25-gram mini-setts of *D. rotundata* and *D. alata* reduced planting sett requirements to about 12% of those for conventional planting. These initiatives, including the possibility of continuous production, can be further enhanced with the use of plant biotechnology.

### Role of plant biotechnology

Plant biotechnology can contribute to research and development for yam and other root crops through preserving germplasm, cleaning planting material and facilitating the exchange of elite genotypes. Researchers at IITA have produced microtubers through in vitro tuberisation of yams (Ng 1988). These tubers are disease free, will survive better in transit, and can be stored for up to three months before being raised as normal sett tubers.

Food crops research in PNG would benefit from the establishment of tissue culture laboratories and rograms for the preservation and production of staple root crops. Improved production would also allow the identification of markets to cater for increased sales of surplus produce.

### Socioeconomic research

Yam is one of the most important staple food crops in PNG, but urban consumers eat little yam in their diet. Studies of current production, distribution and demand trends would expose market-related constraints and opportunities. In 1999, *D. alata* tubers were sold at 2.00–3.00 PNG kina (PGK) per kilogram in Port Moresby and at 1.00–1.50 PGK per kilogram in Lae.[1]

The production of smaller ware yams could be achieved through planting conveniently sized setts that require less laborious planting and have reduced staking needs. Subsequently, this crop would require less effort in harvesting, transportation and marketing. However, there should be assessment and feedback from both producers and consumers before undertaking such research.

### Sustainability

In the last five decades, traditional crops like *Colocasia* taro and yam have had to give way to less demanding crops such as sweet potato, cassava and *Xanthosoma* taro. The resurgence of yam in semicommercial smallholder agriculture for both subsistence and sale will indicate a shift towards sustainable land management. This is because yam production will indicate that farmers have improved the soil fertility to a higher level, as opposed to selecting a less demanding crop (such as cassava or sweet potato) to suit the lower soil fertility. The revival of yam production will be accompanied by a cultural reawakening in areas where yam has a sociocultural role. The resultant technology, from the adaptation of the mini-sett technique, cropping systems and ongoing work on continuous production, could make yam more affordable and more equitably available as a food to both producers and consumers.

1. In 1999, 1 PGK = approx. US$0.39 (A$0.58).

## Conclusion

Yam is an important traditional food crop offering food security as a costaple in many lowland areas of PNG. It has ceremonial ritual associations that bring status and satisfaction to producers in their social settings. In 1997, farmers in remote parts of PNG who had yam in store before the drought struck were able to fall back on stored yam as a food reserve. This experience suggests that yam should be encouraged in suitable environments, as it can be stored for long periods and offers food security during times of disaster. There is little organised and continuing agricultural research to enhance the production of yam.

Yam producers have persisted, despite being unable to achieve an optimum output. Some constraints have been identified through the limited past research devoted to yam production. It is timely to revitalise the yam research effort in PNG in view of technology options that have been generated in other countries and need testing and adaptation for local conditions. Farmers and extension agents should participate at all stages of yam research and development.

The return to prominence of this ancient crop will permit more sustainable use of available resources in cropping and farming practices. If there is a single crop that can restore some power into the social fabric of PNG cultures, it is yam with its ‘spiritual touch’ for food and social security.

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# Anthracnose (*Colletotrichum gloeosporoides*): a Cause for the Decline of Yam (*Dioscorea alata*) Production in PNG

**Tony G. Gunua* and Peter A. Gendua***

*Abstract*

Field trips were made in November 1999 to June 2000 to collect *Dioscorea alata* leaf samples affected by yam viruses and anthracnose (*Colletotrichum gloeosporoides*) in yam-growing areas of PNG. Loss of varieties and decline in production were found for this yam species. This paper discusses the role of anthracnose as one of the possible causes of the loss of *D. alata* varieties and its decline in production.

While local varieties can be screened and selected for anthracnose tolerance, the introduction of selected lines from the International Institute of Tropical Agriculture is suggested as a quick impact option for rural yam growers. Research is needed on the epidemiology and control of this, and other, yam disease in PNG.

EDIBLE yam species of the *Dioscorea* genera are used as staple food in some parts of Africa, Asia and the Pacific island nations. The species commonly grown in PNG include *D. alata, D. esculenta, D. nummularia, D. bulbifera, D. pentaphylla* and now *D. rotundata*, recently introduced from the International Institute of Tropical Agriculture (IITA) in Nigeria. Of these species, *D. alata* (referred to as water yam or greater yam in other countries, and as true yam in PNG) has been associated with traditional farming and cultural practices in PNG. It plays an important role in the ceremonial and ritual life of the people in most yam-growing areas of this country. This species is very susceptible to the anthracnose disease caused by the fungus *Colletotrichum gloeosporoides*.

At early infection, the disease shows black spots on affected plant organs. The spots gradually increase in size to produce characteristic dark concentric rings. Some strains of the fungus affect only leaf petioles and main veins causing early senescence of leaves, but others spread further to the vines, completely killing the plant. Under favourable conditions, infected plants can be completely killed in a few days. *Dioscorea bulbifera* is susceptible to the fungus; *D. nummularia*, *D. pentaphylla* and *D. rotundata* are slightly susceptible; and *D. esculenta* is resistant. Similar observations of the susceptibility of these edible *Dioscorea* species to anthracnose have been reported by Booth (1978). The disease can affect the plant at any stage of its growth.

In PNG, edible *Dioscorea* species were only recently examined as a research crop, unlike other root crops such as taro (*Colocasia esculenta*) and sweet potato (*Ipomoea batatas*), which have been subject to research for much longer. Thus, information on all aspects of yam in PNG is limited. With regard to plant pathology, the small amount of information that is available mentions only the existence of different pathogens, but fails to present data on the importance, epidemiology and control of those pathogens. As a result, anthracnose may not necessarily be implicated as the cause of loss of varieties of *D. alata* and consequent

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reduction in its production in PNG. However, close examination in the field indicates that, among other diseases, anthracnose definitely reduces yield drastically and may have contributed to the loss of certain varieties. An IITA report on research carried out in 1976 (Nwankiti and Arene 1978) showed that anthracnose caused yield reductions of more than 67% on *D. alata* varieties in Nigeria.

True yam *(D. alata)* cultivation has declined in most areas of PNG and some varieties have become lost, probably because of the vulnerability of *D. alata* to this disease. People tend to grow more of other, less susceptible *Dioscorea* species. This paper outlines the severity of the disease, the varieties now being cultivated, the varieties lost and other *Dioscorea* species grown in each locality in the yam growing areas visited in PNG.

# Materials and Method

## Location

The provinces growing mostly *D. alata* that were visited were: Enga, Western Higlands, Simbu, Eastern Highlands, Madang, Morobe, Central, Milne Bay, New Ireland, West New Britain and East Sepik. Together with Bougainville and Oro (Northern) provinces, which were not visited, these provinces are the main true yam-growing areas of PNG. The trips commenced at the beginning of November 1999 and were completed in early June 2000.

At least two gardens of each yam-growing area visited were sampled, making sure that the sample areas were quite a distance apart from each other. The age of all the gardens visited was between two and three months old. Data was collected on the number of different true yam varieties being grown, the numbers lost, visual assessment of the incidence and severity of the disease on true yam and the number of other edible *Dioscorea* species grown in the locality.

## Disease assessment

Anthracnose incidence and severity on individual plant stands of *D. alata* species were visually assessed. The extent of anthracnose on individual plant stands was graded on a scale of 0–5. Disease severity scores (DSS) were: 0 (no incidence); 1 (plant partly affected from ground level to about 25% of the plant stand); 2 (26–50% of the plant stand affected); 3 (51–75% affected plant stand); 4 (76–100% affected plant stand); and 5 (complete death of the plant). An overall grading between 1–5 was also given for the whole garden, representing all the *D. alata* varieties grown in that garden.

# Results

The number of *Dioscorea* species grown in each area, the numbers lost and the anthracnose severity grading are shown in Table 1. Very high severity of anthracnose was observed in the villages of Bogia, Kanaugi, Maprik, East Cape and Morehead locations of Madang, and East Sepik, Milne Bay and Western provinces. These are primarily *D. alata* growing areas and had a disease grading of between 4 and 5. True yam varieties in these places were severely affected and plant stands were completely dead 2–3 months after establishment. For example, at Malala in Madang Province, the Sosogi variety was severely affected by anthracnose. The weight of tubers harvested was between 30–40 grams. People from Suki village in Western Province and some villages of East Sepik Province were able to confirm that the disease was responsible for the loss of most of their varieties and were able to give figures and their local names. The rest of the provinces visited had a disease grading of 3 and below. Some areas of East Sepik and Milne Bay provinces and Namatanai still have large numbers of *D. alata* varieties growing. Most villages in Trobriand Island grow the same varieties of *D. alata* and *D. esculenta* and confirmed that they had not yet lost any of their varieties. However, they are accepting introduced varieties.

Most *D. nummularia* varieties are grown in the highland districts of Morobe, Central and West New Britain provinces. The disease gradings in those areas were low. Only a few varieties of *D. pentaphylla* and *D. bulbifera* are grown in some provinces. *Dioscorea esculenta* is grown mostly in coastal areas. *Dioscorea rotundata* mini setts were given out during the survey in exchange for local *D. alata* tubers. A substantial number of *D. alata* varieties that had previously been grown, were reported to have been lost in most provinces; thus, people could not give actual numbers and variety names. Generally, those areas with a high incidence of anthracnose grew more varieties of *D. esculenta*.

Assessment of disease severity of *D. alata* was not carried out in some villages of Morobe, Milne Bay, Enga and Western Highlands provinces where the crop had not been planted, or planting had been delayed.

**Table 1.** Number of *Dioscorea* species collected, grown and lost, and anthracnose disease severity grading of *D. alata* varieties in some villages in yam-growing areas of PNG.

| Province | District | Village | *Dioscorea* species[a] | | | | | DSS |
|---|---|---|---|---|---|---|---|---|
| | | | *alata* | *esculenta* | *nummularia* | *bulbifera* | *pentaphylla* | |
| East Sepik | Kanaugi | Haniak | 2 | 2 | | | | 3 |
| | Wewak | Wautagit | 1 | 5 | | | | 4 |
| | Wewak | Makopin | | 4 | | | | 4 |
| | Wewak | Turubu | 4 (3) | 5 | | 2 | 2 | 4 |
| | Wewak | Sinabilai | 12 (6) | 9 (0) | | 2 (0) | 2 | 4 |
| | Kanaugi | Memboru | 13 (3) | 13 (0) | | 2 (0) | | 3 |
| | Maprik | Kinbangua | 15 (6) | 16 (0) | | 2 (0) | | 5 |
| | Kanaugi | Tonumbu | 7 (2) | 6 (0) | | 3 (0) | | 3 |
| | Wewak | Bogumatai | 2 (7) | 6 (0) | | 2 (0) | | 5 |
| Madang | Transgogol | Kulili | 3 (1) | 4 | | | | 2 |
| | Bogia | Ulige | 5 (*) | 4 | | | | 4 |
| | Bogia | Moro | 0 (*) | 5 | | | | |
| | Rai Coast | Sakuamum | 0 (*) | 2 | | | | |
| | Saidor | Lalok | 0 (*) | 6 | | | | |
| | Sumkar | Bunabun | 0 (*) | 3 | | | | |
| | Bogia | Malala | 3 (2) | 6 | | | | 5 |
| Morobe | Wasu | Hongo | 2 (*) | | | | | |
| | Wasu | Kikiong | 5 (*) | | | | | |
| | Pindu | Zaning | 6 (*) | | | | | |
| | Sialum | Kanome | 1 (*) | | | | | |
| | Sialum | Afon | 2 (*) | | 1 | | | |
| | Boana | Pepundu | | | 1 | | | |
| | Wau | Wadumi | 2 (*) | | 1 | | | |

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**Table 1** (cont'd). Number of *Dioscorea* species collected, grown and lost, and anthracnose disease severity grading of *D. alata* varieties in some villages in yam-growing areas of PNG.

| Province | District | Village | *Dioscorea* species[a] | | | | | DSS |
|---|---|---|---|---|---|---|---|---|
| | | | *alata* | *esculenta* | *nummularia* | *bulbifera* | *pentaphylla* | |
| Morobe (cont'd) | Wau | Sandy Creek | 1 (*) | | | | | |
| | Wau | Wau station | | | 2 | | | |
| | Wau | Biawen | | | 1 | | | |
| | Kaiapit | Atzunas | 1 (*) | | 1 | | | 3 |
| | Mumeng | Station | 5 (*) | 3 | 4 | | | 3 |
| Milne Bay | East Cape | Tuidobu | 2 (*) | 2 (0) | | | | 5 |
| | East Cape | Munamunalia | 4 (0) | 4 (0) | 2 | | | 3 |
| | Alatoau | Laute watewa | 1 (0) | 3 (0) | 2 (0) | 1 (0) | | 3 |
| | Maramatan council area | Higowi | 4 (*) | 3 (0) | | | | |
| | Maramatan council area | Didiluna | 2 (*) | 4 (0) | 2 (0) | 1 (0) | | 2 |
| | Trobriand Island | Moku buigaitu[b] | 12(0) | 12(0) | 4 | 1 | | 2 |
| | Trobriand Island | Kuli kuaw | 12 (0) | 12 (0) | | | | 2 |
| | Trobriand Island | Mula sida | 13 (0) | 12 (0) | | | 1 | 2 |
| | Trobriand Island | Kayawa | 16 (0) | 12 (0) | | | | 2 |
| | Normanby Island | Lomitawa | 2 | | | | | |
| | Normanby Island | Meudana | 7 | | | | | |
| | Normanby Island | Yelu yeluwa | 2 | | | | | |
| Central | Abau | More | 8 (0) | 6 | 1 | | | 2 |
| | Abau | Amau | 7 (0) | 3 | | | | 2 |
| | Abau | Iano | 8 (*) | 8 | 2 | | | 1 |
| | Hisu | Hisu | 1 (*) | 6 | | | | 1 |
| | Gabadi area | Ukaukana | 7 (*) | 8 | 2 | | | 3 |

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**Table 1** (cont'd). Number of *Dioscorea* species collected, grown and lost, and anthracnose disease severity grading of *D. alata* varieties in some villages in yam-growing areas of PNG.

| Province | District | Village | *Dioscorea* species[a] | | | | | DSS |
|---|---|---|---|---|---|---|---|---|
| | | | *alata* | *esculenta* | *nummularia* | *bulbifera* | *pentaphylla* | |
| Enga | Wapenamanda | Aikles | 1 | | | | | |
| | Wapenamanda | Sandep | | | 3 | 1 | | |
| Western Highlands | Angelip | Manden | | | 1 | | | 2 |
| | Banz | Kwina | 2 | | 1 | | | 1 |
| | Jimi | Koskala | 4 | | | | | |
| Simbu | Kerowagi | Taugl Pene | 1 | | | 1 | | 1 |
| | Nomane | Wara Sua | 1 | | 3 | | | 1 |
| | Chuave | Pira | 6 (*) | | 4 | | | 2 |
| | Gumine | Gonul | 6 (*) | | 7 (0) | | | 2 |
| Eastern Highlands | Henginofi | Hei | 1 (*) | | | | | 1 |
| | Goroka | Rapigu | (*) | | 1 | | | 1 |
| | Kainantu | Nimura | (*) | | 1 | | | 1 |
| | Ungaibena | Bena | 4 (*) | 1 | 2 | | | 1 |
| New Ireland | Kavieng | Kaut | 5 (*) | 4 (0) | | | | 3 |
| | Namatanai | Burabula | 10 (*) | 8 (0) | | | | 2 |
| | Namatanai | Nomorodu | 10 (*) | 8 (0) | | | | 2 |

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**Table 1** (cont'd). Number of *Dioscorea* species collected, grown and lost, and anthracnose disease severity grading of *D. alata* varieties in some villages in yam-growing areas of PNG.

| Province | District | Village | *Dioscorea* species[a] | | | | | DSS |
|---|---|---|---|---|---|---|---|---|
| | | | *alata* | *esculenta* | *nummularia* | *bulbifera* | *pentaphylla* | |
| West New Britain | Kimbe | Galai | 7 (*) | 9 (0) | | | | 3 |
| | Kimbe | Saraklok | 14 (*) | 10 (0) | | | | 1 |
| | Biala | Barima | 4 (*) | 6 (0) | 4 (0) | | | 2 |
| | Bialla | Soi | 6 (*) | 7 (0) | | | | 1 |
| | Bialla | Kabaya | 1 (*) | 6 (0) | 2 (0) | | | 2 |
| Western Province | Morehead | Suki | 7 (6) | 8 (0) | | | | 5 |
| | Middle Fly | Obo | 3 (*) | 5 (0) | | | | 2 |
| | Middle Fly | Atkamba | 2 (*) | 6 (0) | | | 1 | 2 |
| | Morehead | Yokwa | 4 (*) | 7 (0) | | | | |

DSS = disease severity score (see text for definition)

[a]Numbers in brackets indicate number of varieties lost; asterisks indicate an unknown number of lost varieties.
[b]This village also had one variety of *D. rotundata.*

## Discussion

It is evident from these results that anthracnose is one of the causes of loss of some *D. alata* varieties in PNG. The very high incidence and severity of the disease has forced people in some areas of Madang Province to completely abandon *D. alata* cultivation and concentrate on *D. esculenta*. This decision may have been easy to make as *D. alata* is not as ceremonially important as it is in the Trobriand Islands of Milne Bay Province and the Maprik area of East Sepik Province. Despite the very high incidence of anthracnose in these two areas, people still grow a large number of *D. alata* varieties because of the ceremonial importance of the species. Except for Maprik, villages of the Trobriand Islands have not yet lost a variety of *D. alata.*

Other important *D. alata* growing areas that were visited indicated a loss of varieties but were unable to report correct figures and local names. They reported obtaining smaller sized tubers for some of the varieties still being cultivated. They were not sure of the cause of the loss of these varieties, nor of the cause of the decline in yield. Most areas in the lowlands tend to grow more *D. esculenta*, while in the highlands *D. nummularia*, or other root crops such as sweet potato, cassava, *Xanthosoma* and *Colocasia* taro are grown. Increased cultivation of these two *Dioscorea* species occurs because they are highly tolerant to anthracnose. Lea (1966) predicted that the cultivation of ceremonial yam (*D. alata*) in the Abelam area of East Sepik Province would gradually disappear when the traditional culture for growing yam broke down, easy-to-grow tuber crops became available and young yam-growers became engaged in other business activities. This prediction was made without considering the effects of anthracnose on the *D. alata* species. In this area, five out of the reported 21 varieties have been lost.

With little information available on disease epidemiology, control and importance of anthracnose in PNG, it is difficult to state with certainty that anthracnose disease is the only cause of the loss of *D. alata* varieties and its decline in production. However, the extent of damage caused by anthracnose on some varieties and the severity of the disease in mainly *D. alata*-growing areas indicates that the disease is definitely one of the main causes of variety extinction and decline in production. Yield loss in each area was not possible to predict. However, people found smaller tubers in high anthracnose-incidence areas. Anthracnose was reported to cause more than 67% yield loss on *D. alata* varieties in Nigeria (Nwankiti and Arene 1978). The disease was reported as causing serious losses when it attacked the plant immediately after tuber initiation or during bulking (Hahn et al. 1987). Although we were unable to estimate yield losses in this survey, it is obvious that serious losses do occur.

Despite the disease pressure and the move to growing more disease-tolerant *Dioscorea* species and other easy-to-grow crops, the value of *D. alata* in terms of its drought tolerance, longer storage life and nutritional properties cannot be ignored. Most of the varieties currently being grown in areas of high disease incidence were seen to tolerate the disease. Tolerance of *D. alata* varieties to anthracnose has been reported in Nigeria (Nwankiti and Arene 1978). Anthracnose-resistant lines of *D. alata* are now available for international distribution from IITA (IITA 1986; Hahn et al. 1987).

## Conclusion

From this survey, the anthracnose disease of true yam is seen as one of the main causes for the loss of some varieties of *D. alata* and decline in production. In PNG, research on yams only started recently. As a result, there is little or no information on many aspects of the crop. For plant pathology, it is suggested that research is needed on the epidemiology and the control of this disease and other yam diseases present in PNG. Furthermore, disease-tolerant *D. alata* varieties observed in this survey should be properly screened to establish their disease-tolerance levels and for distribution to farmers. Tolerant varieties could then be maintained in ex situ collections in anticipation of future breeding activities, giving a quick solution for rural yam growers in PNG.

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# The Status of Introduced White Yam in PNG

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*Abstract*

The white yam (*Dioscorea rotundata* Poir.) was introduced into PNG in 1986 at Saramandi Research Station, where a small working collection was established and basic characterisation was done. This species of yam has many similarities to the greater yam (*D. alata*) in its morphology and agronomic requirements. Clients who have assessed the material from TDr 90-1-1 (a promising line) for growth performance and consumer preference have readily accepted this yam, leading to random adoption in many provinces of PNG. The white yam was observed to be tolerant to drought during 1997. It is a convenient research tool as it does not have the cultural sensitivity associated with *D. alata* and *D. esculenta* in PNG yam-growing societies.

THE white yam (*Dioscorea rotundata* Poir.) originated in West Africa, and is widely cultivated in the West African forest zone where it has special socio-cultural importance (Akoroda 1983). It is a dietary staple and a preferred food (Coursey 1967; Onwueme 1978; Onyilagha 1986).

Seeds of breeding lines from the Tropical Root Crop Improvement Program at the International Institute of Tropical Agriculture (IITA) in Nigeria were introduced into PNG in 1986. From these, a small working collection of *D. rotundata* lines was established at Saramandi Research Station (SRS) in East Sepik Province.

This paper revisits the introduction, describes the accessions, reviews the extent of the yam's spread to other parts of PNG, and discusses production and utilisation attributes.

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## Introduction of White Yam

In 1986 the SRS agronomist brought back two packets of seeds from maternal lines TDr 90-1 and TDr 66 after attending an IITA training course. Seeds were sown on moist filter paper in the field laboratory and those that germinated were transferred into Jiffy pellets and later transplanted onto a seedbed enclosed in a screenhouse.

Close observations on pests and diseases revealed nothing unusual, and 30 seedling plants were harvested and recorded. Thereafter, the *D. rotundata* accessions were maintained through conventional vegetative propagation as part of the Saramandi Yam Collection.

### Plant morphology

The white yam closely resembles the greater yam *D. alata*, twining to the right and producing only one tuber or a few tubers per plant. The dark brown tuber skin is smooth and without thorns. Also like the greater yam, the meristematic buds are distributed over the entire tuber surface. This trait makes both species highly suitable for rapid multiplication using the 'mini-sett' technique. The white yam differs from *D. alata* in having a rounded stem cross-section with darker green leaves, which may also be relatively small.

# Crop Management

## Preparing planting material

White yam, like the greater yam, can be propagated from whole tubers weighing 300–1000 grams or from cut sett pieces weighing 25–100 grams. By the second vegetative generation at SRS, all varieties were propagated using the 'mini-sett rapid multiplication technique' (IITA 1984). This involves cutting sprouted post-dormancy mother sett tubers into mini-setts weighing between 25 and 50 grams. Wood ash is rubbed into the cut surfaces and the treated setts are cured for at least several hours before planting in the germination seedbed. The seedbed sprouting medium can be a mixture of good topsoil (two parts) and old weathered sawdust (one part). The setts are placed side by side in the medium, with the outer skin (periderm) layer facing down and in contact with the medium; they are then covered with a 2–3-centimetre (cm) layer of the medium. With adequate watering, mini-setts should sprout after 4–5 weeks and should be transplanted when sprouts are 5–10 cm long.

# Planting Techniques

Planting yam involves first digging a hole wide and deep enough to accommodate the anticipated tuber. A hole with a diameter of 20–25 cm and 75–100 cm deep would be average for a ware yam tuber. A straight pole about 1.5 cm in diameter is stuck into the centre of the hole and guides the farmer in the placement of the sett during planting.

After the hole is dug, it is filled with loose topsoil from near the hole or with the dug up soil. In the latter case, the soil is pulverised by hand, and stones and other foreign objects are removed. When the hole is filled to the surface, a small mound 20–30 cm high is formed over the top. The top of this planting mound is formed around the planting guide stick. A small plateau is levelled off and the guide stick is removed with as little disturbance of the soil as possible.

The sett is positioned over the hole of the guide stick so that the tuber will develop into the centre of the planting hole. To complete the planting, the sett is covered with 5–10 cm of soil and the top of the mound is rebuilt.

## Planting density

Yam planting densities in traditional gardens are generally about 2000–3000 plants per hectare (Kesavan 1983). Spacing for the white yam can range from two-metre squares (2 m × 2 m) to 1 m × 0.5 m, depending on the cropping system followed and the desired yield and tuber size (IITA 1982). While total yield increases with planting density, the net yield (total yield less weight of planting material) is determined by density and the type of sett used.

## Manuring and fertilisers

Yams are normally used in the first planting after a garden is cleared from forest fallow and may not respond to fertiliser application. If land is used too soon after a previous crop, fertiliser is necessary. The rate of application would depend on the soil type, site history and type of fertiliser. Fertiliser is used more efficiently if applied monthly in two or three split applications, starting at planting. Application of nitrogen encourages vine growth from 1 to 4 months after planting (MAP) while potassium application would help tuber development from 5 to 7 MAP.

## Staking

As for other yam species, staking increases yield. Available staking techniques include single pole staking, trellis and pyramid methods. The technique used is determined by the availability of staking material and the cost of labour in erecting the stakes. The gain in additional yield must be justified against the cost of the staking system used for a given crop. A standard height for staking is about 2 m; taller stakes can drastically increase installation costs without real yield benefits (King and Risimeri 1992). For long-term yam production, the trellis method has the advantage of allowing the materials to be reused over several seasons and can help in weed control.

## Pests and diseases

The Saramandi Yam Collection has been free of major pests and diseases since its introduction. At SRS the major pest encountered was the mealybug *Planno-coccus dioscorea* (COPR 1978), which was observed during storage. This was expected, as the storeroom was designed to have airconditioning and is poorly ventilated without it. Random field attacks of a yam defoliator, *Tagiades nestus* (feldar), and a few taro beetle holes on several tubers have been observed at the Bubia Research Station. Wilting was observed in 1996 on *D. rotundata*: symptoms resembled those caused by *Fusarium* spp. when they attack the root systems of yams.

### Weeding and earthing up

Severe weed competition during the early stages of the crop can adversely affect canopy establishment and lead to yield reduction. In the first three months after planting, weeding is essential until the yam canopy is established and shades out some of the ground area. Cultural techniques used in the husbandry of the crop can be modified to help control weeds. These include the staking method used, the height of staking, the type of mulching and the planting density.

Earthing up is done for two reasons: firstly, to rebuild damaged mounds or ridges; and, secondly, as tubers are approaching maturity, to cover any exposed tubers. Mound or ridge repairs can be done along with weeding, while tuber covering is done specifically to avoid sun-scorching and subsequent microbial infection and rotting of tubers.

### Harvesting

Harvesting of tubers intended for consumption or sale can be done seven months after planting, at the onset of leaf yellowing, before senescence. However, people who peel tubers harvested from plants with leaves on the vines may experience stinging of the hands, caused by oxalates. Thus it may be preferable to harvest when all the leaves have senesced. Harvesting is carried out using digging sticks, bushknives, spades and other digging implements, taking care to avoid injuring the tubers. Once out of the ground, tubers must be covered, as observations and literature show that exposure to direct sunlight renders them susceptible to rotting in storage.

### Yield

The yield data given in Table 1 are extrapolated from 10 plants per line for all lines, except for TDr 90-1-1, which was multiplied in a plot with a total area of 800 square metres. Both the collection and the TDr 90-1-1 multiplication plot were planted at a density of 20,000 plants per hectare. Thus, these figures are only tentative until the promising lines are formally tested in replicated trials. An interesting feature of our observations is that mini-setts have yielded ware tubers (mean 3 kilograms) similar to those obtained from head setts or whole tubers.

## Post-Harvest and Storage

Under conditions at the Bubia Research Station, tubers broken or damaged during harvest and transportation have been observed to heal well under ambient temperature. However, tubers exposed to direct sunlight upon harvesting suffered bacterial rot in storage. Most tubers broke dormancy 6–8 weeks after harvest, in contrast to the 12–14 weeks reported in West Africa (Knoth 1993).

## Utilisation

Many farmers and consumers who have had the opportunity to eat this yam have ranked it higher than the local species they are accustomed to eating. This preference is based on the cooked texture of *D. rotundata*, which is firmer when boiled in coconut cream, and has a taste similar to potato. Many clients have returned to send planting material to their home areas. Sopade et al. (in press) reported a bitter after-taste in chips and cooked yam of TDr 90-1-1 and suggested a need for further studies into these factors.

## Current Distribution

The current distribution of material from the introduced lines needs to be surveyed, but from talking to farmers and from records of previous movements, planting materials, especially of TDr 90-1-1, are established in East Sepik, Sandaun (West Sepik), Morobe, Western Highlands and Milne Bay provinces.

All 21 lines then held at SRS were introduced to Milne Bay Province in 1991; to date eight lines are established there. It has been noted that in some areas where African giant snails have recently been introduced, the *D. rotundata* have been less severely damaged than the indigenous species. Milne Bay farmers have also adopted some of these lines for their desirable eating qualities (David Leonard, pers. comm.).

The current distribution of the snail species and its likely impact on the native yam species need to be assessed. Feedback is ongoing, with stories of large tuber harvests from rural yam growing areas of Morobe Province. For example, farmers from Dinangat village in the Kabwum District have a very high regard for the large tubers of *D. rotundata* they harvest. This could lead to the danger of neglect of local cultivars, leading to loss of yam genetic material.

Farmers in the Markham Valley from Intoap and other villages have taken up the white yam as a commercial crop. Production for the Lae market has started on a small scale, with sales at 1.00 to 1.50 PNG kina (PGK) per kilogram[1].

**Table 1.** Yield and tuber characteristics of white yam lines maintained at Bubia during the 1996 season.

| Accession No. | Yield (tonnes/hectare) | Tuber shape[a] | Tuber branching[b] | Flesh colour |
|---|---|---|---|---|
| TDr 90-1-1 | 61.0 | Cylindrical | H | White |
| 90-1-10 | 56.0 | Long—fair | M | Creamy white |
| 90-1-5 | 45.8 | Fair | X | Yellow |
| 90-1-7 | 45.8 | Short—fair | H | White |
| 90-1-8 | 43.8 | Long—cylindrical | X | Creamy white |
| 90-1-1 | 35.0 | Long—cylindrical | M | Creamy white |
| 66-1 | 34.8 | Cylindrical | X | White |
| 90-1-4 | 30.0 | Long—fair | M | White |
| 90-1-3 | 27.0 | Long—fair | M | Creamy white |
| 90-1-6 | 27.0 | Fair | X | Yellow |
| 90-1-2 | 24.6 | Cylindrical (hairy) | X | Yellow |
| 66-3 | 22.0 | Long—curved | M | White |
| 66-5 | 20.0 | Long—cylindrical | X | White |
| 66-11 | 17.0 | Long—fair | X | Creamy white |
| 90-1-9 | 14.0 | Long—cylindrical | M | Creamy white |
| 66-10 | 9.4 | Long—cylindrical | M | White |
| 66-8 | 11.2 | Long—cylindrical | M | Creamy white |
| 66-9 | 3.3 | Short (small) | X | White |

[a]Fair = a well formed tuber with a good visual appeal to consumers
[b]H = high branching; M = moderate branching; X = no branching

Since 1997, clients from virtually all PNG provinces have purchased planting material for relatives back home. Further spread and adoption into PNG farming systems appear inevitable, ahead of further research and recommendations.

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1. In July 2000, 1 PGK = approx. US$0.4 (A$0.6).

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# Future of Cassava in PNG: Outcomes of the Cassava Workshop, 1999

**Ian Grant*[*] and Matthew G. Allen[†]**

*Abstract*

This paper reports on the outcomes of a workshop held in Lae, Morobe Province, PNG, at the Forest Research Institute on 2 July 1999. The purpose of the workshop was to raise the profile of cassava in PNG and to focus the attention of research workers, development agencies, private enterprise and policy makers on the potential of the crop to serve this nation. The workshop aimed to define the importance of cassava in the various agricultural systems in PNG; anticipate likely changes in its importance in the future; identify and publish past research work involving cassava; and develop a research and development strategy that will improve the use of cassava in PNG.

FEW farmers attended a workshop on cassava held at the Forest Research Institute in Lae, Morobe Province, PNG, on 2 July 1999. The contrast with the first National Agricultural Research Institute (NARI) workshop on vanilla production, in which many farmers contributed to setting the research and development agenda, could not have been greater. Cassava is regarded as a poor man's food, pig food, lazy man's food or dog food in PNG. Throughout the Pacific, cassava tends to be regarded as an invader that replaces traditional staples, and has been blamed for poisonings and increased rates of human malnutrition and soil erosion (Thaman and Thomas 1982). This attitude to cassava, together with ignorance among policy makers and researchers of its importance, limits our capacity to initiate and undertake an effective research and development program for the crop.

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At the workshop, Dr Bourke emphasised the importance of cassava where agricultural systems were considered to be at risk. 'Cassava is free of any major pests and diseases and can be grown under a wide range of environments, especially adverse conditions, and in particular is tolerant of poor soil fertility' (Bourke and Vovola 2000). Professor Onwueme pointed out that cassava is likely to play an even greater role in feeding Papua New Guineans in the future as the population rises and pressure on land resources increases. Dr Bourke supported this idea, observing that the importance of cassava had increased markedly over the last 50 years. This is a Pacific-wide trend (Thaman and Thomas 1982).

Thaman and Thomas (1982) identified some of the factors contributing to the so-called cassava invasion.

> 'As more and better quality lands have been taken up in cash and long-term tree crops; as more time and effort have been required to cultivate cash crops; as more young men have moved out of the rural areas to take up wage employment; as population pressure has grown; and as schooling effectively removed the bulk of the young labour force for most of the day, there was neither land, nor time and frequently insufficient motivation, to continue more demanding cultivation of traditional staples. As pressure on land increased and

> fallow periods became shorter, and soil fertility and yields of traditional staples decreased some answer was obviously needed. Almost without exception the answer, not only in the Pacific but throughout the Third World, has been cassava.'

Dr Rao highlighted the potential of cassava based on his experiences in India and PNG. In India, areas where the crop is of increasing importance correspond with industrial development of processing capacity and effective marketing of cassava products. These areas have environments in which cassava has a competitive advantage over other crops, use irrigation and have relatively low wages. Cassava has become a cash crop that is the basis for many products used in paper and textile manufacture, alcohol production, as a flavouring agent, manufacture of adhesives and an ingredient in glucose and dextrose. It can also be processed into flour, chips and crisps, it can provide fuel, and dried chips and leaves can be used as livestock feed. Dr Rao concluded that for PNG there are opportunities for development of value-added products from cassava and potential to transform the crop from a subsistence food crop to a cash crop. However, a well-prioritised and planned research and development effort is required.

Using currently available cassava varieties, 30–50 tonnes per hectare per year of fresh tuber (30% dry matter) could be produced. Mr Yunus Musa, from the University of Hasannuddin in Indonesia, suggested that further yield improvements (up to 90 tonnes per hectare per year) might be expected using a Mukibat grafting technique. Budding or grafting of rubber trees (*Manihot glaziovii*) to rootstocks of cassava results in a more vegetatively robust plant, increasing the yield per plant by up to five times. There are also suggestions that grafted plants are more drought tolerant. This technique is used extensively in Indonesia, with adoption rates close to 100% in some areas. No increase in hydrocyanic acid (HCN) concentration in tubers has been detected, although Professor Onwueme suggested that this should be checked. It was also suggested that the leaves were valuable forage for livestock, which was a surprise. Mr Musa stressed that high yields were only possible when combined with sound agronomic practices such as weeding, use of fertilisers, nurturing of seedlings, irrigation and when suitable soil conditions were maintained. G. Wiles was not sure that such an innovation was needed, given the very high yields possible with conventional cassava growing. L. Fooks pointed out that mechanical harvesting would certainly be more straightforward if the whole plant was lifted. Grafted plants were established in 1999 at the University of Technology in Lae for evaluation, and more widespread testing is planned.

One of the aims of this workshop was to collect previously unpublished results of past research involving cassava. These studies have concentrated on evaluating local and introduced cassava varieties in different environments. The effects of various agronomic practices on yield have also been investigated (Ansin and Gurnah 1992). Only a few studies have considered taste and fibrous consistency as important when evaluating varieties. More emphasis is needed on taste unless growing for livestock feed.

HCN content has been measured in two trials and a few of the best yielding varieties were found to have moderately high levels, although the majority were very low in HCN (King 1988; Wiles 2000). Age at maturity and occurrence of tuber rot have also been studied. Later maturing varieties (> 10 months), which do not easily rot during the long dry season, have been identified and successfully tested on farms in the Upper Ramu area. Follow-up surveys are needed to see how widely farmers have adopted these new varieties.

Research has lead to the identification of superior varieties of cassava. A program of distribution and onfarm evaluation, in collaboration with provincial governments and nongovernment organisations, is needed to get the full benefit from these studies. Local knowledge suggests that further useful varieties of cassava, with better taste, exist but have not yet been collected. Promising local varieties should be collected and evaluated in each key location. It is important to establish cassava collections at mid-altitude (600–1200 metres above sea level) and at higher altitude (1600 metres above sea level) to replace the collections at Kuk Research Station and Menifo. Varieties that perform best at one altitude may not perform well at other altitudes, as observed by Swift and Nalu (1981).

Research and development priorities for improving use of cassava in PNG are listed in Table 1. The highest priority for cassava research is to continue to identify superior varieties in each agroecological zone and to ensure that farmers have access to those varieties (Bourke and Vovola 2000). The selection criteria for superior varieties will depend on the end use of the crop. For human consumption, good taste, soft consistency after cooking, possibly yellow pigmentation and low HCN content are considered to be important. Consideration may also be given to nutritional quality. A cassava cultivar bred at the International Center for Tropical Agriculture (CIAT), in South America, has increased ß-carotene, iron and zinc content and could be useful in PNG (Dr J. Stangoulis, Plant Nutrition

Group, University of Adelaide, pers. comm. 1999). In some areas, time to maturity, susceptibility to root rot, resistance to insect pests (*Amblypelta* spp.; King 1988) and resistance to anthracnose (Swift and Nalu 1981; Bourke 1982) may be important.

For other applications, such as industrial processing or feeding to livestock, characteristics such as high tuber or leaf yield, high content and availability of leaf protein, suitable arrangement of tubers (for mechanical harvesting) and high starch (> 30%) and low moisture content (55–65%) would be important. Little information is available on the characteristics of cassava varieties currently used for feeding livestock. These so-called pig varieties have been implicated in human poisonings (Swift and Nalu 1981), suggesting that they may be high in HCN. This could be important in discouraging rat and wild pig destruction of tubers and possibly in extending storage life in the ground. Simply peeling tubers may be sufficient to reduce toxicity of tubers sufficiently for feeding to livestock. However, chronic poisoning, which reduces productivity, would result if levels are over about 15–20 milligrams HCN per 100 grams of fresh tuber. These varieties also appear to be higher yielding than the more palatable yellow varieties used for human consumption (King 1988).

For intercropping with peanut, cowpea, French bean and sweet potato, cassava varieties with a small canopy size would be desirable. At least one such variety has been identified (King 1988). For planting under tree crops, a degree of shade tolerance would be an advantage as cassava is not particularly shade tolerant (M. Johnston, Cooperative Centre for Sustainable Sugar Production, James Cook University, pers. comm. 1999).

**Table 1.** Research and development priorities for improving utilisation of cassava in PNG.

| Area | Comments |
|---|---|
| Agronomy | • Characterisation of collections at Laloki Research Station, Lowlands Agricultural Experiment Station (Keravat) and the PNG University of Technology (Unitech); sort out duplicate numbers.<br>• Establishment and evaluation of collections at mid-altitude (600–1200 metres above sea level) and highlands (1600 metres above sea level), wet and dry locations.<br>• Onfarm trials of best cultivars at key locations incorporating promising local varieties.<br>• Evaluation of the results from Mukibat grafting at key locations for tuber and leaf yield, HCN and drought tolerance.<br>• Identify suitable varieties for intercropping with crops such as soybean, cowpea, peanut, French bean, sweet potato.<br>• Characterisation of cassava varieties used for pig feeding. |
| Nutrition/processing | • Promotion of cassava tubers and leaves as a national food resource. This will involve testing of leaves for HCN and evaluation of local HCN detoxification procedures as well as assembling suitable recipes to promote consumption. |
| Downstream process | • Using chips, flour, local and more general processing. |
| Market assessments | • Human consumption—fresh tuber, processed foods.<br>• Livestock feed—tubers and leaves, either fed fresh or dried/ensiled, compounded locally or by feed mill.<br>• Industrial potential—starch, ingredients in glues, flavouring agent, ingredient in dextrose, etc.<br>• Export potential. |
| Extension practices | • Awareness, model farms and demonstrations, extension publications, training. |
| Industry linkages | • Feed mills, livestock industry groups, feed producers and retailers, cottage industries. |
| Partnerships and alliances | • International Institute of Tropical Agriculture, International Center for Tropical Agriculture, Unitech, University of Papua New Guinea, Pacific Adventist University, agricultural training centres, provincial governments. |

Some emphasis is also needed on the promotion of local consumption of leaves, which contain remarkably high levels of protein. Proper methods of preparation that avoid possible toxic effects and maximise nutritional value and palatability need to be developed. At least two varieties with highly palatable leaves are present in the Laloki Research Station collection (R. Kambuou, NARI, pers. comm. 1999). They are consumed green in some areas, but need to be evaluated in other locations and tested for HCN content.

In general, PNG studies involving feeding cassava to livestock have compared cassava and cereal-based diets that are balanced for protein, amino acids, minerals and energy, with mostly predictable results. Farmers, because of the difficulty and cost involved in obtaining ingredients, have not used this technology. It would be better to concentrate on developing and evaluating diets that can be grown and obtained locally. Farmers (and researchers) would have to accept lower livestock productivity against a much-reduced feed cost. The value of feeding cassava leaves to livestock (pigs, rabbits, ducks) also needs to be promoted, as this may be a key way to improve the utilisation of the crop. This may require the introduction of some detoxification techniques or variety selection, which would include measurement of leaf HCN concentration. It may also be better to promote medium- to large-scale growing and processing of cassava for sale to local feed manufacturers.

Substitution of up to 40% of the grain currently imported for feeding to chickens and pigs by local cassava production is theoretically possible. Given that approximately 50,000 tonnes of grain are imported each year, at a cost of 300 PNG kina (PGK) per tonne,[1] this would save PNG approximately six million PGK each year in foreign exchange. To realise this potential, large-scale planting of cassava and development of a local processing industry to chip and dry tubers would be needed (Onwueme 2000). Given that there are large areas of suitable land available that are currently under-utilised, and that labour costs in PNG are only 80% of those in neighbouring Asian countries (M. Manning, Institute for National Affairs, pers. comm. 1999), there is the potential to develop a cassava processing and export industry. A feasibility study, followed by a pilot study, is needed to assist policy makers and private enterprise to decide if commercial development is warranted.

[1] In July 2000, 1 PGK = approx. US$0.40 (A$0.60).

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# Potato Production in PNG: the Contribution of Research to Alleviating Constraints to Potato Production

**Geoff Wiles***

*Abstract*

This paper presents a review of potato research in PNG from 1990–95, and its contribution to PNG potato production. During this period, research has focused on evaluating potato varieties for bacterial wilt tolerance and processing quality, improving agronomic practices for the production of potato varieties for processing, managing bacterial wilt and optimising seed production methods. PNG has long relied on the ware potato variety Sequoia and, despite many trials of other varieties, this variety has not been replaced or superseded. Although some varieties have improved bacterial wilt tolerance, they do not have the high yield or tuber quality required to replace Sequoia. The cultivar Kennebec has potential for French fry processing, but has yielded less than Sequoia in most trials. However, trials during 1990–95 have shown that improved management can increase Kennebec yields and reduce production costs. Potato crops have been shown to respond well to boron application: fertiliser recommendations have been revised to take this into account and suppliers have agreed to include boron in potato fertiliser mixes. A minituber-based, seed production scheme relying on tissue-cultured potato plantlets has also been developed. This has replaced the practice of multiplying imported Australian seed potatoes on government farms, which had become seriously infected with bacterial wilt by the early 1990s, and were generally not suitable for seed potato production. It has also been shown that incorporating maize into crop rotations can suppress bacterial wilt in potato crops following the maize.

THIS paper reviews potato research undertaken by the Food Management Division of the PNG Department of Agriculture and Livestock (DAL) from 1990–95, and examines its contribution to the development of PNG potato production.

## Potato Research in PNG Before 1990

In reviewing potato research up to 1990, I have relied heavily on papers presented at the 1987 DAL Potato/ Sweet Potato Workshop (Pitt and Yandanai 1987) and work in Enga Province from 1985–88, reported by Preston (1988). The outcomes of potato work up to 1990 contributed to the preparation of the *Potato Pocket Book* (Sawanga 1987), the *Papua New Guinea Seed Potato Scheme Technoguide* (Hughes et al. 1989) and the *Lowland Potato Technoguide* (Woodhouse 1989).

Before 1990, potato research in PNG focused mainly on variety evaluation and fertiliser trials. Gunther (1987) reviewed potato research up to 1987 and reported that 16 variety trials had been conducted in five provinces. Further variety trials were conducted in the late 1980s (Pitt et al. 1987; Preston and Kowor 1987): the results are summarised in Table 1. Sequoia was used as the control variety because it had been the main variety for multiplication and distribution through the

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PNG seed scheme. It is clear from Table 1 that Sequoia has consistently yielded well over many trials. While Sequoia is a good ware potato, unfortunately it is not suitable for the commercial production of French fries. The cultivar Kennebec has been used and promoted for this purpose in PNG, but has yielded consistently lower than Sequoia. Only a few varieties yielded better than Sequoia, and none of these were readily available from

**Table 1.** Potato variety trial yields.

| Potato variety | Mean yield (tonnes/hectare) | Sequoia yield equivalent[a] (tonnes/hectare) | No. of trials | Yield (% of Sequoia yield) | Suitability for processing |
|---|---|---|---|---|---|
| Walanga | 18.9 | 17.1 | 2 | 110.9 | unknown |
| 800935 | 24.6 | 22.3 | 3 | 110.1 | possibly |
| 800926 | 27.5 | 25.9 | 5 | 106.1 | unsuitable |
| 800941 | 25.5 | 24.8 | 8 | 102.9 | unsuitable |
| DTO 33 | 25.1 | 24.5 | 4 | 102.7 | possibly |
| 800144 | 26.6 | 26.0 | 3 | 102.4 | unknown |
| Sequoia | 23.0 | 23.0 | 28 | 100.0 | unsuitable |
| Dalisay (720088) | 24.1 | 24.4 | 8 | 99.0 | possibly |
| Pontiac | 19.5 | 20.8 | 19 | 93.6 | unsuitable |
| Katella | 28.5 | 30.5 | 4 | 93.4 | unsuitable |
| DTO 2 | 22.7 | 24.5 | 4 | 92.7 | possibly |
| Cipanas | 23.8 | 25.9 | 5 | 91.8 | unsuitable |
| Sebago | 19.4 | 21.3 | 14 | 90.8 | suitable |
| Bison | 20.3 | 23.2 | 2 | 87.5 | unknown |
| Up-to-Date | 19.3 | 22.7 | 22 | 85.0 | possibly |
| Red La Soda | 18.8 | 22.4 | 19 | 84.0 | unsuitable |
| Onka | 19.8 | 24.1 | 13 | 82.0 | possibly |
| Exton | 16.2 | 19.8 | 2 | 81.6 | suitable |
| Cosima | 20.2 | 25.9 | 5 | 77.9 | unsuitable |
| Taiwan 1284-18 | 17.2 | 22.1 | 7 | 77.7 | suitable |
| Serrana (720087) | 18.4 | 23.9 | 8 | 76.8 | unsuitable |
| 800929 | 19.3 | 25.9 | 5 | 74.6 | unsuitable |
| Coliban | 16.3 | 21.9 | 11 | 74.3 | unknown |
| Kennebec | 16.7 | 22.7 | 18 | 73.4 | suitable |
| Taiwan 1282-15 | 17.4 | 23.8 | 6 | 73.1 | suitable |
| Tasman | 16.8 | 23.1 | 16 | 72.7 | unsuitable |
| LT2 | 16.9 | 23.4 | 6 | 72.2 | unsuitable |
| Desiree | 15.0 | 22.1 | 7 | 67.8 | suitable |
| Katahdin | 14.6 | 22.1 | 16 | 66.3 | unsuitable |
| 800934 | 16.9 | 25.9 | 5 | 65.3 | unsuitable |
| Alpha | 15.4 | 24.7 | 5 | 62.6 | unsuitable |

[a]Based on Sequoia mean yield in trials with this variety
Source: Pitt et al. (1987); Preston and Kowor (1987)

commercial sources in Australia. As a result, at the start of the 1990s, Sequoia remained the dominant ware potato in PNG.

Gunther (1987) also reviewed seven fertiliser trials in highlands soils. Six of the seven trials showed a response to applied phosphorus (P), leading the author to the conclusion that the level of P required for maximal yields was more than 175 kilograms per hectare (kg/ha). On the other hand, response to applied nitrogen (N) was generally small and 100 kg/ha of applied N was generally sufficient to optimise yields. The response to applied potassium (K) was not significant. It appears that K provided by the standard 12:12:17:2 (N:P:K:magnesium) fertiliser is more than adequate for potato. On the basis of these results, the application of a mixture of 12:12:17 (N:P:K) and triple superphosphate (TSP) fertilisers was recommended in the *Potato Pocket Book* (Sawanga 1987).

While most research was focused on variety evaluation and defining fertiliser requirements, potato production development activities focused on establishing a PNG-based seed multiplication scheme. It was soon recognised that the major constraint to production of healthy seed for the multiplication scheme was bacterial wilt, a soil-borne disease (Tomlinson and Gunther 1985; Hughes et al. 1989), which was also a significant threat to smallholder potato production. The disease was recognised as a major threat worldwide, and potato clones with tolerance to bacterial wilt became available around this time through breeding and selection work at the International Potato Center (CIP) in Peru.

# Potato Research in PNG: 1990–95

Based on work done before 1990, potato research priorities in PNG from 1990–95 were to:

- select varieties with improved tolerance to bacterial wilt;
- select processing varieties with improved yield to Kennebec;
- refine potato fertiliser recommendations;
- optimise production methods for processing potatoes; and
- optimise production practices for seed potatoes.

By 1991, both Tambul Research Station (DAL) and Taluma Research Station (Enga Division of Primary Industry), which had been used for seed potato multiplication activities since the mid-1980s, were infested with bacterial wilt. Research to study crop rotation practices to reduce levels of bacterial wilt was initiated, following promising overseas results.

## Screening of potato varieties for bacterial wilt tolerance

In 1990 and 1991, DAL imported a range of CIP potato clones from the Plant Research Institute (PRI), Burnley, Australia.[1] These lines were screened in a bacterial wilt-inoculated field at the Highlands Agricultural Experiment Station (HAES) at Aiyura. From 1992 onwards, the introduction of CIP lines through Australia ceased, but the Southeast Asian Program for Potato Research and Development (SAPPRAD) facilitated the introduction, from the Philippines, of microtubers or tissue culture plantlets of CIP lines and lines from the Philippines' breeding program. Most introductions to PNG from PRI were also screened at a clean site at Tsinsibai, Western Highlands Province in 1992 (Wiles 1993). Further promising introductions were evaluated in a multilocational trial in 1993 (Bang 1995a).

The results of bacterial wilt screening using inoculation (HAES trials AST 03–08) are summarised in Table 2. Trials AST 05–07 were carried out concurrently as varieties were divided into small groups for screening against Sequoia, the control variety. Trial AST 08 contained clones previously tested in earlier trials. There were problems in standardising wilt inoculation procedures, so that wilt tolerance was not effectively tested in trials AST 03 and AST 04. Some clones did show lower wilt incidence or lower incidence of tuber rots than Sequoia in some of the trials. However, some of the varieties with apparently lower wilt incidence tended to produce small tubers and would not have been commercially acceptable. Some clones were selected on the basis of either lower wilt incidence or promising agronomic characteristics (yield, tuber size, specific gravity) for further evaluation in yield trials at wilt-free sites.

The same set of potato varieties that were screened on a deliberately wilt-infested site at HAES were tested on a clean, high-altitude site at Tsinsibai, Western Highlands Province (Wiles 1993). At Tsinsibai, Sequoia gave the highest marketable yield, but 20 other clones gave yields that were not significantly lower than Sequoia. Further selection of clones in the Tsinsibai trial was on the basis of tuber size and suitability for processing. From the results of this trial and trials AST 04–08, 13 varieties were selected for a multilocational trial at four sites—

1. Australian potato research activities have since been transferred to the Institute for Horticultural Development, Toolangi, Victoria, Australia.

**Table 2.** Results of bacterial wilt tolerance screening trials AST 03–08.

| Trial | Date planted | Date harvested | Outcomes | Source |
|---|---|---|---|---|
| AST 03 | 4/5/91 | 2/8/91 | • Inoculated 83 DAP (late inoculation: trial could not be used for BW resistance)<br>• < 10% wilt before planting<br>• Four CIP lines (720088, 379673.156, 573079, 385130.11) had acceptable tuber size and uniformity<br>• Three CIP lines (379673.156, 573079, 385130.11) also had high specific gravity and should be assessed for processing quality | Gunther (1992a) |
| AST 3A | 25/11/91 | 13/2/92 | • Mechanical inoculation 29 DAP<br>• All clones were severely infected with BW (> 50% infection)<br>• Lines 379663.156, 379667.421, 573079 and 380510.4 showed less BW than Desiree at 35 DAI<br>• Clones 379667.421 and 573079 had the lowest incidence of tuber rot and relatively high yields of large tubers | Gunther (1992b) |
| AST 04 | 10/9/91 | 11/91 | • Infected site previously used for trial AST 03<br>• Severe infestation of target spot; this masked the effects of BW<br>• BW 45 DAP was low or nil<br>• Eight clones scored significantly higher for BW incidence than Sequoia, which was not infected<br>• Clone 384091.11 yielded significantly better than Sequoia and produced significantly more large tubers<br>• Six other clones yielded more large tubers than Sequoia (on a kilogram/plant basis) | Gunther (1992c) |
| AST 05 | 20/8/92 | 14/11/92 | • Inoculated by pouring a BW suspension over the plants (no physical wounding)<br>• Differences in BW infection were not significant<br>• Four clones (385080.9, 379697.153, 385130.5 and 381064.3) had significantly less tuber rotting: of these, only 381064.3 had acceptable tuber size | Bang and Wiles (1993) |

*Continued on next page*

**Table 2** (cont'd). Results of bacterial wilt tolerance screening trials AST 03–08.

| Trial | Date planted | Date harvested | Outcomes | Source |
|---|---|---|---|---|
| AST 06 | 20/8/92 | 14/11/92 | Trial carried out alongside AST 05<br>No variety had significantly fewer wilted plants than Sequoia<br>Four clones (BP 86152.7, 384008.5, 379673.151 and 384011.3) had less tuber soft rot; all of these had smaller tubers than Sequoia, with less than 40% reaching marketable size | Bang and Wiles (1993) |
| AST 07 | 20/8/92 | 14/11/92 | Trial carried out alongside AST 05<br>No significant difference in the percentage of wilted plants or incidence of soft rot<br>Of the CIP clones, only 378597.1, 384101.2, 379693.110 and 720087 had > 50% of tubers marketable | Bang and Wiles (1993) |
| AST 08 | 18/3/93 | 9/7/93 | Physical inoculation 30 DAP with a needle dipped in BW suspension<br>Clone 385313.4 had significantly less BW incidence than Sequoia at 35 DAI, and clone 379697.153 had fewer wilting plants at 14 DAI<br>Clone 385313.4 had unacceptably small tubers, but clone 379697.453 had reasonably sized tubers and fewer rotten tubers than Sequoia | Bang and Wiles (1993) |

BW = bacterial wilt; DAI = days after inoculation; DAP = days after planting

Tsinsibai, Mt Hagen (Highlands Agricultural Training Institute (HATI)), HAES (Aiyura) and Taluma Research Station (Enga Division of Primary Industry). The commercial varieties Sequoia, Kennebec and Atlantic were included for comparison.

The results of the multilocational trial have been reported by Bang (1995a). Yields at Taluma Research Station, Tsinsibai and HATI were low to very low. At HATI, low yields were partly caused by bacterial wilt infestation. There were no significant yield differences between clones at any of these sites. At HAES, yields were much better and significant yield differences were found, so more weight was given to HAES data in selecting clones for further trials. Clones were also assessed on the basis of tuber size and suitability for production of French fries or crisps. Some clones (Table 3) showed promise either as alternative ware varieties to Sequoia (379697.153) or alternative processing varieties to Kennebec (Atlantic, 384071.3, 573079). The variety 385313.4, which had shown promise in trials AST 07 and AST 08, as a wilt-tolerant variety, was again found to produce small tubers and was, therefore, considered unlikely to meet market requirements.

In 1994, five further CIP clones (BW-2, BW-3, BW-4, BR-69-84 and BR-63-5), introduced because of their reported bacterial wilt tolerance, were compared in a yield trial with Sequoia as a control (Bang 1995b). These were the first set of clones introduced from the Philippines, imported as microtubers in 1991. The seed used in this trial had been field-multiplied for three generations. All the introduced clones yielded significantly less than Sequoia. Incidence of bacterial wilt in this trial was not recorded, so wilt tolerance of the clones was not compared with Sequoia. Only clones BW-2 and BW-3 had acceptable tuber size. However, they both had pink skin and deep eyes and are therefore unlikely to replace Sequoia. It is desirable to further assess their susceptibility to bacterial wilt using high inoculum pressure.

## Improvement of potato production for processing

Another major focus of work has been to improve the production of processing potatoes. Based on preliminary work by Pitt (1988), the variety Kennebec was selected as the most suitable for processing (French fry) production in PNG. Kennebec's significantly lower yields than Sequoia, combined with prices paid to growers by the processing company, explained why farmers in the highlands were reluctant to produce processing potatoes (Wiles 1991). DAL, with support from the major processing company in Port Moresby, therefore decided to use a dual approach. Potato varieties were imported and tested against Kennebec, and trials were also conducted to determine why yields of Kennebec were low, and whether changes in agronomic practices could raise these to an acceptable level.

### *Variety trials*

The results of trials conducted in 1991–92 and 1992–93 are summarised in Table 4. The first trial seemed to confirm previous reports that Kennebec tends to yield less than Sequoia. However, no variety was found that gave yields similar to Sequoia and met processing quality standards. The three trials conducted in 1992 used the same seed source and were planted and harvested at approximately the same time. In these trials, Kennebec production was almost as high as that of Sequoia (83–99%). However, Kennebec seed was larger, so the multiplication rate must have been lower. Winlock and Sebago produced smaller tubers than Sequoia in all trials. Spunta yielded as well as Sequoia,

**Table 3.** Potato varieties selected from the Highlands Agricultural Experiment Station (Aiyura) trial as promising varieties on the basis of yield and/or processing quality.

| Variety | Total yield (t/ha) | Large tubers (t/ha) | Average tuber weight (g) | Processing suitability | |
|---|---|---|---|---|---|
| | | | | French fries | Crisps |
| 379697.153 | 36.9 | 11.6 | 78.3 | unsuitable | unsuitable |
| Sequoia | 34.6 | 11.7 | 104.5 | unsuitable | unsuitable |
| 384071.3 | 33.6 | 11.1 | 76.9 | suitable | suitable |
| Atlantic | 27.4 | 8.2 | 107.6 | suitable | suitable |
| 573079 | 25.3 | 8.4 | 87.2 | unsuitable | suitable |

**Table 4.** Results of trials to assess commercially available processing potato varieties.

| Site | Date planted | Date harvested | Outcomes |
|---|---|---|---|
| Tambul Research Station | Late 1991 | 22/11/92 | • Five commercial varieties (imported from Australia) were compared with Sequoia<br>• Sequoia gave the highest marketable yield (22.0 t/ha) followed by Spunta (16.2 t/ha), Atlantic (16.1 t/ha) and Kennebec (15.3 t/ha)<br>• Kennebec and Atlantic gave the best processing quality<br>• Red Craig Royal and Winlock both tended to produce more, but smaller tubers than Sequoia |
| Tambul Research Station | 9/92 | 29/12/92 | • Five commercial varieties were compared with Sequoia<br>• Marketable yields were (t/ha): Sequoia—26.7; Spunta—25.1; Kennebec—22.2; Winlock—19.3; Sebago—19.3; Atlantic—19.0 |
| Highlands Agricultural Experiment Station (Aiyura) | 9/9/92 | 7/1/93 | • Four commercial varieties were compared with Sequoia<br>• Marketable yields were (t/ha): Sebago—27.9; Winlock—27.2; Sequoia—26.9; Kennebec—26.3; Spunta—25.4 |
| Taluma Research Station | 9/92 | 4/1/93 | • Same seed source and planting date as previous two trials<br>• Marketable yields were (t/ha): Spunta—27.7; Winlock—24.9; Sequoia—24.7; Kennebec—24.4; Sebago—22.9 (no significant differences) |

but its seed size was larger. In the previous trial, Spunta's processing quality was lower than Kennebec and Atlantic and it appeared susceptible to target spot. These trials again showed that, under some conditions, Kennebec can give yields comparable with Sequoia. Spunta also showed some potential as a processing variety, but its yellow flesh and tendency to produce very large, irregular shaped tubers may be a problem.

*Spacing, fertiliser and seed cutting trials*

Trials compared different spacing and fertiliser rates, to see if low yields of Kennebec could be improved by improving agronomic practices. In the first trial, conducted at two sites (Tambul Research Station and HAES), Kennebec was planted at three different spacings and with the recommended, and double the recommended, fertiliser rates. Marketable yields are shown in Table 5. Significant responses to both fertiliser rate and spacing were seen at both sites. At HAES, there was also a significant interaction between fertiliser rate and spacing. In general, yields were higher at both closer spacings and higher fertiliser rates. However, reducing the within-row spacing from 40 centimetres (cm) to 30 cm reduced marketable yields at the lower fertiliser rate at both sites, but had increased marketable yields at the higher fertiliser rate. Average yield increases due to increased fertiliser ranged from 20% at Tambul Research Station to 41% at HAES. This strongly suggests that the recommended rate (1000 kg/ha of a 3:1 mix of 12:12:17 N:P:K and TSP fertilisers) is inadequate for maximum yields. Larger tubers were produced with the higher fertiliser rates and wider spacings at both HAES and Tambul Research Station.

The response of Kennebec potatoes to fertiliser was further studied in a trial carried out at three sites (Tables 6, 7 and 8). The Taluma Research Station site did not have such acidic soil as Tambul Research Station and HAES. Calcium levels at Tambul Research Station were much lower than those at other sites. At HAES, magnesium (Mg) levels were high, as were Mg:K ratios. Both Tambul and Taluma research stations (but not HAES) had high P retention levels. At Tambul Research Station, where the soil is peaty, organic carbon (C) levels and C:N ratios were high.

The main result of this trial was that fertiliser responses differ between sites. At HAES, where P levels were higher and P retention lower, the response to P was not as strong as at the other two sites. At Tambul Research Station, rather surprisingly, there was no response to applied N. At HAES, the intermediate N level was optimal, but at Taluma Research Station there was a response up to the highest level of N. There was no significant response to K at any site, but at Tambul Research Station there was a significant P:K interaction such that a P response was observed only in the presence of applied K. This trial demonstrated the benefits of modifying fertiliser rates according to the soil conditions at different sites.

**Table 5.** Effect of spacing and fertiliser rate on Kennebec potato yields (tonnes/ha).

| Site and plot spacing | Fertiliser rate (kg/ha) | | |
|---|---|---|---|
| | 1000 | 2000 | Mean |
| HAES | | | |
| 80 cm × 30 cm | 20.4 | 35.0 | 27.7 |
| 80 cm × 40 cm | 21.9 | 28.0 | 25.0 |
| 80 cm × 60 cm | 21.1 | 26.7 | 23.9 |
| Mean | 21.2 | 29.9 | |
| LSD (5%) | Fertiliser (2.42); spacing (2.96); interaction (4.19) | | |
| Tambul Research Station | | | |
| 80 cm × 30 cm | 31.6 | 41.3 | 36.4 |
| 80 cm × 40 cm | 34.5 | 36.6 | 35.6 |
| 80 cm × 60 cm | 24.1 | 30.5 | 27.6 |
| Mean | 30.2 | 36.1 | |
| LSD (5%) | Fertiliser (5.18); spacing (6.35); interaction (9.09) | | |

HAES = Highlands Agricultural Experiment Station (Aiyura); LSD = least significant difference

**Table 6.** Application rates of fertiliser in a Kennebec potato response trial.

| Nitrogen (as urea) (kg/ha) | Phosphate (as TSP fertiliser) (kg/ha) | Potassium (as KCl) (kg/ha) |
|---|---|---|
| N0 = 0 | P0 = 0 | K0 = 0 |
| N1 = 75 | P1 = 100 | K1 = 75 |
| N2 = 150 | P2 = 200 | K2 = 150 |

TSP = triple superphosphate

**Table 7.** Marketable yield of Kennebec potatoes in response to applied fertiliser at three sites.

| | Tambul Research Station | HAES | Taluma Research Station |
|---|---|---|---|
| Nitrogen (N) | No significant response | Significant response (both linear and curvature) | Significant response |
| Phosphate (P) | Significant linear response | Significant linear response | Significant response |
| Potassium (K) | No significant response | No significant response | No significant response |
| Interactions | P response much stronger when K was applied | No significant interactions | N response much greater when P was applied and vice versa |

HAES = Highlands Agricultural Research Station (Aiyura)

**Table 8.** Soil analysis data for potato trials at three sites.

| | Tambul Research Station | Taluma Research Station | HAES |
|---|---|---|---|
| pH | 4.7 | 5.7 | 4.8 |
| Extractable bases (me%) | | | |
| Calcium | 1.5 | 9.7 | 8.5 |
| Magnesium | 0.71 | 1.45 | 3.52 |
| Potassium | 0.50 | 1.04 | 0.32 |
| Sodium | 0.07 | 0.03 | 0.08 |
| Cation exchange capacity | 36.6 | 36.4 | 27.7 |
| Base saturation (%) | 6.7 | 33.0 | 44.7 |
| Phosphorus (Olsen) (mg/kg) | 3.8 | 7.2 | 8.7 |
| Phosphorus retention (%) | 95.3 | 94.7 | 67.7 |
| Organic carbon (C) (%) | 16.20 | 9.74 | 6.76 |
| Total nitrogen (N) (%) | 1.08 | 0.91 | 0.55 |
| C:N ratio | 15.0 | 11.0 | 12.3 |

HAES = Highlands Agricultural Experiment Station (Aiyura); me = millequivalent; mg/kg = milligrams per kilogram

The 1992 trials were followed by a further trial on the farm of a major Kennebec producer at Tomba, Western Highlands Province in 1993. In this trial, a commercially available potato mix fertiliser (10:27:12 N:P:K) was applied with or without additional TSP fertiliser. Treatments are summarised in Table 9 and marketable yield and average tuber weight shown in Table 10. Increasing the application rate of potato mix fertiliser from 800 kg/ha to 2000 kg/ha only resulted in a 28% yield increase. However, adding 235 kg/ha TSP fertiliser at the lowest rate of potato mix fertiliser resulted in a 60% yield increase. There was no further yield increase when mixtures containing higher rates of potato mix:TSP fertilisers were used. When TSP fertiliser was added, the tuber size also increased (Table 10). The results of this trial suggest that, at least at this site, the potato mix fertiliser used in the trial did not contain adequate P. There was also some concern that P in potato mix fertiliser may not be as readily available to potatoes as P from TSP fertiliser.

The final trial in this series was planted at Tomba in 1994. Based on information from the Philippines (Aromin 1994), and observed boron (B) deficiencies in other crops in the Western Highlands, B application was included as a treatment in this trial. All plots received a basal dressing of 750 kg/ha of fertiliser (12:12:17 N:P:K). Additional P was supplied as TSP fertiliser and B was applied by spray application of Solubor fertiliser. Trial details are given in Bang (1996). Trial yields are shown in Table 11. While yields were lower than in previous trials, there was a highly significant response to applied P and a significant response to application of B. The trial site had very low P status (2.5 milligrams (mg)/kg by Olsen's method) and high P retention (96%). By increasing P, both number and size of tubers increased, while application of B increased the number of tubers harvested but did not affect tuber size.

This was the first and, as yet, only trial to investigate responses of potatoes to B in PNG. However, based on this trial, the fertiliser manufacturer has since included 2% boron in the standard potato mix fertiliser sold in the PNG highlands.

After earlier work on spacing, a trial was conducted on seed cutting. Seed cutting was recommended as standard practice for Kennebec production by Pitt (1988) and can substantially reduce the cost of planting material. The trial was planted at Tomba in November 1993 and harvested on 10 February 1994. While yields from this trial were very poor, it served to confirm that:

- crops from cut seed yielded almost the same (91%) as crops using whole seed, while using only half the weight of planting material;
- as spacing was reduced from 90 cm × 60 cm to 90 cm × 30 cm, total yields only increased by 52%; even with cut seed, there was little or no benefit from planting at within-row spacing of less than 40 cm;

**Table 9.** Commercially available potato mix (PM) fertiliser treatments with and without additional triple superphosphate (TSP) fertiliser (kg/ha).

| PM[a] | TSP | N | P | K |
|---|---|---|---|---|
| 800 | 0 | 80 | 96 | 80 |
| 800 | 235 | 80 | 144 | 80 |
| 1200 | 0 | 120 | 144 | 119 |
| 1200 | 352 | 120 | 216 | 119 |
| 1600 | 0 | 160 | 192 | 159 |
| 1600 | 470 | 160 | 288 | 159 |
| 2000 | 0 | 200 | 240 | 199 |
| 2000 | 587 | 200 | 360 | 199 |

[a]Commercially available (10:27:12 N:P:K)

**Table 10.** Response of Kennebec to potato mix (PM) fertiliser and triple superphosphate (TSP) fertiliser treatments (detailed in Table 9).

| PM (kg/ha)[a] | Marketable yield (t/ha) | | Average tuber weight (g) | |
|---|---|---|---|---|
| | Without TSP | With TSP | Without TSP | With TSP |
| 800 | 11.4 | 18.2 | 41.7 | 58.9 |
| 1200 | 12.3 | 17.5 | 46.1 | 60.7 |
| 1600 | 13.9 | 17.4 | 50.8 | 51.5 |
| 2000 | 14.6 | 18.5 | 46.7 | 61.2 |
| Mean | 13.1 | 17.9*** | 46.3 | 58.0 |

***$P$   0.001
[a]Differences in PM application rate gave no significant difference ($P > 0.05$); there was no significant interaction between TSP and PM ($P > 0.05$).

**Table 11.** Effect of phosphate and boron applications on the yield of Kennebec potatoes.

| Phosphate applied (kg P/ha) | Yield (t/ha) | | |
|---|---|---|---|
| | Without boron | With boron | Mean |
| 40 | 6.23 | 6.23 | 6.23 |
| 80 | 7.63 | 8.50 | 8.07 |
| 120 | 7.21 | 9.09 | 8.15 |
| 160 | 7.87 | 8.70 | 8.29 |
| 200 | 9.29 | 10.50 | 9.89 |
| Mean[a] | 7.65 | 8.60 | |

[a]LSD (least significant difference) (5%) response to phosphorus = 1.33 ($P$   0.001); LSD (5%) response to boron = 0.88 ($P$   0.05); LSD (5%) phosphorus:boron interaction = 1.88 (not significant, $P > 0.05$)

- average tuber weight was greater at the wider spacings, but was not affected by seed cutting; and
- based on this trial and earlier work on spacing, the most economical practice is to plant cut seed at a spacing of 80–90 cm between rows and 40 cm within rows.

## Optimising seed potato production

Much of the emphasis of DAL activities with potato has been on seed potato production. Until 1986, most seed potato production in PNG consisted of the multiplication of imported Australian seed potatoes on government stations. By 1989, plans were in place to implement a scheme based on rapid multiplication by stem cuttings in screenhouses, using imported minitubers to produce the cuttings (Hughes et al. 1989). These cuttings were then field planted to produce tuberlets, again on government farms. By 1992 it was evident that the government land was contaminated with bacterial wilt and, as a result, some of the tuberlets produced carried wilt disease. It was then planned to produce minitubers at Tambul Research Station using plantlets raised in tissue culture at the Coffee Research Institute (CRI), Aiyura.

Research activities were begun in support of the seed potato scheme. The main research activities were:

- investigating the effect of seed size and spacing on conventional seed multiplication;
- defining optimum practices for minituber production under PNG conditions; and
- defining spacing and agronomic practices for production of G1 seed from minitubers.

In addition, a long-term trial was started in December 1991 to investigate the effect of different crop rotations on survival of bacterial wilt in the field.

*Effect of plant spacing and seed size on Sequoia seed production*

The first trial investigated planting practices for conventional seed multiplication with the cultivar Sequoia. The trial compared planting of different seed sizes at different spacings, planted in January 1992 and harvested on 7 April 1992. Unfortunately, planting coincided with a dry spell and emergence was somewhat patchy. Later cold, wet conditions prevailed, and the trial was badly affected by the fungus *Rhizoctonia*, resulting in a high proportion of small and rotten tubers at harvest. Trial yields are summarised in Table 12. Yields of damaged and rotten tubers (on average about 20% of all tubers) have been omitted from the yield results. Yields of seed-size tubers were highest using medium-sized seed, planted at close spacing. There was no evidence from this trial that varying the plant spacing affected the proportion of tubers harvested in different size grades (see Table 13). However, planting small seed resulted in a higher proportion of undersized seed at harvest. The proportion of undersized tubers harvested in this trial was unacceptably high.

**Table 12.** Sequoia seed spacing trial yields (tonnes/hectare).

| | Undersize (< 28 g) seed yield (t/ha) | Correct size (28–200 g) seed yield (t/ha) | Oversize (> 200 g) seed yield (t/ha) | Total seed yield (t/ha) |
|---|---|---|---|---|
| Seed planted | | | | |
| Small | 3.72 | 4.83 | 0.45 | 9.00 |
| Medium | 4.02 | 8.92 | 1.13 | 14.07 |
| Large | 3.74 | 6.48 | 0.95 | 11.17 |
| | ns | * | ns | * |
| Spacing (cm) | | | | |
| 80 × 15 | 4.61 | 8.68 | 1.32 | 14.61 |
| 80 × 20 | 4.08 | 6.65 | 0.63 | 11.36 |
| 80 × 25 | 3.78 | 6.94 | 0.91 | 11.63 |
| 80 × 30 | 2.83 | 4.72 | 0.51 | 8.06 |
| | * | ns | ns | * |

*$P$ 0.05
ns = not significant

**Table 13.** Effect of seed size and spacing on percentage of tubers in different size grades.

| | Undersize (< 28 g) seed | Correct size (28–200 g) seed | Oversize (> 200 g) seed |
|---|---|---|---|
| Seed planted | | | |
| Small | 41.3 | 53.7 | 5.0 |
| Medium | 28.6 | 63.4 | 8.0 |
| Large | 33.5 | 58.0 | 8.5 |
| | * | * | ns |
| Spacing (cm) | | | |
| 80 × 15 | 31.6 | 59.4 | 9.0 |
| 80 × 20 | 35.9 | 58.5 | 5.5 |
| 80 × 25 | 32.5 | 59.7 | 7.8 |
| 80 × 30 | 35.1 | 58.6 | 6.3 |
| | ns | ns | ns |

*$P$ 0.05
ns = not significant

*Changing seed production practices*

Because of bacterial wilt problems experienced on government seed farms a thorough review of the seed production strategy was developed by Hughes et al. (1989). The main changes adopted were:

- production of tissue culture plantlets using tissue culture facilities at CRI;
- production of minitubers from plantlets in screenhouses at Tambul Research Station;
- field planting of minitubers to produce G1 seed;
- reduction of seed multiplication to three generations only; and
- multiplication of G1 and G2 seed was the responsibility of private seed growers.

It is not my intention to review the PNG seed scheme in this paper. However, it is important to note that, partly by trial and error and partly by formal work, methods for producing minitubers from plantlets and G1 seed from minitubers were optimised. Based on this work, the standard parameters for the revised seed scheme were found to be that:

- each plantlet or cutting produces on average three minitubers;
- average weight of minitubers is 10 grams each; and
- each minituber yields 300 grams of G1 seed.

The optimum spacing of plantlets or cuttings in boxes for minituber production was determined, and a suitable soil mix for use in the boxes was formulated. A trial was then conducted to determine the optimum spacing for field planting of minitubers for G1 seed production.

## Control of bacterial wilt by crop rotation

A trial to look at ways to reduce bacterial wilt infestation in soils by crop rotation was established at Tambul Research Station in December 1991. This trial has been previously reported (Bang and Wiles 1996), and only the main conclusions are presented here. The trial was planted over five seasons using the cropping sequences shown in Table 14.

The first potato crop was used to ensure a uniform infestation of bacterial wilt over the trial site. After five cropping seasons (30 months), the main conclusions of this trial were as follows.

- Two or three (but not one) break crops of maize were effective in reducing wilt; alternating potato with maize over five crops (potato–maize–potato–maize–potato) was just as effective.
- Bare fallow for 12 to 18 months (2–3 crops) was effective in reducing wilt, as was alternate potato and bare fallow (potato–bare fallow–potato– bare fallow–potato).
- Weed fallow breaks did not reduce the incidence of wilt and appeared to reduce the yield of succeeding potato crops.

**Table 14.** Design of trial to reduce bacterial wilt infestation by crop rotation.

| Crop 1 | Crop 2 | Crop 3 | Crop 4 | Crop 5 |
|---|---|---|---|---|
| Potato | Potato | Potato | Potato | Potato |
| Potato | Bare fallow | Potato | Bare fallow | Potato |
| Potato | Bare fallow | Bare fallow | Potato | no treatment |
| Potato | Bare fallow | Bare fallow | Bare fallow | Potato |
| Potato | Maize | Potato | Maize | Potato |
| Potato | Maize | Maize | Potato | no treatment |
| Potato | Maize | Maize | Maize | Potato |
| Potato | Sweet potato[a] | | Potato | no treatment |
| Potato | Sweet potato[b] | | Sweet potato[b] | Potato |
| Potato | Weed fallow | Potato | Weed fallow | Potato |
| Potato | Weed fallow | Weed fallow | Potato | no treatment |
| Potato | Weed fallow | Weed fallow | Weed fallow | Potato |
| Potato | Maize | Sweet potato[a] | | Potato |
| Potato | Sweet potato[a] | | Maize | Potato |

[a]One 12-month crop
[b]Two 9-month crops

- Sweet potato breaks alone were ineffective in controlling wilt; a break of sweet potato followed by maize or vice versa did not reduce wilt incidence to an acceptable level.

The benefits of maize in suppressing bacterial wilt infestation have been previously reported (Elphinstone and Aley 1992). However, the failure of weed fallow to reduce carryover of wilt suggests that a weed host of bacterial wilt may be present at Tambul Research Station. The low potato yields following weed fallow may be caused by a reduction in available soil nitrogen. The practice of leaving land fallow to weeds after each potato crop (previously the standard practice at Tambul Research Station) cannot be recommended on the basis of this trial.

## Discussion

The first section of this paper reports attempts to screen introduced potato varieties against Sequoia for improved yield and bacterial wilt tolerance. From 1990–92 DAL introduced 72 potato varieties and clones for screening.[2] Forty-four of these were introduced as seed tubers from Australia, but later introductions were made with SAPPRAD support from the Philippines, either as microtubers or tissue culture plantlets. These were screened both in yield trials and for bacterial wilt tolerance in an infested site at HAES. However, despite a significant research effort, Sequoia has remained the dominant ware potato in PNG. The reasons for this need to be emphasised, as follows.

Several of the introduced clones showed evidence of improved tolerance to bacterial wilt compared with Sequoia, but none of the clones combined this with comparable yield and tuber quality. In order to be successful as a ware variety in PNG, it is assumed that a potato variety should have:

- good yield potential in a wide range of conditions;
- large tubers with smooth skin and shallow eyes; and
- tolerance to bacterial wilt.

It has generally been assumed that white-fleshed potato varieties are preferred in PNG (as in Australia), but this may not be the case, as shown by the acceptance of Granola, a yellow-fleshed variety supplied by the Australian Agency for International Development (AusAID) as part of the relief package for the 1997 drought. For a potato variety to become fully established, it will have to be incorporated into the PNG seed scheme, which will be easier if the variety is also commercially available in neighbouring countries (a readily available supply of plantlets or minitubers is needed as backup for seed production in PNG).

2. Further introductions were made in 1993 and 1994, but none of these were trialled until 1996 and many were lost due to problems experienced with the tissue culture facility at CRI and were never included in field trials.

Other potato varieties introduced as commercial seed from Australia[3] were compared in trials with Kennebec for their potential as processing varieties. However, none was found to be consistently superior to Kennebec. Despite the poor yield of Kennebec relative to Sequoia, no other variety has proved superior for producing French fries. Nor did any of the 72 introductions, referred to above, satisfactorily meet the following requirements of the processing industry:

- large regular tubers with smooth skins and shallow eyes;
- good frying quality;
- high specific gravity; and
- superior yield to Kennebec.

Trials were also conducted to look at ways to increase Kennebec potato yields. In many ways this approach was the more promising, as it provided valuable information on spacing, seed cutting and fertiliser requirements. The fertiliser trials conducted with Kennebec also have implications for ware potato production with Sequoia. These trials provided the following practical outcomes for potato growers:

- for Kennebec, a within-row spacing of 40 cm was the most economical—closer spacings resulted in little or no yield increase unless very high fertiliser rates were used;
- cutting of Kennebec seed was justified as it substantially reduced seed cost with little or no reduction in yield (the old recommendation not to cut locally produced Sequoia seed because of risk of bacterial wilt infection may need to be reconsidered);
- fertiliser rates previously recommended were found to be too low for optimum yields and, at least in soils with high P retention, a higher proportion of P in potato fertiliser mixes was found to be justified; and
- application of B (as Solubor) was found to improve potato yields.

From these trials, fertiliser recommendations given in the *Potato Pocket Book* (Sawanga 1987) were revised in production recommendations of the Fresh Produce Development Company (Sparkes, no date). In addition, fertiliser manufacturers have begun to include B in the standard potato mix fertiliser.

3. These included Spunta, Winlock, Atlantic, Red Craig Royal, Sebago, Taiwan 15, Taiwan 18, Trent, Tarago, Wilcrisp and a number of different lines of Kennebec.

During the first half of the 1990s, major changes took place in the PNG seed production scheme. While most of these changes owed more to technology transfer than research, limited adaptive trials were necessary to modify and test overseas practices in PNG conditions. The changes in the seed potato scheme that were implemented are summarised in Figure 1.

The production practices for minituber production (in screenhouses at Tambul Research Station) and G1 seed potato production (field production from minitubers in a wilt-free site) were tested and benchmarks were established for each stage of production. This new seed scheme shows promise for overcoming the seed shortages experienced in the mid-1990s. These shortages resulted from the bacterial wilt infestation of government seed farms and, furthermore, when PNG was hit by a severe drought in 1997 seed-multiplication activities were severely set back.

The bacterial wilt problem mentioned above was investigated in a crop rotation study. This study provided useful information on the ability of maize to suppress bacterial wilt in soils under PNG highland conditions, and the recommendations of this work need to be implemented on government stations and by farmers engaged in intensive potato production.

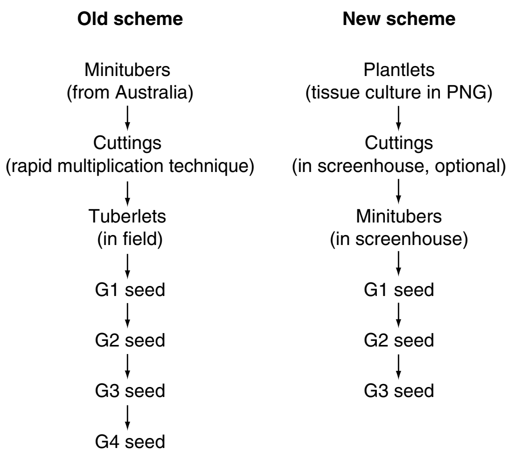


**Figure 1.** Changes implemented in the PNG seed potato scheme during the early 1990s.

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# Review of Germplasm Collections and Agronomic Research on Bananas in PNG

**R.N. Kambuou***

*Abstract*

Although Malaysia is said to be the centre of origin of bananas, nine species of *Musa* are found in PNG, which makes it a major secondary centre of genetic diversity of the primitive diploid cultigens and a major centre for wild banana distribution. The genetic diversity of bananas in PNG arises mainly from botanically primitive diploid cultigens amongst a large number of cultivars, which are grown specifically as staple food crops in many parts of the country.

Collecting expeditions by international organisations have led to the establishment of ex situ field collections. Banana has been rated as the second most important staple food crop of PNG after sweet potato but there has been less agronomic research on banana than on sweet potato or taro. Before independence in 1975, some research was done on the potential for commercial sweet banana production in Oro (Northern) Province. After independence, research by the Department of Agriculture and Livestock focused on cooking bananas and on establishing ex situ field banana collections.

PNG is an important centre of genetic diversity of wild and cultivated bananas, with nine species of the genus *Musa*. The great diversity in the cultivated 'diploid' (AA) bananas has made PNG the only country in the world where diploid bananas are of significance for agricultural food production (Stover and Simmonds 1987).

Cooking bananas are often distinguished from sweet or dessert bananas, though this is a somewhat artificial distinction. In PNG, more cooking bananas are produced and consumed than are dessert bananas. Cooking bananas are an important food crop that form the major staple food for the dry areas of the central Papuan coast, the areas around Rabaul, the Cape Vogel area, the Amele area of Madang Province and the Markham and Ramu valleys of Morobe Province.

There are no recent and reliable national-level data on banana production in PNG, because almost all banana production is based on starchy, cooking types grown under subsistence production systems. The 1961–62 PNG Survey of Indigenous Agriculture estimated that approximately 620,000 tonnes of banana are produced nationally per year (Eele 1983). The Food and Agriculture Organization (FAO) estimated the world production of bananas in 1991 to be 48 million tonnes, with 147,000 tonnes produced in the Oceania region and 120,000 tonnes in PNG (Hallan 1995). Despite differences in production estimates, banana is thought to be third to sweet potato and taro in production and second in consumption, yet there has been very little agronomic research on cooking bananas in PNG (King 1986).

Recently, the importance of banana as a food crop for the indigenous population led to its being placed on the farming systems research agenda. Agronomic research on bananas has been conducted by research officers of the Department of Agriculture and Livestock (DAL) following the establishment of ex situ germplasm collections. Most agronomic studies on cooking bananas were carried out at the Laloki Research Station.

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This paper will discuss the various banana collecting expeditions undertaken in PNG by the international organisations that contributed to the establishment of the various ex situ field collections and the agronomic research on cooking bananas conducted by DAL research officers at various research stations in the country.

## Genetic Material

Simmonds (1956) and Argent (1976) pointed out that PNG is an important centre of wild banana distribution although Malaysia is the recognised origin of bananas. Cultivated bananas belong to the *Eumusa* section of the family Musaceae. They are natural hybrid polyploids, comprising diploids, triploids and tetraploids of the two species of *Musa*: *M. acuminata* (genotype A) and *M. balbisiana* (genotype B). The other edible bananas are the Fe'i types which belong to the *Australimusa* section. This group of bananas originated from PNG, but are not as important as the edible *Eumusa* types (Bourke 1976). Apart from the cultivated edible varieties, there are many wild bananas in PNG that produce nonedible fruits with massive seeds. These wild species include: *M. maclayi*, *M. balbisiana*, *M. acuminata* (with subspecies *banksii*), *M. schizocarpa, M. peekelii* (with subspecies *angustigemma*), *M. boman*, *M. lolodensis* and *M. ingens* (Sharrock 1989).

The interest in the distribution of wild bananas and the genetic diversity of cultivated diploid bananas prompted the Papua New Guinea Biological Foundation (PNGBF) to collect and assemble as many wild and cultivated banana strains in PNG as possible. The objective was to establish a gene pool collection that could be used as a source of material for PNG and international programs on the cultivation of banana as a food crop. The PNGBF banana collection was established at the University of Technology (Unitech), Lae in 1970.

The international banana improvement programs were specifically aiming at high-yielding, good-quality, disease-resistant genetic materials of dessert varieties for commercial production. In the 1970s and 1980s, a number of collecting expeditions were undertaken throughout the country with the objective of collecting plants that were tolerant or resistant to sigatoka disease and could contribute useful genes to international breeding programs.

The agronomic investigations by DAL on cooking bananas were carried out in the 1980s, using the farming systems research approach. The studies showed that bananas are a very important component of the farming systems of the Amele people in Madang Province and in the Vanapa River and Kabadi areas of Central Province. This would also be true for other banana-growing areas. The studies further revealed that diploids are more important in wetter areas, whereas the triploids are more significant in drier seasonal environments (King et al. 1989).

### Collection of material

Dr N.W. Simmonds from the Regional Research Centre, Imperial College of Tropical Agriculture, Trinidad, undertook the first internationally organised banana research expedition to Southeast Asia and the Pacific in 1954. In the early breeding program at the Imperial College of Tropical Agriculture, crosses were made between Gros Michel and the wild strains of *Musa acuminata*, using an edible diploid banana as a male parent. This showed that both wild and edible strains of diploid would probably be needed to achieve success. Dr Simmonds' collecting expedition in PNG aimed to identify, access and collect both the wild and edible diploid strains of *M. acuminata* that would be useful in the breeding program. The most important discovery for PNG was the existence of a cultivation of primitive diploid bananas. A selection of about 20 different diploids were collected and imported to the Imperial College of Tropical Agriculture for intensive study (Simmonds 1956).

In 1970, Dr George Argent was recruited by the PNGBF to assemble as many wild and cultivated PNG strains of bananas as possible as a source of genetic material. Dr Argent made collecting trips to many parts of the country and gathered some 800 accessions of bananas at Unitech (King and Bull 1984). The collection included farmer cultivars as well as six wild types of bananas.

In the 1986–87, a Japanese mission headed by Professor Muneo Iizuka made two trips to collect bananas, sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta*), yams (*Dioscorea* spp.) and Chinese taro (*Xanthosoma sagittifolium*). The first expedition visited East and West New Britain, Bougainville, Morobe and Western Highlands provinces. The second one visited Oro, Milne Bay, Enga and Southern Highlands provinces. The mission obtained 52 accessions of bananas, of which 95% are cooking types, mostly diploids and triploids. The germplasm was later added to the PNGBF collection.

In 1986, an international workshop on banana and plantain breeding strategies was organised by the Australian Centre for International Agriculture Research

(ACIAR) and the International Network for the Improvement of Banana and Plantain (INIBAP). During this workshop, it was recommended that PNG's unique germplasm of diploid bananas should be collected for preservation and use in breeding programs. The International Board of Plant Genetic Resources, now known as the International Plant Genetic Resources Institute (IPGRI), and Australia's Queensland Department of Primary Industries (QDPI), with assistance from INIBAP and in collaboration with DAL, undertook this work. Between 1988 and 1989, four collections were made from mainland PNG provinces and the islands of New Britain, New Ireland and Manus. A total of 264 accessions were collected, comprising mostly cultivated diploids and triploids.

In addition, collecting trips sponsored by the World Bank Drought and Frost Project in 1999 aimed to collect any food crop species in the fields in PNG that survived the El Niño drought. A total of 26 accessions of bananas were collected from the Highlands Region and 11 from the Cape Rodney area of Central Province.

### Establishment of germplasm collections

The PNGBF collection was initially maintained at the Unitech Agriculture Farm in Lae. A total of 234 accessions were later transferred to Laloki Research Station to form the National Banana Germplasm (NBG) Collection. To ensure safekeeping of this valuable germplasm, a duplicate collection of 178 accessions was taken to the Philippines to be maintained in the Southeast Asian Regional Banana Collection in Davao. The current status of the regional collection in Davao is not known.

All the material collected by the Japanese and the IPGRI/QDPI missions was deposited in the National Banana Germplasm Collection at Laloki Research Station. Duplicate material of 52 accessions from the Japanese collection were taken to Chiba University, Japan. The current state of this collection is also not known.

The IPGRI/QDPI material of 264 accessions was taken to Maroochy Research Station, Nambour, Queensland, Australia, for virus indexing; it was later transferred to the INIBAP International Transit Centre (ITC) at Kul in Belgium. This germplasm is currently being maintained in vitro at the ITC for distribution to international breeding and improvement programs. The duplicates of the virus-indexed materials were sent back to PNG to be included in the national collection. The IPGRI/QDPI materials have been characterised and evaluated and the results published in the '*Musa*logue' of PNG (Arnaud and Horry 1988–89).

The 37 accessions collected under the drought project are maintained at Laloki Research Station. After characterisation and preliminary assessment, they will be added to the national collection.

The NBG collection at Laloki Research Station currently holds 309 accessions of both cultivated and wild bananas. The conserved materials are being characterised morphologically and undergoing preliminary assessment for fruit yield, eating quality and resistance/tolerance to pests, diseases and dry conditions. Selections for dry condition tolerance and good eating qualities are multiplied on-station and distributed to farmers on request. Many subsistence farmers along the river basins outside Port Moresby are growing diploid cultivars that originated from Morobe or Madang because of their good eating qualities.

NARI also maintains small working collections at the Lowlands Agricultural Experiment Station (LAES), Keravat (70 accessions) and perhaps at Bubia Research Station and at the Highlands Agricultural Experiment Station (HAES), Aiyura.

## Agronomic Research

### Early research

There was little agronomic research on bananas in PNG before the mid-1970s, except for some observation studies carried out at HAES and LAES (King 1986). However, Heenan (1973) investigated the potential for commercial sweet banana production and carried out a bunch cover study in Oro Province. He was unable to draw any conclusions about the potential for commercial sweet banana production in Oro Province because sigatoka disease and low soil moisture affected yield. The bunch cover study showed that covers consistently reduced the time between bunch emergence and harvest for the dwarf and giant Cavendish varieties (Heenan 1973). Heenan also reported that the skin of the covered bunches was significantly softer than that from the uncovered bunches and that the covered fruits were generally much more attractive, being relatively free of blemishes. However, there was a significant increase in bunch weight only in one case, and the overall results were too variable to draw conclusions about the effects of bunch covers on yields.

### Later research

Most of the DAL agronomic research on cooking bananas has been conducted at Laloki Research Station but studies have also been carried out at HAES and LAES. Research has included studies on varietal evaluation under high and low management conditions, planting density, fertilisers and intercropping, with two observation studies on desuckering and banana bunch cover. The results of this work have not been published although most of the information on the studies can be found in DAL research station reports and annual research reports.

*High and low management conditions*

Six commonly grown cooking banana varieties were selected from the PNGBF collection and four popular dessert varieties were planted under high and low management conditions at Laloki Research Station in 1983. The high management treatment included a complete fertiliser application, nematodicide and fungicide applications, irrigation, sucker pruning and bunch covers. The low management plantings received none of these inputs except irrigation. The study showed that a high level of management increased yields substantially, especially for the dessert varieties (unpublished DAL Annual Research Report 1984–88). Triploid cooking bananas of the ABB genome had better yields under high management than did the diploid AA types.

Other work included the evaluation of 10 good eating-quality cooking banana varieties selected from the NBG collection at Laloki Research Station in 1986, and further studies carried out at Bubia Research Station in 1988, to compare varieties from Central Province and from Laloki Research Station with local Lae varieties. The results of this work have not been published.

*Amount of fertiliser*

In 1993, a study at HAES investigated the effects of different rates of application of the most commonly used fertiliser in PNG (nitrogen, phosphorus and potassium, NPK) on two popular cooking banana varieties from the highlands. The fertiliser was applied at 0, 100, 200 and 400 grams per plant. The results from the first crop indicated no significant difference between various fertiliser treatments. The study area had good soil with no major deficiencies, so fertility may not have had an effect on the first crop. The differences may show up in the second and third ratoon crops. (Anon 1993–95)

*Sucker size*

Robinson (1995) reported that surplus suckers reduce the transmission of radiation, compete directly with the follow-up suckers and reduce the yield of the parent plant. A 1986 study at Laloki Research Station investigated the effects of three different sucker sizes (bites, small and large) and desuckering practice on the yield of two varieties of cooking bananas, *Babi yadefana* (AA) and small *Kalapua* (ABB). The study was terminated at bunching stage due to flood damage. However, visual observations indicated that the absence or size of the sucker did not result in a difference in growth, although the large suckers appeared more vigorous and flowered earlier than the medium suckers and the bites.

*Bunch cover*

To follow up previous work on banana bunch covers (Heenan 1973), research was undertaken at Laloki Research Station in 1986 to see whether using polythene sleeves as bunch covers had any effect on the yield of two dessert banana varieties (Cavendish dwarf and tall) and six cooking varieties. Results from the harvest of the first crop indicated better bunch weights from two covered Cavendish varieties and three cooking varieties. The bunch yields ranged from 8.0–21.0 kilograms (kg) in bunch-covered plots to 5.9–18.0 kg in uncovered plots (unpublished Laloki Research Station annual report 1987). In covered plots the fruit skin was smoother and of better quality, with no blemishes, than fruit from uncovered plots. This confirmed the findings of Heenan (1973). The second and third ratoon crops were not harvested due to flood damage. This work has not been published.

*Chicken manure*

At Laloki Research Station in 1992, two cooking varieties (*Babi yadefana* and large *Kalapua*) and dwarf Cavendish were grown under three different rates of chicken manure (mixed sawdust and chicken manure from Ilimo farm). The chicken manure application rates were 0.41 tonnes per hectare (t/ha), 0.82 t/ha or 1.2 t/ha. In the first crop, the level of chicken manure did not affect fruit yield. This suggested that the level of manure was inadequate to maintain the growth of the plants and thus contribute to the final yield. The trial was terminated after plants were stolen. The results of the study have not been published.

*Intercropping*

In the 1980s, a study on cocoa/triploid banana/betel nut/gliricidia intercropping was initiated at LAES. The objective was to maximise land use in food production and cash-crop returns within a sustainable system. The development and yield of cocoa, banana and betel nut were assessed under six intercropping combinations.

The aim was to select an intercropping combination compatible with the recommended spacing of cocoa at that time: 4 square metres. Betel nut, triploid banana and gliricidia were used as cash crop, food crop and shade tree, respectively. Analysis of the data obtained between 1989 and 1991 indicated that banana intercropping with cocoa alone produced the best banana yield of 11.74 t/ha compared to cocoa/banana/betel nut and cocoa/banana/gliricidia at 7.70 and 6.41 t/ha respectively. If 11.74 t of banana were sold in the main markets of East New Britain at 0.19 PNG kina (PGK)[1] per kg, it would fetch 2231 PGK (unpublished LAES 1991 annual report).

## Farming System Studies

Good-quality cooking bananas were selected from the NBG collection and distributed to selected farmers for production using their planting techniques. No yield results were obtained, but the farmers were asked if they liked the varieties and were encouraged to distribute the planting materials to other farmers living in the same area. These were called 'farmer-managed' observation studies. In a second series of 'researcher managed' studies, a simple observation block was set up in a farmer's field in collaboration with the farmer; and varieties were tested and selected by the researchers onfarm in collaboration with the farmer.

### Researcher-managed studies

*Fertiliser application methods (observation study)*

An observation study on fertiliser application methods was carried out on the Livestock Development Cooperation (LDC) banana planting at Ilimo farm, National Capital District, to examine the effects of two fertiliser application methods on the growth and yield performance of the dessert Cavendish banana variety under flood irrigation conditions. Ammonium sulfate fertiliser was applied at 400 grams per plant either by placing it in bands around the plants (farmer practice) or in covered furrows around the base of the plants (researcher-introduced practice). Observations on the growth performance of the plants before flowering indicated healthy green leaves on plants in plots that received fertiliser in covered furrows compared to those receiving the band application. The study was terminated before bunching because most plants died during a prolonged dry spell.

*Plant density study (observation study)*

This study was carried out at the same time as the fertiliser application study. Two dessert Cavendish varieties (dwarf and tall) were planted at five densities: 1587 plants per ha, 2222 plants per ha, 2679 plants per ha, 4233 plants per ha and 4556 plants per ha. Before the study was terminated as a result of a prolonged dry spell, visual observations indicated an impressive vegetative growth with good canopy formation in the 4233 plants per ha density plots.

*Live-mulch cover study (observation study)*

This study investigated the effect of live-mulch as a cover crop under banana on the growth and yield performance of the dessert Cavendish variety. *Dolichos lablab* was used as the live-mulch cover crop. The study was carried out on the LDC banana planting at Ilimo farm at the same time as the fertiliser study. The *D. lablab* cover initially established well, but died due to lack of water. No data were obtained from this study.

### Farmer-managed studies

Six promising varieties of cooking bananas (*Babi*, *Kurisa*, small *Kalapua*, large *Kalapua*, *Puka* and *Hoodoopataten*) were selected from the preliminary evaluation study from the national collection and tested in farmers' fields at Wosera, East Sepik Province and the Veimauri/Galley Reach area of Central Province.

The farmer-managed studies at Wosera were implemented through the Smallholder Market Access and Food Supply Project in 1989. Twenty farmers (14 from West Nanu and 18 from East Nanu) took part. Three selected varieties (*Babi*, *Kurisa* and large *Kalapua*) were introduced to farms. Researchers made follow-up visits to the farms a year later. Farmers most liked the *Babi* and *Kurisa* varieties (diploid types), maintaining these varieties onfarm as well as distributing the suckers to other farmers in the area.

All six varieties of cooking bananas were tested on 20 farms in the Veimauri/Galley Reach area. Farmers preferred the diploid varieties because they matured early (7–9 months) compared to the triploid types that take 9–11 months to mature. Varieties *Babi*, *Kurisa*, *Puka* and *Hoodoopataten* are now commonly grown in the Brown River–Veimauri/Galley Reach areas for household consumption and for markets in Port Moresby.

1. In 1991, 1 PGK = approx. US$1.05 (A$1.38).

## Garden, Market and Consumption Surveys

Banana garden, market and consumption surveys were carried out between 1986 and 1988 as a collaborative research effort by nutritionists of the Institute of Medical Research (IMR) and the research officers of the DAL Research Division. The project was partly funded by a grant from PNGBF. The surveys aimed to address the lack of previous research on food-crop production by both DAL and nutritionists. The objectives were to describe the role of bananas, compare production methods and yields, describe the uses of various banana cultivars, identify potential constraints to banana production and uses and set research priorities to improve subsistence banana production.

Study locations included the Vanapa River–Kabadi area of Central Province and the Amele area of Madang Province, which had contrasting systems of production and were accessible from Laloki Research Station and the IMR Station at Yagaun near Madang. A total of 106 farm households were interviewed and 197 gardens were surveyed in the Amele area; 58 households and gardens were surveyed in the Vanapa–Kabadi area. It was not possible to collect production figures from the smallholder farmers in these surveys, so the original plan for collecting the production data was abandoned. However, the study in the Amele area showed that the mean banana density was 1032 plants per ha and mean garden area per household was 0.6 ha, giving a mean number of 619 banana plants per household. The survey results showed that about 90% of the bananas grown in the Amele area are diploids, with a mean bunch weight of about 5.4 kg. Most diploids are harvested only once, giving a mean production of bananas per household of 3344 kg or 5573 kg/ha. The triploids (ABB) of the *Kalapua* type are mostly grown in the Vanapa–Kabadi area. The triploids have heavier bunches and would give a higher mean production figure per household per hectare.

The market and consumption surveys were carried out only in Madang. Market surveys indicated that over 60% of the harvested banana bunches were sold (0.20 PGK/kg); 32% of the harvest was consumed by the farm household. The consumption survey was undertaken in the Madang area in order to estimate the frequency of consumption of various types of bananas and other foods by rural and urban residents. The study revealed that the rural diet appeared to vary seasonally with regard to staples like taro and yam. Banana, however, is consumed at similar frequencies throughout the year. The survey also indicated frequent consumption of bananas by the urban residents in Madang (King et al. 1989).

## Future Research

The studies in the Amele area of Madang Province and the Vanapa–Kabadi area of Central Province have clearly indicated that banana is a very important food crop for local people, in both rural and urban areas. Agronomic research on cooking bananas has not yet suggested ways to improve the production of cooking banana as a major food crop in PNG. The triploid ABB varieties *Kalapua* and *Yawa* are very robust, hardy and tolerant to prolonged dry conditions. They were important food sources for the rural people of Central Province and other dry areas of the country during the El Niño drought. Banana is a nonseasonal crop, unlike yam and taro, as indicated by the study carried out with the Amele people of Madang Province. It grows up to 2150 metres above sea-level (R.M. Bourke, pers. comm. 2000). It can be intercropped with cash crops such as cocoa or coffee and used as a temporary shade tree for these crops.

Banana is the third most important food crop in PNG in terms of production and consumption, but in terms of consumption it is second only to sweet potato. Because it is nonseasonal, banana can provide continuous food, thereby improving food security for rural farm families.

There have been achievements in the area of genetic collection and maintenance. However, information on this valuable germplasm needs to be properly documented. Further agronomic research needs to be carried out on cooking bananas as an important food crop. The future research agenda should include varietal assessment, organic and inorganic fertiliser rates, intercropping and crop rotation studies and plant density investigations.

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# Blood Disease and Panama Disease: Two Newly Introduced and Grave Threats to Banana Production on the Island of New Guinea

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*Abstract*

Plant health surveys on the island of New Guinea are regularly conducted by the Australian Quarantine and Inspection Service (AQIS) in collaboration with the governments of PNG and Indonesia. Two lethal diseases of banana known previously to the west now jeopardise subsistence production and valuable germplasm resources. Blood disease, a bacterial wilt, has appeared very recently at Timika, Irian Jaya. The blood disease bacterium is spread extremely rapidly by insects, especially between cooking bananas. An explosive epidemic amongst the cooking bananas of Irian Jaya and PNG now threatens. Fusarium wilt of banana (Panama disease) is caused by the fungus *Fusarium oxysporum* (*Foc*). Three different strains of *Foc* are now present in Irian Jaya and one of these occurs also in border regions of PNG. Movement of infected planting material poses the greatest danger. AQIS information campaigns are being implemented to reduce further spread of both diseases.

THE Northern Australia Quarantine Strategy (NAQS), a program of the Australian Quarantine and Inspection Service (AQIS), conducts regular plant disease surveys in the Indonesian province of Irian Jaya and nearby parts of PNG in collaboration with the governments of these two countries. These aim to provide early warning of new incursions of plant pathogens likely to threaten subsistence agriculture, plant-based industries and/or the natural environment. This paper highlights two extremely serious pathogens of banana (*Musa* sp.) that have recently arrived on the New Guinea landmass, probably from the west.

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## Blood Disease of Banana

### The disease

Blood disease of banana is a wilt caused by a bacterium that invades the vascular tissues. The causal agent is currently named the blood disease bacterium (BDB). The disease is probably unique to Indonesia, where it was first studied more than 80 years ago on the island of Sulawesi (Gäumann 1921). The name 'blood disease' was originally adopted because droplets of a thick red-brown liquid often ooze out of the vascular tissues of infected plants at cut surfaces. Quarantine containment on Sulawesi was apparently successful until the 1980s, when blood disease appeared and rapidly spread on the island of Java (Eden-Green and Sastraatmadja 1990) and, in the 1990s, on Sumatra (Molina 1999, Setyobudi and Hermanto 1999).

## Symptoms of blood disease

Leaves of infected plants become yellow, then wilt, collapse and hang down. Red to brown necrotic markings are seen towards the centre of the pseudostem and/or the peduncle when cut transversely. The droplets that exude from vascular tissues can be milky white, yellow, red or brown in colour. The pulp of the fruit becomes red-brown and is inedible. The male bud below the fruit may ooze droplets and later withers. Bananas with ABB genotypes also show a distinctive and highly visible symptom of infection in male buds. Instead of successively abscising, many bracts on the male buds of such bananas remain on the peduncle, giving a clumped appearance (I. Buddenhagen, Department of Agronomy and Range Science, University of California, pers. comm., 2000). More details of symptoms are given in Eden-Green and Sastraatmadja (1990) and Eden-Green (1994a).

## The blood disease bacterium (BDB)

The BDB is believed to be a member of a group of bacteria unique to Indonesia. This group is closely related to *Ralstonia* (*Pseudomonas*) *solanacearum*, the cause of wilt diseases of numerous plants. Certain strains of *R. solanacearum* attack banana in the nearby Philippines, causing diseases called moko and bugtok.

The BDB shares many physical and biochemical characteristics with *R. solanacearum*. Both can be readily isolated on tetrazolium chloride (TZC) medium (50 milligrams per litre (mg/L)) added to casein–peptone–glucose (CPG) medium. CPG medium consists of Bactopeptone® (10 grams (g)/L), casein hydrolysate (1 g/L), Bactoagar® (15 g/L) and glucose (5 g/L). On this medium, BDB colonies are slow-growing with dark red centres and are nonfluidal (circular with distinct smooth margins). In contrast, colonies of *R. solanacearum* grow faster and run slightly across the surface of the plates, giving irregular shapes.

Noninfectious wilt bacteria deoxyribonucleic acid (DNA) may be obtained for analysis using the tools of molecular biology by incubating bacterial ooze in a lysis medium made from 200 microlitres (μL) of Tris–NaCl–EDTA (TNE) medium, pH 7.6 (100 millimolar (mM) sodium chloride, 100 mM ethylene diamine tetra-acetic acid (EDTA) (pH 8.0), 25 mM 2-amino-2-(hydroxymethyl)-1,3-propanediol hydrochloride (Tris HCl) (pH 7.6)) plus 50 μL of 20% (w/v) sodium dodecyl sulfate and 50 μL of buffer-saturated phenol (Gillings and Fahy 1993). Lysates are then subjected to a polymerase chain reaction (PCR) test that is specific for the group of Indonesian bacteria that includes the BDB (M. Fegan, unpublished data). Although this test cannot eliminate some other strains of *R. solanacearum*, the only organism associated with wilt disease of banana that gives such a test result is the BDB (M. Fegan, unpublished data).

## An outbreak of blood disease in Irian Jaya

Following an NAQS survey of Irian Jaya in April 1999, blood disease was confirmed in the cultivar *pisang kepok* (a cooking banana of ABB or possibly BBB genotype) in parts of the town of Timika (Davis et al. 2000). The initial disease focus was first noted between one and two years prior to the survey (L. Mokodompit, agricultural extension office [Balai Informasi Dan Penyuluhan Pertanian], Timika, Irian Jaya, pers. comm., 1999). The disease appeared to have since spread to many bananas (mostly *pisang kepok*) in Timika.

Earlier claims that blood disease was present in Irian Jaya (Muharam and Subijanto 1991; Baharudin et al. 1994) were not accompanied by diagnostic test results. The available evidence strongly suggests that a recent and isolated introduction of the BDB to the island of New Guinea has occurred. Between 1997 and 2000, two NAQS surveys of Irian Jaya (focusing on areas of transmigrant activity near Jayapura, Sorong, Nabire, Wamena, Biak, Merauke and Timika), two surveys of the PNG side of the PNG–Irian Jaya border, and two surveys of the southwest coast of the Western Province of PNG failed to observe any similar disease epidemics in banana (R. Davis, unpublished data).

## Blood disease epidemiology

Local spread is thought to occur from banana bud to banana bud by insects (Stover and Espinoza 1992). In the field, male buds of the apparently highly susceptible cultivar *pisang kepok* appear to be particularly attractive to insects such as wasps, bees and flies. This may be because the male flower nectar has a high sugar content (Setyobudi and Hermanto 1999). In addition, the bracts on most ABB/BBB male buds are nonpersistent, falling off one by one to leave a series of moist abscission scars over a period of several weeks. This is thought to facilitate insect transmission because the BDB ooze in droplets at the places where flowers and bracts fall off and insects visit these sites because nectar is usually present. When they do so, they pick up bacteria, then carry it to the same sites on healthy plants and transmit the disease. In banana plantings, the disease is also readily spread on contaminated knives used for pruning and cutting fruit. It is thought that the BDB does not spread in the soil very efficiently (I. Buddenhagen, pers. comm., 2000). Blood disease can spread long distances in infected planting material and fruits. However, infected fruits and suckers are unlikely to appear symptomless (Stover and Espinoza 1992), and this may reduce rates of spread by growers in PNG.

### The threat posed by blood disease

Blood disease has apparently almost eliminated *pisang kepok* from the diet of the inhabitants of Sulawesi (Molina 1999). The impact of this disease on banana production on the islands of Java and Sumatra after its introduction was explosive. The disease spread on Java at rates exceeding 25 kilometres (km) per year (Eden-Green 1994b), and on Sumatra at around 200 km per year (Setyobudi and Hermanto 1999).

Blood disease is now poised to devastate banana production on the island of New Guinea in a similar way, as *pisang kepok* is grown widely in Irian Jaya and similar bananas (genotypes that shed male flowers and bracts) occur throughout PNG (Arnaud and Horry 1997).

This disease also concerns Australian producers because bananas with ABB genotypes can be found in Queensland on most Torres Strait islands (Daniels 1997) and across the Cape York Peninsula (Daniels 1995), providing a potential pathway of infection from New Guinea to Australia's commercial plantations of Cavendish bananas. Whilst dwarf Cavendish banana plantlets were susceptible to this pathogen in artificial inoculation tests (Eden-Green 1994b), the behaviour of blood disease in field plantings of modern Cavendish cultivars under current Australian management conditions remains unknown. Cavendish bananas (AAA) have different floral characteristics from those of most ABB/BBB cooking bananas. A variable proportion (depending on cultivar) of male flowers and bracts on Cavendish bananas are retained and insects visit male buds less frequently. These features are likely to help reduce blood disease spread. Infection of the common dessert banana, *pisang berangan* (AAA), which is similar to Cavendish in many ways, has apparently not been observed by growers in Timika.

### Controlling the spread of blood disease in New Guinea

Simple cultural control measures have been highly effective in reducing the spread of the similar (but less damaging) insect-transmitted bacterial wilt of cooking bananas in the Philippines known as *tibaglon* or *bugtok* (Molina 1996). As the epidemiology of *bugtok* is very similar to that of blood disease, these techniques, combined with basic quarantine and sanitation practices, are likely to control the spread of blood disease in Irian Jaya. This information has been compiled into a control strategy outlined in an AQIS-funded information leaflet. The leaflet is aimed at extension and quarantine officers and growers in the Timika region. The recommendations are as follows:

- prohibit movement of banana plants or plant parts (including fruits) out of regions where the disease occurs, and ensure all planting material is disease free;
- remove male buds immediately after the last fruit hand emerges;
- destroy (using herbicides) diseased plants and their immediate neighbours as soon as they are discovered; and
- in areas where disease is present, make sure that knives used on bananas are properly disinfected (using heat, diluted formaldehyde or bleach).

Further control could be achieved if the highly susceptible *pisang kepok* was replaced with an acceptable resistant ABB cooking banana. *Pisang puju* from Sulawesi may be suitable because this cultivar aborts the male bud, blocking insect transmission (I. Buddenhagen, pers. comm., 2000).

## Panama Disease (Fusarium Wilt)

### The disease

A lethal wilt of banana caused by the fungus *Fusarium oxysporum* (*Foc*), was originally named Panama disease because it became prominent in that country in the early 1900s. However, fusarium wilt is the preferred name to avoid confusion with other diseases (Pegg et al. 1996). The pathogen infects bananas through the roots, then invades vascular tissues. *Foc* is difficult to eradicate once established in the soil. *Foc* can be readily isolated from air-dried vascular strands excised from the base (close to rhizome tissue) of the pseudostem of infected bananas (Moore et al. 1995).

### Symptoms of fusarium wilt

As *Foc* disrupts the plant's water-conducting vessels, leaves become yellow (progressing from older to younger leaves) and wilt. This is also a sign of drought stress that is reduced when water supply is abundant.

Distinctive symptoms are found inside the banana pseudostem: discoloured strands (red, brown or yellow) of vascular tissue and necrotic flecking in the corm. Later, all leaves turn yellow and die and internal rotting becomes extensive. Splits may also appear in the pseudostem. Infected plants usually do not survive to produce good fruit bunches and also pass the disease on to suckers. Further details of symptoms are given in Moore et al. (1995).

## *Foc*

There is great strain variation within *Foc,* and several methods have been developed to enable characterisation. Strains can be classified using pathogenicity towards different banana cultivars as observed in the field (as 'races' 1, 2 or 4), or analysis of vegetative compatibility groups (VCGs) (Brake et al. 1990, Pegg et al. 1996). More recently, DNA fingerprint analysis has provided finer differentiation between and within VCGs (Bentley et al. 1998).

## Emergence of *Foc* on the island of New Guinea

During the 19th century, *Foc* spread from its probable Asian centre of origin (Ploetz and Pegg 1997) to most major banana production regions of the world. The island of New Guinea remained free from this pathogen until the 1990s, when it was found near Manokwari, in the northwest of Irian Jaya (Shivas et al. 1996). Subsequently, fusarium wilt of banana has been confirmed at four more locations in Irian Jaya and three in PNG (Table 1).

VCG 0126 was the first strain to appear and is the one detected most frequently (one record from Irian Jaya and all three records from PNG). VCG 0126 is known from nearby Sulawesi and Halmahera in Indonesia (Bentley et al. 1998) and is considered to be 'race' 1 (I. Buddenhagen, pers. comm., 2000). VCG 0124/5 ('race' 2) was confirmed only in Irian Jaya (at Nabire). VCG 01213/16 is present at three widely separated locations in Irian Jaya (Biak, Timika and Merauke). This strain is referred to as 'tropical race' 4 because it has recently caused severe losses in Cavendish plantations in Indonesia and Malaysia (Bentley et al. 1998). A limited outbreak of fusarium wilt caused by 'tropical race' 4 in Australia's Northern Territory is currently under quarantine containment (N. Moore, unpublished data., 1999).

## The threat posed by fusarium wilt

In addition to its potential impact on banana production in the region, the spread of *Foc* into Irian Jaya and PNG is likely to jeopardise valuable germplasm resources. The diverse native bananas of the island of New Guinea are thought to have evolved in the absence of *Foc*, and will probably have little natural resistance to this disease (Ploetz and Pegg 1997).

**Table 1.** *Fusarium oxysporum* f.sp. *cubense* records on the island of New Guinea.

| Date | Location | Cultivar (genotype) | VCG[a] | 'Race'[b] | Reference |
|---|---|---|---|---|---|
| 1993 | Manokwari, Irian Jaya | Unknown (ABB) | 0126 | 1 | Shivas et al. (1996) |
| 1996 | Bewani, Sansaun Province, PNG | Unknown (ABB) | 0126 | 1 | Shivas and Philemon (1996) |
| 1997 | Timika, Irian Jaya | *Pisang raja* (AAB) | 01213/16 | 4 | Davis et al. (in press) |
| 1997 | Biak, Irian Jaya | *Berangan* (AAA) | 01213/16 | 4 | Davis et al. (in press) |
| 1998 | Merauke, Irian Jaya | *Pisang raja* (AAB) | 01213/16 | 4 | Davis et al. (in press) |
| 1998 | Vanimo, Sandaun (West Sepik) Province, PNG | Unknown (ABB) | 0126 | 1 | Davis et al. (in press) |
| 1998 | Kiunga, Western Province, PNG | Unknown (ABB) | 0126 | 1 | Davis et al. (in press) |
| 1999 | Nabire, Irian Jaya | *Pisang raja* (AAB) | 0124/5 | 1 | Davis et al. (in press) |

[a]Vegetative compatibility group (VCG) as determined by VCG analysis or DNA fingerprint analysis.
[b]A clear correlation between VCG and pathogenicity has been demonstrated for 'races' 1 and 4.

### Controlling the spread of fusarium wilt in New Guinea

*Foc* is readily transmitted in banana planting material (suckers or rhizome pieces) and this presents the greatest danger because infected suckers often appear symptomless. An information leaflet describing this disease threat and warning against unregulated movement of banana planting material has been produced by AQIS. It has been translated into appropriate languages and distributed to smallholder banana producers on both sides of the border.

## Summary

Fusarium wilt and blood disease of banana are potentially devastating recent introductions to the island of New Guinea. If left unchecked, both will cause great hardship because bananas provide a major food source for many inhabitants. They are poised to spread across the New Guinea landmass equally swiftly, but in very different ways. Blood disease would disseminate from a point source as insects fly from host to host. In contrast, fusarium wilt would spread in a more insidious way, concealed in apparently healthy banana planting material moved by growers from garden to garden.

To combat these diseases, public awareness must be heightened and quarantine measures enforced. Information leaflets produced and distributed by AQIS should initiate the process of alerting growers to these problems. The Australian government is also directly assisting quarantine in Irian Jaya through the Australian Agency for International Development (AusAID)-funded Strengthening Quarantine in Irian Jaya (Papua) Project, and in PNG through the AusAID-funded Agricultural Quarantine Support Project.

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# The First National Sago Conference

**A.P. Power**[*]

*Abstract*

This paper reports on the First National Sago Conference held at the PNG University of Technology, Lae in November 1999. The conference came about as a result of a belated appreciation of the importance of sago as a staple for millions of Papua New Guineans. The severe drought of 1997 brought home to many in government, donor agencies and the community, the precarious nature of PNG food sufficiency in times of disasters. In the 1997 drought, without massive efforts by Australia, amongst others, in supplying food and, more importantly, distributing supplies, thousands in PNG would have perished. Sago, were it produced commercially, clearly has the potential to provide a domestic product for disaster relief, alleviating the almost total dependence on imported rice and flour. The conference brought together general practitioners, scientists, students, politicians and community representatives and the papers reflected the diversity of their interests. The conference produced a set of recommendations for further action leading up to PNG hosting the next International Sago Symposium to be held in Port Moresby in mid-2001.

THE First National Sago Conference held in Lae, PNG, in November 1999 was a significant milestone in PNG development, reflecting official national government recognition of the potential of sago to contribute in a positive way to several government development priorities. These policy issues have matured over the last few years from a series of government meetings, conferences, negotiations with donor agencies and implementation reviews. Government, industry, research organisations, universities and donor agencies all provided input. In the last few years, medium-term development strategies and associated research priorities and trading policies have been developed, announced and rolled over again and again without much to show for it on the ground.

The severe drought in 1997 elicited a response from donor countries to assist PNG. The Australian government, through the Australian Agency for International Development (AusAID), threw the resources of the Australian Army into the task of logistics; and research scientists were brought in to conduct a nationwide needs assessment and to gather feedback on the success of the assistance. Near famine had been faced before as a result of severe frosts in the highlands but those problems had been confined to one or two provinces only. The 1997 drought, and consequent bushfires, were the worst in living memory and they affected the entire nation. This disaster helped focus the attention of the nation, including research scientists, nongovernment organisations and donor agencies, on food security for PNG.

The National Agricultural Research Institute (NARI) focused attention on food security, and sago was finally given the recognition it deserved. Consequently, NARI was one of the promoters of the First National Sago Conference.

The Department of Agriculture and Livestock (DAL) has for many years supported the Food Technology Department at the University of Technology (Unitech) in Lae. In the early 1980s, the East Sepik Provincial Government sponsored some research into sago food

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products, the result being the production of 'sago pops' (fried crackers), which are still being manufactured.

The international community of sago scientists and practitioners has held six international sago symposia since the first in Kuching, Malaysia, in 1976. The proceedings of those symposia contain a wide range of papers on aspects of sago, ranging from historical narrative, social anthropology, archaeology, geography, agronomy, molecular biology, taxonomy, biotechnology and technology of processing (both upstream to produce sago and downstream to produce starch products). PNG has been represented at most of those symposia and for many years the international sago community was keen for PNG to host a conference. Lack of interest and support in PNG meant that other countries (mainly Indonesia and Malaysia) took on the responsibility. DAL maintained the link with the international sago community and continued to press for PNG to host a symposium.

When Dr Sopade joined the Food Technology Department at Unitech, he revived interest in sago and began to conduct and facilitate research into various aspects of sago. Dr Sopade revived the connection with the international sago community and attended an FAO-sponsored roundtable meeting on 'Sustainable Small-Scale Sago Starch Extraction and Utilization' held in Thailand in August 1999. (The FAO had also sponsored a consultation in Jakarta in January 1994—'The Development of the Sago Palm and its Products' at which PNG was represented.)

## The Conference

The First National Sago Conference, having been postponed a month because of a student strike at the university, was conducted in a very professional manner that reflected the hard work of Dr Sopade and his team of helpers. About 30 to 40 participants attended the sessions. The papers were well presented, assisted by state-of-the-art facilities at the university lecture theatre. Participants included the Head of the Food Technology Department at Unitech, the Secretary for Agriculture, the Director of NARI, the Minister for Labour and Industry and the Governor of Morobe Province. Practical demonstrations of sago processing were shown to participants, who also had the opportunity to taste about twenty different sago food products, some of which were really delightful.

The papers presented at the conference covered aspects of sago research and development, including:

- social and cultural aspects of sago use;
- small-scale processing and utilisation;
- review of field research into sago commercialisation to date;
- sago's contribution to food security and the impact of the 1997 drought and fire;
- microbiology of sago processing;
- sago toxicology;
- report from the Thai roundtable meeting (August 1999);
- review of work to date on sago properties plus a comparative study of samples from different PNG provinces; and
- policy statements from government officers.

The conference fulfilled several important functions by:

- placing sago in the spotlight for the first time in PNG's history;
- highlighting the importance of sago as a food crop;
- advocating the possible role of sago commercialisation as an engine for rural development, rural employment, import replacement and backstop for food security on a local and national level;
- witnessing a public commitment to begin a feasibility study for commercialisation of sago in the Gulf and the Western provinces of PNG;
- giving a boost to our local scientists who have begun to conduct research into aspects of sago related to their fields; and
- giving a boost to PNG bureaucrats in technical departments which confirmed their interest in sago.

## Conclusions and Recommendations from the Conference

The First National Sago Conference came to a number of general conclusions and recommendations relating to research, development, policy information and extension. For those who do not have copies of the proceedings, it is useful to repeat them here as a reminder that considerable follow-up work is needed in order to be able to enjoy the potential that sago has to offer PNG and the world over the next few decades.

### General conclusions

- Commercialisation of sago starch processing will generate employment in the sago-growing areas but the environmental effects should be carefully assessed.
- The amount of sago coming into the local markets has increased to the extent that there is a need to adopt initiatives in relation to commercialisation.

### Research and development recommendations

- Examine the various processing, uses, handling, quality and health issues of sago starch in each community.
- Look into the possibility of making other products from the sago palm.
- Identify and provide the necessary support for appropriate scales of processing.
- Investigate management and agronomy of the sago palm plantation.
- Conserve different genetic varieties of sago palm.
- Investigate optimum propagation of plant materials for development (tissue culture).

### Policy recommendations

- Various sago-producing provinces to draw up policies for the utilisation of sago starch in their areas.
- Set up a national sago council to coordinate activities on sago research and issues round the country.
- Adopt a national policy on sago starch research and management.
- Replace traditional minimum husbandry practices ('plant and forget') with a more cultivation-centred approach.
- Identify linkages from processors to farmers.
- Increase stakeholder commitment to all issues (including research and development, environmental impact and sustainable development), not just profit.
- Research aspects of the socioeconomics of sago supply.
- Manage carefully the transition from a subsistence to a commercial economy.
- Investigate technological innovation at the local processing level.
- Develop intermediate technology of one or more critical stages of sago production.
- Facilitate development of the industry through national government finance and policy agencies.
- Promote sago starch product development research.
- Consider sago palm as a plantation crop, rather than a forest product.
- Enforce sustainable agricultural and processing practices (nutrient depletion, crop competition and environment issues need to be addressed).
- Give assistance to sago-producing villages to increase sustainable sago production while conserving ecosystems.

### Information and extension recommendations

- Establish national, regional, and local production and distribution of information material on aspects of sago production (health, propagation, management and processing).
- The conference also produced a set of recommendations for further action leading up to PNG hosting the 7th International Sago Symposium in Port Moresby in mid-2001.

## Conclusion

The First National Sago Conference has resulted in:

- a positive government policy towards sago with emphasis on food security;
- increased momentum towards a commercial sago industry; and
- commitment by PNG scientists to sago-related research (the papers of this conference alone cited 106 works connected with sago and PNG).

The success of the Conference is a strong sign that sago development will be pursued vigorously in the immediate future. It is recommended that interested parties obtain a copy of the full proceedings from DAL, Unitech or NARI.

# Sago Starch, Food Security and Nutrition in PNG: the Triple Web

**P.A. Sopade***

*Abstract*

Sago starch remains a staple food for many people in PNG and it has found wide uses in many traditional foods and products. Therefore, it features strongly in the food security issues of the country. The 1999 National Conference on Sago Starch and Food Security in Papua New Guinea highlighted various issues related to improving its processing, handling, storage and utilisation. Some of the recommendations of that conference are reviewed in this paper and their possible effects on nutritional issues in the country are projected. Certain sago-based traditional foods are listed and the major ingredients, with their nutritional constituents, are emphasised. Extensive studies on the composition of PNG traditional foods are required and international collaborations and assistance ought to be solicited. Such studies should include the impact of processing techniques. A case study on the nutritional implications of *mumu* on model food systems is briefly discussed. The paper concludes by emphasising the need for an effective policy on traditional foods of PNG to allow the full realisation of their potential for the nutritional wellbeing of the people.

SAGO palm (*Metroxylon sagu* Rottb.) grows readily in PNG, with about two million hectares and close to 23 varieties under cultivation (Ulijaszek and Poraituk 1993; Schuiling 1995; Flach 1997). It grows in every province of PNG (Sopade 1999a), although it varies locally in density, with the largest areas in swampy and lowland regions. Its main product, sago starch, is cherished in many communities, as is indicated by the saying '*saksak i stap, na mipela i stap*', which literally means 'as long as there is sago, our existence is guaranteed' (Bosro et al. 1999). If a community relies this much on a food commodity, it means that the food is paramount to its survival or, more appropriately, that it secures the wellbeing of its inhabitants. It is estimated that close to 80% of Papua New Guineans have eaten sago. Sago is the most important food for 10% of the rural population and provides an estimated 6% of calories consumed by rural Papua New Guineans (see The 1997 Drought and Frosts in PNG: Overview and Policy Implications by Bryant J. Allen and R. Michael Bourke, in these proceedings).

The wellbeing of the population is a direct function of the level of nutrition. Cox (1983) related the high incidence of malnutrition in the Gulf, East Sepik and Sandaun (West Sepik) provinces of PNG to a dependence solely on sago starch. Hence, it is plausible to propose a sago–food security–nutrition web. However, what is unclear is the level of acceptance of this web in PNG and, more generally, the role of the traditional foods of PNG in the food security–nutrition interface. Traditional foods elsewhere (e.g. Europe) are receiving increased recognition in view of their present and potential contributions to the health and wellbeing of consumers, as elegantly emphasised in the Food, Nutrition and Health action of the Quality of Life Program of the European Community (Toldrá and Navarro 2000).

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There may be identical programs elsewhere, even in PNG, but the concern is the thorough local acceptance of and adherence to the issues. Traditional foods are associated with particular cultural groups, linked to territory and traditions (Jordana 2000). Fellows (1997) noted that traditional foods are made using memorisedtechniques that are handed down from generation to generation by word of mouth. These characteristics ensure the continuity of traditional foods over time. From a historical perspective, sago starch perfectly fits this domain. To substantiate this assertion, however, it is necessary to examine the body of knowledge on the commodity for its relevance to the food security and nutrition of Papua New Guineans.

## Sago Starch: the Past and Present

Sago palm is an ancient crop in PNG, and the extraction and use of its starch is likely to have been practised for a long time. Although Power (1999) traced the recorded use of sago starch in PNG to 1953, the energy crisis of the 1970s brought it into the limelight as a likely raw material for alcohol production. When the energy crisis subsided, the emphasis appropriately shifted to food uses, even though sago has always been a major food amongst the people, particularly the Sepiks (Flach 1997), who refer to it as '*bun Sepik*' (the backbone of the Sepiks). Many feasibility studies followed, that were aimed at improving and commercialising sago starch extraction, but, at the beginning of the new millennium, extraction processes remain rudimentary, inefficient and wasteful (Sopade 1999a). This is despite periodic PNG food and nutrition policies, action plans on food, health and nutrition, and national agricultural council meetings. Also, substantial developments on sago starch in Malaysia and Indonesia, for example, have not been significant enough to catalyse policy refinement and action in PNG, despite being the centre of diversity of the sago palm (Flach 1997). The PNG Food Security Committee did not accord sago starch its rightful place in its deliberations and the commodity was consequently relegated to insignificance. This apathy led to the need to assemble sago farmers, users, scientists and researchers in the country for the 1999 First National Conference on Sago Starch and Food Security. Information given in another paper in these proceedings (The First National Sago Conference by A.P. Power) has examined the cogent issues from the 1999 conference as well as the main recommendations.

The conference represented a major advance for the role sago starch could play in the food security of PNG. The following recommendations are worth revisiting in the present context:

- to investigate technological innovation at the local processing level;
- to develop intermediate technology for one or more critical stages;
- to promote sago starch product development research; and
- to consult various sago provinces to draw out policies for the use of sago starch in their areas.

These recommendations, and others, were supposed to maintain the interest (governmental, provincial and institutional) in sago starch across the country and to take it to the next level of more efficient processing and handling. In fact, the future of sago starch, and hence its role in food security policy, depends on how faithfully these recommendations are adopted. They are paramount to the production of good quality sago starch, which in turn will influence its domestic and industrial use.

From our studies (Sopade 1999a) on traditional sago starch processing, the following issues were identified:

- the particle size of the ground pith was large and not uniform (about 90% was retained on a 2-millimetre sieve);
- starch extraction was about 20%;
- sedimentation recovered about 50% of the extracted starch, implying that the yield from typical traditional processing was about 10% of total starch;
- the moisture content of retail sago starch ranged from 30 to 40%;
- retail sago starch was fairly acidic, with pH from 3.7 to 5.1; and
- the colour of processed starch was generally brown, indicating gross enzymatic browning.

The microbiological quality of some retail samples was also poor (Omoloso 1999). However, the main reason for the low quality can be traced to poor processing technique and the absence of appropriate technological tools such as grinding machines, mixing tanks, sedimentation tanks or centrifuges and driers, and good packaging. The recommendations are, therefore, vital to the production of quality starch and improvement of starch yield. This has significant implications for food security and nutrition in PNG because sago starch is a main ingredient of many traditional foods in the country. The level of industrial use of locally produced sago starch is unknown, but noticeable amounts of starches and sago products are imported (Sopade 1999a). In 1999 (or possibly earlier), some big supermarkets in Lae conspicuously displayed sago starch on their shelves with other products (local and imported). This observation suggests that the demand for sago starch was increasing.

## Use of Sago Starch and its Relevance to Nutrition

Sago-based traditional PNG foods (see Fig. 1) are many and spread across the country, and flowcharts describing them are available elsewhere (Sopade 1999a; 1999b). It is obvious from these foods that traditional users mix other ingredients with sago starch to improve the various characteristics of the end-products (Table 1) . Nutritional considerations possibly play a role in the choice of other ingredients: Table 2 shows the nutritional composition of typical sago starch and some of these ingredients. Information on the proportions of ingredients in these foods is unavailable but is necessary if a full analysis of their nutritional contribution is to be made.

After compensating for losses due to processing, handling and component interactions, the nutrients in the final products or mixtures are expected to be related to those in the raw materials. Plahar and Hoyle (1991) described the following procedure to calculate the protein quality of a mixture.

- On a worksheet, record the weights of the components and calculate the protein and nitrogen (N) contributions as a percentage of each component's weight. This is done by multiplying the protein or N content of the component by the weight and then dividing by 100.
- For each component, calculate individual essential amino acid contributions by multiplying the literature value (in grams (g)/g N) by the amount of N.
- Add up the weights or amounts of protein, N and individual amino acids contributed by the components to get their respective totals.
- Divide each amino acid total by total N (g) in the blend to obtain the essential amino acid composition in terms of g/16g N.
- Obtain the amino acid scores by dividing the amount of each amino acid (g/16g N) by the corresponding value (g/16g N) for the Food and Agriculture Organization (FAO) pattern, and multiplying by 100.
- Record the lowest amino acid score (i.e. limiting amino acid score) as the score for the whole blend. Multiplying this value by the protein content (%) of the blend and dividing by 100 gives the net protein value (NPV).

Plahar and Hoyle (1991) were able to explain about 90% of the assayed value through this procedure. Sopade and Koyama (1999) mixed sago starch and peanut paste (Table 3), and it appears that the proximate composition of the blend can be estimated from the ratios of the blend (Assayed = 1.04 × Calculated, $R^2 = 0.9788$, $P < 0.001$). Although there are limitations to this mathematical approach, it serves as an approximate guide if analytical facilities are not readily available.

The low protein content of sago is of nutritional concern in diets that are based on a high proportion of this one ingredient, just as a diet mainly of rice will be grossly deficient in vitamin B. This is because protein and vitamins are essential nutrients for growth and for cell and tissue replacement. But, being a carbohydrate, sago starch is not expected to be a source of protein—just as other starches of domestic and industrial importance are known to lack protein. High contents of protein and fat in starches are quality defects (Swinkels 1992) because:

- fats repress swelling, solubilisation and water binding ability;

**Table 1.** Minor ingredients in selected sago-based traditional PNG foods.

| Traditional food | Minor ingredient |
|---|---|
| *Alung* | Grated coconut |
| *Boubaya* | Coconut cream, grated coconut |
| *Buling-au* | Grated coconut |
| *Dia* | Banana |
| *Kalua* | Banana, fish, grated coconut |
| *Karamap saksak* | Coconut milk, grated coconut, peanuts |
| *Kilikan* | Coconut cream, shellfish |
| *Lupeto* | Coconut cream, fish |
| *Mona sagu* | Coconut cream |
| *Nhangu* | Fish, vegetables |
| *Pahpa* | Banana, coconut cream, fish |
| *Pariva* | Banana, coconut cream |
| *Rabia* (*Bakibaki*) | Coconut milk |
| *Sago dumping* | Coconut cream, grated coconut |
| *Sago pop* | Grated coconut, peanuts |
| *Sagu forno* | Grated coconut |
| *Saksak* | Coconut cream, grated coconut |
| *Saleh* | Banana, coconut cream |

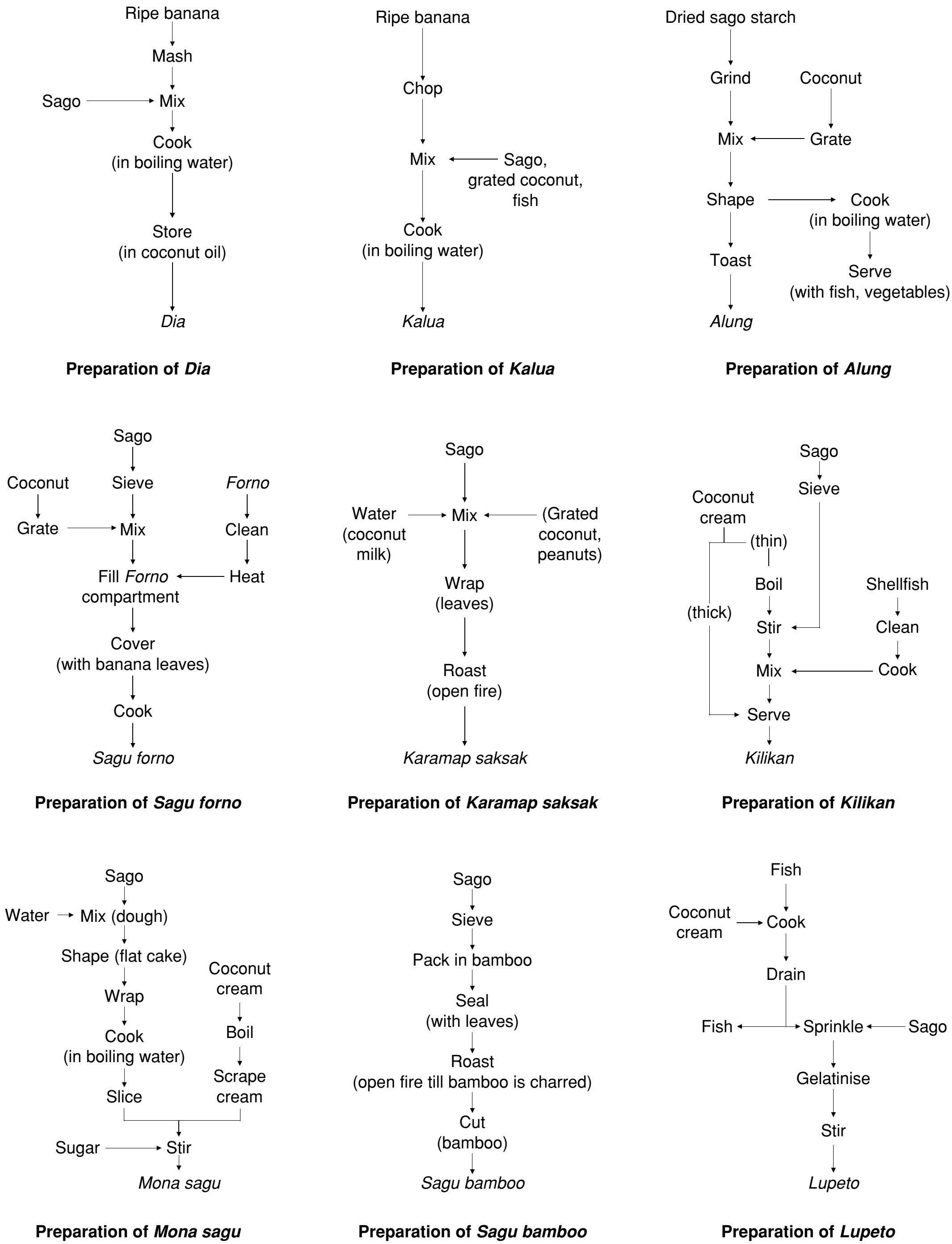



**Figure 1.** Preparation of traditional products from sago starch in PNG.

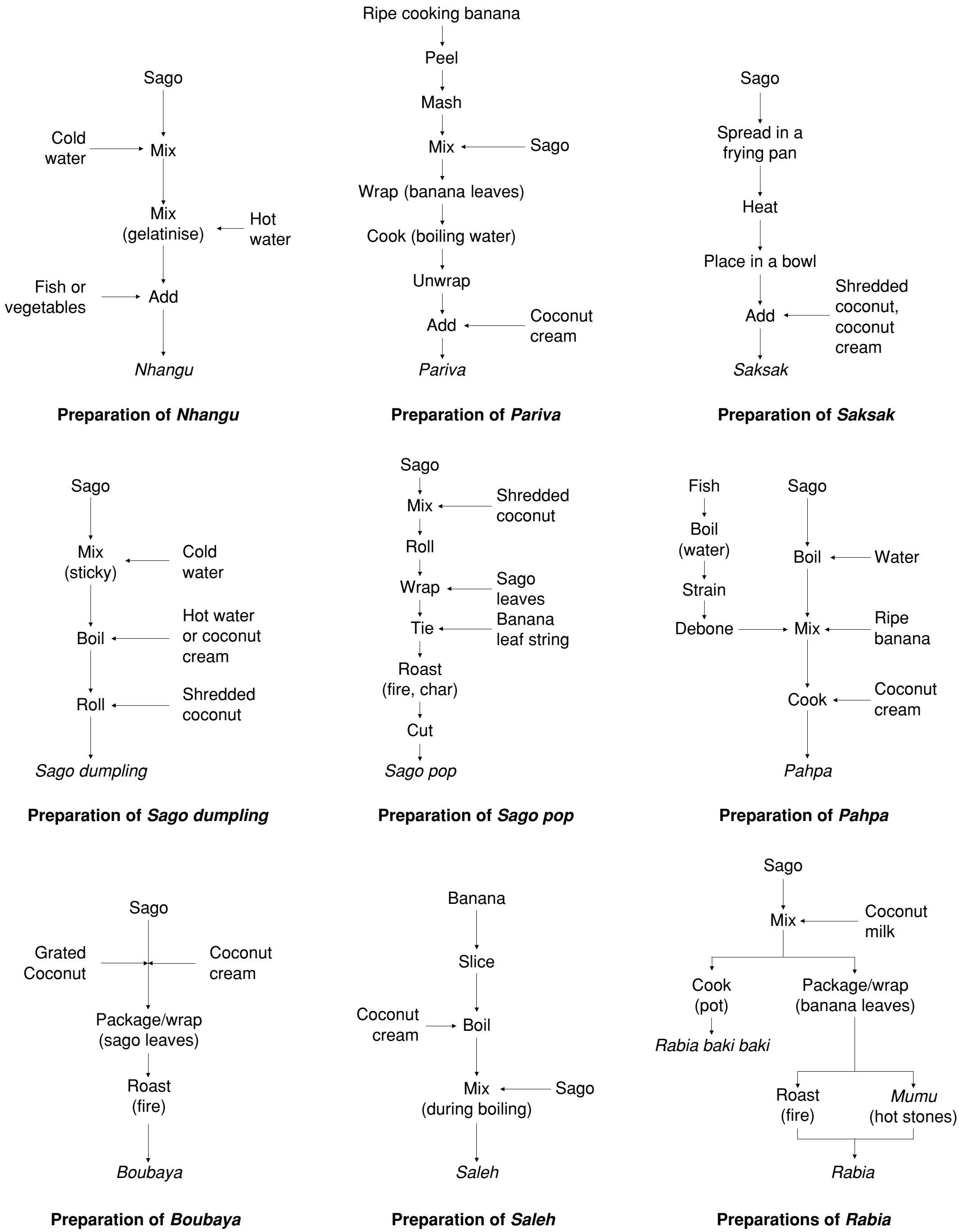
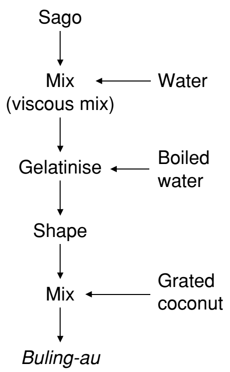



**Figure 1** (cont'd)**.** Preparation of traditional products from sago starch in PNG.




**Preparation of *Buling-au***

**Figure 1** (cont'd)**.** Preparation of traditional products from sago starch in PNG.

- unsaturated fatty acids increase the susceptibility to oxidative rancidity;
- protein aids foaming during cooking of starch pastes; and
- discolouration of starch hydroxylates is pronounced in the presence of protein.

New (1986) noted that protein is used more efficiently when the carbohydrate supply is increased. Both sago starch and protein sources, as used by sago eaters (Table 1), therefore complement one another, but better protein sources can be used. Soerjono (1980) recorded that people who depend on sago starch in Papua, Maluku and neighbouring islands of Indonesia have a firmer body than those whose main food is rice or maize. Generally, comparable information for PNG is lacking.

The generation of relevant data on the composition of PNG foods is essential for an adequate evaluation of the nutritional status of the people, and some data are available (Bradbury and Holloway 1988). With modern techniques, new evaluations can be done faster and old ones validated. Analytical facilities, adequate financial support and expertise are required. There are some facilities in PNG, but they are scattered and may be underused. Perhaps, with the current food security–nutrition initiative and the substantial role food composition can play in it, it may be appropriate to adopt an effective food analysis strategy, maximise the limited resources and seek international collaboration and assistance. As the PNG contact for the Asia–Pacific Food Analysis Network (APFAN) for many years, we have been able to fund some researchers and support staff from PNG for training at the Queensland Government Chemical Laboratory in Brisbane, Australia. Presumably, APFAN will continue to assist within the limits of its budget, but more funds will be needed because of the volume of studies required. Also, there need to be commitments from and collaborations among local laboratories and international researchers, particularly those based in Australia because their close proximity is an advantage. The Australian Centre for International Agricultural Research (ACIAR), a cosponsor of this conference, has funded and is still involved with similar studies in Fiji, and this interest could be extended to PNG. For example, the Swedish International Foundation for Science-sponsored research studies in PNG are very small in comparison with some other developing countries. Food composition studies fall within its food science mandate and the foundation targets young researchers with grants of US$10,000 that are renewable twice. There are also funds available for training and conference attendance. With collaboration among PNG laboratories and scientists, many applications could be made to address different aspects of the national research thrust on food composition.

However, it is pertinent to note that food composition should not be seen strictly in terms of nutrient content; the analysis of antinutrients is also important. Burlingame (2000) observed that what makes a food component an antinutrient is a matter of degree: some classical antinutrients are now known to have beneficial properties, while many nutrients act as antinutrients when consumed in higher than physiologically tolerated doses. The stability of food components under various processing techniques continues to be topical and there is no reason why this aspect too cannot be a component of the national strategy.

Recently, Savage et al. (2000) studied the effect of cooking on oxalate content of some New Zealand foods and Sopade (2000) reported the stability of cassava cyanogens in cassava–coconut cream during the cooking of foods in *mumu*. *Mumu* is a popular cooking technique in PNG (and other Pacific islands); it is used widely but differently across PNG (Sopade 1997). Using acid hydrolysis procedures (Bradbury et al. 1991), it was found that the cyanogenic potential of the cassava dough was less degraded in the presence of coconut cream than when water was mixed with the cassava. Although sago starch is essentially free of cyanogens, the relevance of these findings is that the presence of some ingredients might offer a buffer to the destruction of antinutrients. Cyanogens are lethal above a particular dose and the Codex Alimentarius Commission standard

**Table 2.** Composition of selected ingredients from sago-based traditional PNG foods (per 100 grams).

| Parameter | Sago flour | Sago palm heart, raw | Spinach, raw | Galip nut *Canarium indicum* | Tuna, yellow fin, smoked | Peanuts, skin and kernel, raw | Desiccated coconut | Coconut cream, fresh, no water | Coconut water/ milk/ juice | Banana (common varieties) |
|---|---|---|---|---|---|---|---|---|---|---|
| Energy (kilojoules) | 1387 | 158 | 103 | 1838 | 606 | 2309 | 2626 | 1347 | 93 | 426 |
| Water (grams (g)) | 12.6 | 90.8 | 89.7 | 35.4 | 66.2 | 4.8 | 2 | 54.1 | 92.2 | 73.3 |
| Protein (g) | 0.4 | 1.8 | 2.8 | 8.2 | 27.2 | 24.7 | 6.3 | 4.4 | 0.3 | 1.3 |
| Fat (g) | 0.1 | 0.6 | 0.8 | 45.9 | 3.7 | 47.1 | 65.1 | 32.3 | 0.2 | 0.4 |
| Ash (g) | na | 1.0 | na | 2.6 | 2.5 | na | na | na | na | na |
| Dietary fibre (g) | 0.5 | 2.6 | 2.1 | 10.6 | < 0.1 | 8.2 | 14.7 | 1.7 | 0 | 0.8 |
| Sugars (g) | na | 1.3 | na | 0.2 | 2.1 | na | na | na | na | na |
| Starch (g) | na | 5.1 | na | 0.3 | < 0.1 | na | na | na | na | na |
| Carbohydrate (g) | 83.4 | na | 1.57 | na | na | 8.9 | 6.7 | 4.7 | 4.9 | 23.6 |
| Calcium (milligrams (mg)) | 9.0 | 68 | 170 | 44 | 2 | 55 | 12 | 15 | 29 | 11 |
| Sodium (mg) | 3.0 | 26 | 140 | 18 | 593 | 1.0 | 18 | 13 | 110 | 29 |
| Zinc (mg) | na | 0.5 | na | 2.4 | 0.6 | 3.0 | 1.3 | na | na | na |
| Copper (mg) | na | 0.3 | na | 1.6 | 0.7 | na | na | na | na | na |
| Potassium (mg) | 5.0 | 357 | 500 | 627 | 368 | 540 | 650 | 280 | 310 | 241 |
| Magnesium (mg) | 3.0 | 37 | 54 | 284 | 40 | 160 | 95 | na | na | na |
| Manganese (mg) | na | 0.1 | na | 1.1 | < 0.1 | na | na | na | na | na |
| Iron (mg) | 0.7 | 0.2 | 2.1 | 3.5 | < 0.1 | 2.3 | 2.6 | 1.8 | 0.1 | 0.6 |
| β-carotene equivalent (micrograms (µg)) | na | < 5 | 3535 | 165 | 0 | 4.0 | 0 | 0 | 0 | 46 |
| Niacin (mg) | na | 1.1 | 1.2 | 1.7 | 8.3 | 15.0 | 1.3 | 0.5 | 0.1 | 0.7 |
| Riboflavin (mg) | na | 0.05 | 0.09 | 0.06 | < 0.02 | 0.1 | 0.02 | 0.01 | 0 | 0.08 |
| Thiamin (mg) | na | < 0.02 | 0.07 | 0.13 | 0.06 | 0.79 | 0.02 | 0.02 | 0 | 0.07 |
| Ascorbic acid (mg) | na | 2 | 26 | 8 | < 1 | 0 | na | 1 | 2 | 17.3 |

na = not available

Source: English et al. (1996); Diet™ software developed by the South Pacific Commission (Oceania Foods)

**Table 3.** Approximate composition of sago starch–peanut blends.[a]

| Parameter | Sample | | | | | |
|---|---|---|---|---|---|---|
| | Peanut | 100S0P[b] | 80S20P[b] | 70S30P[b] | 60S40P[b] | 50S50P[b] |
| Moisture | 8.9 ± 0.53 | 58.2 ± 0.21 | 52.1 ± 0.38 | 48.4 ± 1.08 | 37.9 ± 0.34 | 33.3 ± 0.96 |
| Protein (N × 6.25) | 28.3 ± 0.64 | 0.1 ± 0.02 | 8.3 ± 0.76 | 9.4 ± 0.86 | 13.2 ± 1.14 | 19.1 ± 0.42 |
| Fat | 43.1 ± 1.72 | 0.2 ± 0.01 | 9.5 ± 0.88 | 10.0 ± 1.31 | 14.0 ± 0.74 | 19.0 ± 2.17 |
| Ash | 2.5 ± 0.08 | 0.2 ± 0.01 | 0.8 ± 0.07 | 1.0 ± 0.09 | 1.0 ± 0.11 | 1.2 ± 0.13 |
| Carbohydrate | 17.2 | 41.3 | 29.3 | 31.2 | 33.9 | 27.4 |
| Energy (MJ/kg) | 24.0 | 6.9 | 9.9 (43) [c] | 10.6 (53) [c] | 13.2 (90) [c] | 15.0 (117) [c] |
| Energy ratios (%) contributed by: | | | | | | |
| – protein | 20.0 | 0.2 | 14.3 | 15.2 | 17.1 | 21.7 |
| – fat | 68.2 | 1.1 | 36.6 | 36.0 | 40.4 | 48.2 |
| –carbohydrate | 11.8 | 98.7 | 49.1 | 48.8 | 42.5 | 30.2 |

[a]Carbohydrate was calculated by difference, and the energy content (MJ/kg) was calculated using the Atwater factors (kJ/g) protein 17 and fat 38; 16.5 was used as the average of the factors for starch and sugar.
[b]80S20P = 80% sago starch, 20% peanut, etc. Values are means ± standard deviations.
[c]Figures in brackets are percentage increase relative to the unfortified sample.
Source: Sopade and Koyama (1999)

specifies the safe limit as a maximum of 10 milligrams hydrogen cyanide equivalent per kilogram of fresh root. The observation that coconut cream delays its destruction raises a health concern, as coconut cream is a popular dietary item in PNG (Table 1).

The study by Savage et al. (2000) also highlights a nutritional dilemma. Oxalic acid forms water-soluble salts with sodium, potassium and ammonium ions, and binds with calcium, iron and magnesium ions, rendering the bound minerals unavailable for physiological activities. Soluble oxalates are usually leached out during wet-cooking, but traditional baking (some types of *mumu*, toasting over fire or hot surfaces like *forno*) gives no opportunity for leaching losses to occur. Removing soluble oxalates by leaching is desirable, but, with iodised salts in the mixture, the iodine supplementation level might be reduced. Iodine deficiency remains a nutritional issue in PNG.

These issues highlight the complexity of nutrient interactions and the need for an organised study on the composition of raw and processed PNG foods. The low level of technology in food processing and handling across the country compels the populace to use various traditional techniques yielding diverse products. Some of these products are for household uses while others have formed items of trade and are retailed in open markets. A large proportion of Papua New Guineans, therefore, rely on these traditional foods for their daily nutrients to secure their heath and promote their wellbeing. Sago starch plays a prominent role in this web.

## Conclusions

Traditional foods are consumed by Papua New Guineans for their nutrition. The supply of these foods and/or their raw materials in the right quality and quantity is paramount to securing good nutrition for the people. Sago starch is an important raw material, the source of which, sago palm, is abundant and widely distributed across PNG. The starch forms the basis of more than 23 different traditional foods. However, the present processing and handling procedures need urgent improvement for safe and quality sago starch production. An earlier conference on this commodity highlighted the various issues, and the present conference should adopt policies to recognise and reinforce the strong connection between sago starch, food security and nutrition in PNG. The proposed international conference on sago starch in 2001 will be an opportunity to measure further progress on this issue.

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# A Coconut-Farming Systems Approach to Food Production in the PNG Lowlands

**Will Akus,* Jean Ollivier,* Kurengen Mesah* and Pius Pulo***

*Abstract*

Land for food production is critically limited in some areas of PNG where the coconut plantation industry is prominent. Sixty to seventy-year-old coconut stands need to be rehabilitated because they occupy large amounts of land that could be more efficiently used. A suitable crop-production system is needed to enable farmers to efficiently produce food and cash crops simultaneously. This is especially important in the areas of high population and land pressure.

A number of intercropping combinations involving coconuts are being studied to assess and identify economically viable and sustainable farming systems options. Preliminary results have shown that food can be successfully grown under coconuts. Furthermore, most of the cropping combinations under trial appear to be resource-use efficient at this very early stage of evaluation, thus diversifying and increasing cash-earning options. Future research should be directed towards intensifying food production under coconuts.

WITH diminishing resources and an increasing population, food production and security is one of PNG's most serious concerns. Economically viable and sustainable food production options must be identified, and long-term plans made to ensure continued food production and security. Equally important is the need for subsistence farmers to have access to cash when required. Where food cannot be produced for immediate domestic use, as in subsistence farming, sustainable, cash-earning opportunities other than paid employment and remittances need to be investigated. This money can then be used to buy food.

The PNG Cocoa and Coconut Research Institute (CCRI), through its agronomy and farming systems program, is investigating methods of rehabilitating aged coconut stands to increase land-use productivity. One of the methods under study is the farming systems approach to production. A number of options have been trialled, including intercropping food and alternative cash crops with either young coconuts and/or under old (60–70 year) coconut palms.

Coconut is cultivated and used in all PNG provinces, but it is in the lowlands where it attains the greatest importance, especially in the island and Madang provinces where it supports copra, copra meal and coconut oil industries.

Amongst its many uses, coconut is the most important indigenous nut food in PNG. About 300 million coconuts (tender and mature) are consumed every year. If copra was to be made of this amount of nuts it would net 60,000 tonnes, worth US$17 million at the current (June 2000) price. If this volume of coconut was sold at a conservative price of 0.2 PNG kina (PGK)[1] per nut on the domestic market, it would be worth US$24 million. The coconut-products industry is a further source of cash employment and also generates foreign income.

The smallholder sector currently accounts for 80% of total copra production (Omuru 1999). There are

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1. In June 2000, 1 PGK = approx. US$0.40 (A$0.60).

two reasons for this. Firstly, widespread planting since 1946 by smallholders continued into the 1970s, giving rise to increased smallholder production. Secondly, the neglect and abandonment of many plantations, for various reasons, has decreased large-scale copra production.

Apart from obvious reasons of high production costs, low prices and land tenure uncertainties, the large-scale plantation-sector palms have also aged considerably and are at a stage where even good management will not revamp production. The trend of increasing costs and decreasing productivity will continue unless the groves are rehabilitated.

# Objectives

The investigations are being conducted to:

- assess and identify economically viable and sustainable intercropping combinations involving coconuts;
- identify options suitable for different situations, including rehabilitation of old coconut stands; and
- identify opportunities for research involving coconuts, with respect to increased crop and cash production in the future.

# Methods and Results

Currently, trials are being conducted at the CCRI's Stewart Research Institute in Madang Province. The soil can be generally described as of alluvial origin based on past sedimentary deposition and modified by organic matter build-up. Drainage is good, with isolated locations possessing a high water-table. The mean annual rainfall is approximately 3000 millimetres.

The cost of material and labour data have been collected and total costs have been calculated for the different types of farming system that have been studied. Labor input was monitored on a daily basis. This is presented in terms of the number of working days, with one working day representing eight working hours. The cost of labour was calculated using the actual hourly rates paid for the work done. Produce was harvested and sold for revenue generation. This was done for all intercropping combinations, and will continue for the experimental life of the trial.

## Coconut and vanilla intercropping

Research work was begun at the end of 1996, followed by field establishment in March 1997. Material and labour inputs were measured for a 4.7-hectare block (Table l).

## Coconut, banana and pineapple intercropping

Clearing work started in early 1997. By January 1998, banana and pineapple were planted under coconuts at spacings of 4 × 4 metres or 4 × 2 metres, respectively, on an area of 1.5 hectares. Banana production remains prolific, while pineapple production has stopped (Table 2).

## Coconut and pineapple intercropping

A mixed planting of three different varieties of pineapple was carried out on a 1.8-hectare block of land under coconut palms. Pineapple suckers, spaced at 3 × 2 metres, were planted in January 1998 (Table 2).

**Table 1.** Details of coconut and vanilla intercropping.

| Plant species | Variety | Spacing (metres) | Plants per hectare | Comments |
|---|---|---|---|---|
| Coconut | Local Tall | 10.12 × 10.12 | 98 | Planted in the early 1930s<br>Maintained<br>Palms bearing at lower yield levels<br>Some palms destroyed by strong winds and other natural causes<br>Copra made and revenue generated |
| Vanilla | *Vanilla fragrano*<br>*V. tahitiensis* | 2.25 × 2 | 2000 | Planted in November 1997<br>*V. tahitiensis* flowering and fruiting<br>Cuttings sold and bean harvest to start in 2000<br>*V. fragrano* yet to flower |

**Table 2.** Summary of plants and area planted for various system combinations.

| System combination and crops planted | Density (plants per hectare) | Area planted | Comments |
|---|---|---|---|
| Coconut, banana and pineapple intercropping | | 1.5 hectares | Block well established<br>Maintained and revenue generated for the last two years |
| Coconut | 98 | | Planted in 1930s<br>Copra made and revenue generated |
| Banana | 625 | | Planted in December 1997<br>After the second year, ratoon crop still good for Cavendish |
| Pineapple | 1250 | | Planted in December 1997<br>Initial crop average<br>Very little ratoon crop |
| Coconut and pineapple intercropping | | 1.8 hectares | Planted in December 1997<br>Block well established<br>Two good seasons<br>Block maintained and revenue generated |
| Coconut | 98 | | Copra harvested |
| Pineapple | 1667 | | Original density was doubled in second year<br>Fruit sales continue |

### Coconut, cocoa, mangosteen, banana and kava intercropping

New coconut seedlings, planted at 16 × 7 metres, were interplanted with mangosteen, cocoa and kava (Table 3). Harvest and sales continue for banana and copra. Sales of kava cuttings have started.

Both banana and kava will be used as short-term perennials and will be terminated after four years; leaving coconut, mangosteen and cocoa. Banana is used here for shading as well as for fruits.

## Discussion

Cost and return on investment varied with both the cropping system type and timing. This is expected, as requirements and returns are different for each product. Of the systems tested, coconut intercropped with vanilla is currently costly (Table 4). Under this system, costs currently outweigh earnings by about 1990 PGK per hectare. This does not necessarily mean that the cropping system is not viable. The system is dynamic and may change with time (Akus in press). The high cost per hectare is mainly due to the high establishment cost of vanilla; furthermore, the present income is from copra alone. Vanilla products will go on sale shortly, and this is likely to continue for the next 10 years. The fluctuating nature of copra and vanilla prices are other important factors to consider, and there is every chance that the cost–benefit situation will change as the intercropping combination matures.

The coconut, banana and pineapple intercropping system is currently resource-use efficient. Similar findings have been reported by Gallasch (1976), from trial work at the Lowlands Agricultural Experiment Station, Keravat. The system is producing a net income of about 1575 PGK per hectare. Similarly, coconut and pineapple intercropping is making a profit of about 1300 PGK per hectare. The money generated has repaid the cost of establishment and production. The two systems produce food and generate a cash income, and can be considered as economically viable, but it is unclear whether they are sustainable. These trials need to continue in order to assess sustainability for both intercropping systems.

The coconut, cocoa, mangosteen, banana and kava underplanted in an old coconut stand are interesting. The period until the first harvest bears food, or income generation spreads from planting time (old coconuts providing income) to six years (mangosteen). The combined productive life of this system is about 100 years. At present, kava and banana propagation material is generating cash income, while banana fruit simultaneously provides food and cash production.

**Table 3.** Details of coconut, cocoa, mangosteen, kava and banana intercropping.

| Plant species | Variety | Spacing (metres) | Plants per hectare | Comments |
|---|---|---|---|---|
| Old coconut | Local<br>Tall | 10.12 × 10.12 | 98 | Planted in 1930s, still producing<br>Copra made and sold for revenue generation |
| New coconut | MRD × RIT hybrid | 16×7 | 89 | Planted in November 1998 and maintained<br>Palms growing well |
| Mangosteen | Open-pollinated | 16×7 | 89 | Planted in November 1998 and maintained<br>Slow to establish but growing well |
| Cocoa | SG2<br>Small | 4×3.5 | 715 | Planted in November 1998<br>Replanting done<br>Maintained<br>Cocoa flowering and podding |
| Kava | Iwi | 2×2 | 2500 | Some planting in November 1998<br>Planting to continue as material become available |
| Banana | Tall Cavendish | 4×2 | 1250 | Planted in November 1998<br>Maintained<br>Produce sold and data used in cost–benefit analysis |

Table 4. Costs and earnings (in PGK[a]) of the different system combinations tested between 1997 and 1999.[b]

| Crop combination | Cost per hectare | Income per hectare | Balance |
|---|---|---|---|
| Coconut and vanilla | 4156.1 | 2165.2 | –1990.9 |
| Coconut, banana and pineapple | 1517.5 | 3090.6 | +1573.1 |
| Coconut and pineapple | 1541.8 | 2842.3 | +1300.5 |
| Coconut, cocoa, mangosteen, kava and banana | 2786.7 | 2831.6 | +44.9 |

[a]In 1997, 1 PNG kina (PGK) = approx. US$0.70 (A$0.95); in 1999, 1 PGK = approx. US$0.38 (A$0.58).
[b]Coconut, cocoa, mangosteen, banana and kava intercropping is calculated for 1998 and 1999.

Money is made from the copra from the old palms. The nuts could alternatively be used for food. Cocoa, mangosteen and newly planted coconut palms have yet to produce either food or money.

Within each intercropping system, the species used influenced the viability of the system (Table 5). The systems involving food crops are early producers of food as well as cash. The fact that coconut has already been established (in the case of food crops underplanted in mature coconut stands) is in itself useful. It is a source of food, cash and shade for the other intercrop species. Spice crops took longer to become useful. This is the case with coconut and vanilla intercropping. When vanilla products are sold, the cost and return margin will narrow to some kind of an equilibrium and, hopefully, make a profit. The long-term crop species are still in the establishment phase and will not be producing food and cash for some time yet. This is the case with mangosteen and young coconut, and is probably true for any system involving perennial tree crops.

A number of general observations have been made about the intercropping systems being tested. Each system produces food that could be consumed immediately and each is producing, and will produce, products that may be sold for cash at some stage. All systems could produce food for immediate consumption whilst simultaneously a source of cash income. Perhaps the most important point to stress is that these coconut-farming system approaches diversify opportunities and sources for food production and cash generation.

**Table 5.** Sources of revenue generation (per hectare) with each intercropping combination, 1997–99.

| | Source of income (PGK[a]) | | | | | Total |
|---|---|---|---|---|---|---|
| Coconut and vanilla[b] | Vanilla cuttings | Vanilla beans | Coconut | | | |
| Income | 6.4 | 0 | 2158.8 | | | 2165.2 |
| Coconut, cocoa, banana, mangosteen and kava[c] | Banana | Cocoa | Coconut | Mangosteen | Kava | |
| Income | 1253.3 | 0 | 1031.2 | 0 | 547.1 | 2831.6 |
| Coconut, banana and pineapple[c] | Banana | Pineapple | Coconut | | | |
| Income | 1704.3 | 231.4 | 1154.9 | | | 3090.6 |
| Coconut and pineapple | | Pineapple | Coconut | | | |
| Income | | 1551.6 | 1290.7 | | | 2842.3 |

[a]See Table 4 for conversion rates of the PNG kina (PGK) over this period.
[b]A three-year period
[c]A two-year period

These investigations are commercially oriented and aim to identify systems that will diversify and maximise farm income. Our off-farm socioeconomic investigations show that traditional farming supplies sufficient food for subsistence consumption but that changes in dietary habits (consumption of rice, tinned fish, etc.) put pressure on the farmer to enter into the cash economy. More than half of this income is spent on household maintenance (food, clothing, etc.), with much of the money originating from coconut and other cash crops. This trend will continue.

Furthermore, natural disasters such as the effects of El Niño of 1997–98 put enormous pressure on the production systems to support continued healthy living. One crop species that tolerated the drought of 1997 and its effects better than others is the coconut. Because of its diverse usefulness (as both a food and as a source of income to purchase food), it alleviated some of the food problems of the coastal region. Investigations here indicate that systems involving coconut are quite viable, but further work is required to establish their level of sustainability. Thus, we believe that research involving this crop with respect to continued food production is the way forward.

# Conclusions

A number of concluding remarks can be made.

- General trends of economic viability and sustainability are appearing in these trials, and are becoming more distinct with time for coconut-based farming systems and for each intercropping combination.
- There is much scope for research with respect to food production and security using the coconut-farming systems approach.
- The coconut-farming systems approach simultaneously diversifies opportunities for food production and cash production. Preliminary results of the tested systems involving coconut show that 50% are economically viable and that the others appear to be following this trend. Much-needed cash can be generated from coconut products and from the other products originating from these farming systems.

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# Avocado in the Highlands of PNG: 'The Silent Provider'

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*Abstract*

In PNG, avocado growing has developed from seed introductions over the past century. It was not significantly established in the highlands until the 1950s, and the past 30 years has seen an accelerated pace of spread and adoption into the most remote villages. Avocado is not a staple crop but is now a substantial dietary supplement with high energy content. It is particularly valuable to babies, children and older people in highland villages. In many cases it is also used to supplement the diet of pigs, dogs and poultry. There is some understanding of seasonal production periods for certain areas and altitudes in the highlands but the genotype-by-environment (G × E) factors overall are not well-defined and require clarification for use in future development.

The avocado gene pool appears to have changed, improving fruit quality over the past 40 years, probably due to grower selection. The development of avocado in the highlands has been unheralded and has largely developed from villager initiatives. Interventions could solve pest problems, improve adaptability within the gene pool and lengthen the season of harvest, particularly at high elevations.

AVOCADO (*Persea americana*) is a common fruit grown throughout PNG. It is productive from sea level to 2100 metres above sea level (asl), and to a lesser extent up to 2430 metres asl (R.M. Bourke, Research School of Pacific and Asian Studies, The Australian National University, pers. comm.), but not in areas with continually waterlogged soils or where there is seasonal flooding. The 'silent provider' subtitle of this paper highlights that village avocado production is much more important in the highlands of PNG than is generally realised.

The majority of Papua New Guineans consume avocado to some extent, but the intensity of production for human and livestock use is much higher in the highlands than in other areas. Limited surveys in Eastern Highlands Province suggest that for the highlands overall there are on average 2.1 trees per household, with around 80 fruit per tree, with an average weight of 300 grams, giving 50 kilograms per household per year. If there are some 320,000 farming families in the highlands then annual production could be of the order of 16,000 tonnes per year.

Avocado (*bata* in *Tok Pisin*) is important in the highlands in villager diets and is also fed to pigs, dogs, and poultry. The characteristics of moderate-to-high polyunsaturated oil (fat) content, easy digestibility and useful amounts of protein and vitamins are unusual for any fruit. Avocado has a very high energy value and is particularly valuable for infants, young children and the aged. Table 1 shows the composition and nutritional value for avocados in comparison to sweet potato. The energy value of avocado is reduced for

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ruminant animals because of lesser oil digestibility capacity (I. Grant, Wet Lowlands Mainland Programme, Bubia, pers comm.) Recommended dietary allowances for children are shown in Table 2.

The world avocado gene pool is derived from three groups or races—West Indian, Mexican and Guatemalan. West Indian strains are common in the lowlands and are often watery in texture, with oil content in the range 3–10%. Mexican strains are the most resistant to cold and have the highest oil content (15–30%), while Guatemalan strains have intermediate oil content (10–20%).

The PNG highlands avocado gene pool at present consists mainly of Guatemalan and Guatemalan–Mexican hybrids, possibly with some West Indian influence. Guatemalan characteristics are most evident in the general highlands gene pool, suggesting that in the relatively short life of the crop in the highlands there has been active villager selection for higher oil characteristics. These are known as *swit* and *strongpela*, meaning high oil content and dry, nutty flavour. However, avocado races cross readily and the seeds produced are highly heterozygous, even without cross-pollination, giving rise to substantial variability

**Table 1.** Food composition and nutritional values for avocado and comparison with sweet potato.

| Per 100 grams (g) of product | Sweet potato[a] | Avocado[a] | Avocado[b] | Avocado[c] | Avocado[d] |
|---|---|---|---|---|---|
| Dry matter (%) | 30 | 25 | 14–35 | 17–41 | 21 |
| Energy (kilojoules) | 477 | 690 | 600–800 | 856 | |
| Protein (g) | 1.5 | 1.5 | 1–4 | 1.1–4.4 | 1.1 |
| Fat (g) | 0.3 | 15.0 | 5.8–23.0 | 9.8–31.6 | |
| Carbohydrate (g) | 26 | 6 | 3.4–5.7 | | |
| Fibre (g) | 1.0 | 1.5 | | 3.3 | |
| Calcium (milligrams (mg)) | 25 | 10 | | 10 | 12 |
| Iron (mg) | 1.0 | 1.0 | 0.8–1.09 | 0.6 | 0.7 |
| Vitamin A (IU) | 100 | 200 | 75–135 | | |
| Vitamin B complex (mg) | | | 1.5–3.2 | 8.0 | |
| Thiamine (mg) | 0.10 | 0.07 | | | |
| Riboflavin (mg) | 0.04 | 0.15 | | | |
| Niacin (mg) | 0.70 | 1.00 | | | |
| Vitamin C (mg) | 30 | 15 | | | |
| Flesh recovery (%) | 85 | 70 | 65–75 | 75 | |

IU = international units
Sources: [a]Platt (1962); [b]Purseglove (1977); [c]Soouci et al. (1990); [d]French (1986)

**Table 2.** Recommended dietary allowances per day for children under 12 years.

| Category | Energy (kilojoules) | Protein (grams) |
|---|---|---|
| Age 1 year, 8.2 kilograms (kg) | 3635 | 35 |
| Age 2–3 years, 11.2 kg | 4277 | 40 |
| Age 4–6 years, 15.5 kg | 5560 | 50 |
| Age 7–9 years, 20.0 kg | 7057 | 60 |
| Age 10–12 years, 20.9 kg | 8554 | 70 |

Source: based on Heywood and Morris-Hughes (1992) of seedlings. All highland village trees are seedlings and there is no clonal development. Thus, the scenario is very different from countries such as Australia, South Africa, the United States and Israel, where production is based on clones, giving consistent quality.

The West Indian avocado race performs well at the high temperatures found in the lowlands of PNG. However, the fruit produced by Mexican and Guatemalan races is substantially reduced in the tropical lowlands, because of high rates of respiration in leaves and fruit at elevated temperatures that prevent effective accumulation of the products of photosynthesis. Also, flowering of Guatemalan and Mexican types is insubstantial and irregular in the tropical lowlands because of temperature effects. In northern Australia (Cairns to Atherton Tableland, latitude 16°S) there is a progressive reduction in fruit size for the cultivar Hass (Guatemalan) from 1000 metres asl to sea level and the crop is not economic below 350 metres asl.

## History of the Avocado in the Highlands

The first avocados grown in PNG were probably introduced by the German colonial administration in the late 1800s and early 1900s (Rogers 1992), although connections with the Dutch administration in Papua (Irian Jaya) may have had some influence.

Most trees were initially grown in the Rabaul area and were probably West Indian types. Over 30,000 seeds were distributed from Keravat to the highlands before 1968 (Rogers 1992). Assuming that these were predominantly West Indian types, it is not clear why Guatemalan types are now in the majority.

Missionaries, particularly Seventh Day Adventists, may have introduced substantial quantities of seeds into the highlands from Australia from the 1950s (F. Robinson, formerly Australian Contribution to the (PNG) National Agricultural Research System Project advisor, Aiyura, pers. comm.). These would have been predominantly Guatemalan and Guatemalan–Mexican hybrids, introduced into the western part of the Eastern Highlands and Simbu provinces. Villagers at Maropa and Onamuna (who we surveyed in May 2000) recall that the first seeds were obtained from trees in Goroka in 1963. Robinson suggests that substantial planting did not occur in Enga and the Southern Highlands provinces until the early 1970s, whereas by 1980 villagers in the Waghi area were already feeding excess fruit to their pigs. There were no avocados at Porgera in 1985 but there are now substantial numbers. Avocado trees were widespread in Simbu Province, and avocados were commonly eaten by villagers, especially in the Kerowagi area, by the late 1970s (R.M. Bourke, pers. comm.).

All economic trees in Asiranka village in the Aiyura basin of Eastern Highlands Province and Upa village on the Nembi plateau of Southern Highlands Province were surveyed by Bourke in 1984. Asiranka had a mean of five avocado trees per household (one-third fruit-bearing) whilst Upa had a mean of one tree per household and none bearing. Current Mapping Agricultural Systems of PNG (MASP) data are incomplete for avocado distribution because the crop was not included in early surveys but has been included in some more recent surveys (R.M. Bourke, pers. comm.).

## Recent Avocado Surveys

The authors conducted surveys of three villages in Eastern Highlands Province in May 2000. The villages were Susupa–Oiyana (2100 metres asl), Maropa (1580 metres asl) and Onamuna (1540 metres asl). The surveys were conducted in three parts:

- house gardens and numbers and status of avocado trees;
- interviews with village men regarding avocado culture; and
- interviews with village women regarding avocado use.

### House gardens

Additional data for house gardens were incorporated from other Eastern Highlands Province surveys conducted by The Salvation Army in mid-1999. Avocados are generally planted within 100 metres of houses. In Table 3, the number of avocado trees of all ages are shown, with average number per house, whether or not there was a house garden. On average, 75% of all houses had gardens with avocados.

### Avocado culture

Earliest plantings dated from 1963 for Maropa and Onamuna, and 1970 for Susupa–Oiyana. Trees at Susupa in the 0–5-years-old group died in the 1997 frosts but older trees recovered from damage. Some original trees are still present.

Regarding planting and seeding, there is both intentional planting from selected seeds and random development of discarded seeds. Pigs and dogs will uproot and eat new seeds and seedlings.

**Table 3.** Mean number of avocado trees per household in selected Eastern Highland Province villages.

| Village | Trees (mean number) | Village | Trees (mean number) |
|---|---|---|---|
| Susupa–Oiyana | 1.9 | Misapi | 2.3 |
| Maropa | 2.3 | Kamila | 3.0 |
| Onamuna | 1.8 | Ofafina | 2.0 |
| Onamuga | 2.5 | Kokopi | 3.2 |
| Norikori | 0.3 | Mean | 2.1 |

Source: unpublished data of B.Watson et al., Australian Contribution to the (PNG) National Agricultural Research System Project (2000) and M. Muntwiler, The Salvation Army (1999)

Villagers surveyed said they now had near-sufficient production but would continue to plant selected material to upgrade quality. Self-sown seeds are generally allowed to grow but are cut out at first fruiting if the quality is poor. Quality aspects selected for are mainly *swit* and *strongpela*.

With regard to seasonality, flowering in Susupa–Oiyana is mainly in May–June and harvest in December–April, with a peak in March–April. In Maropa, there is reputedly some flowering in every month on different trees or different parts of the same tree; harvest is fairly constant but with a February–March peak. On 25 May 2000, fruit at all stages of development was apparent. Some flowering and harvest occurs throughout the year at Onamuna but harvest is mainly in December–April.

When asked about fruit maturity, survey respondents generally said they could judge maturity from change in skin colour. Others said they waited until a few fruit fell and then started picking the largest fruit. Of 20 different fruit samples obtained from Onamuna and Maropa on 25 May, 17 softened without shrivelling within 7 days, indicating that villagers had a good understanding of fruit maturity.

Only Onamuna villagers said they did not market and that surplus avocados went to livestock. In Susupa–Oiyana and Maropa, villagers marketed in Kainantu and at the Summer Institute of Linguistics–Ukarumpa. Both Maropa and Onamuna are Seventh Day Adventist villages, and excess or rotten fruit is fed to dogs and chickens. Susupa villagers mainly feed excess avocados to pigs.

Villagers generally reported few pest and disease problems, and none of real significance. A hard galling in the outer flesh of some fruit may be caused by the spotting bug (*Ambypelta lutescens*) or fruit fly (*Bactrocera frauenfeldi*). There was also some incidence of stem borers and premature fruit fall but no evidence of pink wax scale (caused by *Ceroplastes rubens*) or root rot. There was some premature fruit rot after harvest but this was not significant and the affected fruit went to livestock.

## Avocado use

In each of the three villages, four women were interviewed individually. The majority said that family members ate some avocado at least twice a day when available. Respondents were asked if they preferred watery (low oil), medium or dry–oily (*strongpela*) fruit. The majority (11) said adults prefer the dry–oily ones. Six said their children preferred dry–oily (one said her children threw away the watery ones). Three said their children ate any type and one said that watery ones gave her children diarrhoea. One said that her children might each eat up to five fruit in a day.

All respondents said that they eat fruit uncooked and usually together with sweet potato or rice. They generally said that children liked avocado because it was soft and 'sweet'. Most said that the old people liked it because it was good for them and two said it was good for people who had lost their teeth. Seven women said they fed avocado to babies at 3–4 months, two at 2–4 months and two at 6–8 months. One said she fed it to babies at 1 year and some months.

## Fruit analysis

The authors sampled 16 fruit from different trees from Maropa and Onamuna villages in May 2000. Flesh recovery ranged from 64.7–79.2% (mean 72.6%). Results of a further sampling in June 2000 from 12 trees at Maropa village alone are shown in Table 4. Oil is calculated as 67% of flesh dry matter.

The above figures are compared with data cited by Rogers (1992). Samples from Keravat in 1967–68 contained13–25% dry matter and 9.4–19.0% oil. Samples from Goroka in the same period contained 26–29% dry matter and 17.2–19.2% oil (no means were provided). This suggests Guatemalan or Guatemalan–Mexican characteristics in the Eastern Highlands Province and the possible influence of grower selection. For seedlings, flesh recovery and oil content of Maropa fruits are generally good.

**Table 4.** Avocado fruit characteristics from 12 trees in Maropa village.

| | % Flesh recovery | % Dry matter | % Oil |
|---|---|---|---|
| 1 | 86.4 | 26.6 | 17.8 |
| 2 | 81.4 | 25.0 | 16.6 |
| 3 | 80.5 | 28.5 | 19.0 |
| 4 | 79.3 | 24.4 | 16.3 |
| 5 | 78.9 | 26.0 | 17.3 |
| 6 | 77.2 | 23.9 | 15.9 |
| 7 | 76.3 | 24.8 | 16.5 |
| 8 | 75.5 | 22.4 | 14.9 |
| 9 | 75.3 | 25.7 | 17.1 |
| 10 | 72.3 | 24.1 | 16.1 |
| 11 | 70.8 | 34.9 | 23.2 |
| 12 | 70.6 | 35.5 | 23.6 |
| Mean | 77.0 | 26.9 | 17.8 |

### Participatory rural appraisal survey implications

A participatory rural appraisal survey conducted at Maropa village in April 2000 found no issues raised specifically for avocados (B. Humphrey, National Agricultural Research Institute, pers. comm.). It appears that avocado has found a place in the villagers' farming systems with no evident problems. The author asked an elder in Onamuna village: 'How would the people feel if tomorrow all the trees did die from a mysterious disease?' The elder replied, 'The people would be extremely unhappy because the avocado is now very important to them'.

## Seasonality

Surveys of markets are available, particularly for the period 1979–82 (Bourke et al., in press). These indicate the monthly presence or absence, volume of sales and total value of avocado available in selected markets in the highlands and major centres. The fluctuating price, which could give an additional insight of seasonality if avocado prices are elastic, is not well established, and there are little data on production patterns as measured in village trees. If villagers only sell surpluses, then the production pattern at times when there are no surpluses may not be clear. There is also no clear indication of specific altitude effects on cropping because a major market in the highlands may draw on production from areas with up to 600 metres difference in altitude. The situation in Maropa village, where the production season appears to be much more protracted than in other villages at both higher and lower altitudes, needs to be explored. There is no doubt that minor altitudinal differences can produce major differences in production patterns in a number of other crops. The 4–6 week difference between coffee flowering and harvesting at Mt Hagen–Banz (1700 metres asl), Aiyura (1600 metres asl) and Yonki (1300 metres asl) illustrates altitudinal anomalies and possibly microclimates: harvest is earlier at Yonki and Mt Hagen than at Aiyura.

The major avocado seasonal periods in PNG are generally well established. Studies cited by Bourke et al. (in press) indicate that the main production in the highlands and in Enga Province is from February to May. The main seasons in the lowlands (Keravat), were described in one study as November–May and August–November, and in another study as January–March, with lesser production in May–August and November–December (there are multiple flowerings each year). Seasonality may also vary from year to year with variation in climatic conditions, as suggested by Bourke et al. (in press) regarding year-to-year variation in total value of fruit on display each month at Aiyura, Ukurumpa, Kainantu Basin and Goroka markets from June 1979 to September 1982.

Overall seasonality of avocado production in PNG has not been well researched. However, if market volume reflects the production trend, then Figure 1 may be relevant. The figure summarises total purchases by the Food Marketing Corporation from buying centres in Port Moresby, Wau, Goroka, Lae, Kainantu and Mt Hagen from December 1979 to July 1981. The pattern for Goroka alone in the same period has an identical trend.

## Marketing

Due to quarantine and quality problems, and an already well-supplied world market with very competitive prices, export of avocados from PNG is not considered viable. Thus, this paper focuses on the domestic scene. The sophisticated PNG market for avocado (expatriates and more affluent nationals) is not well catered for, due to the lack of a clonal industry, the unpredictability of individual fruit quality and the variable quality of lowlands-produced fruit close to major markets. Transport reliability and

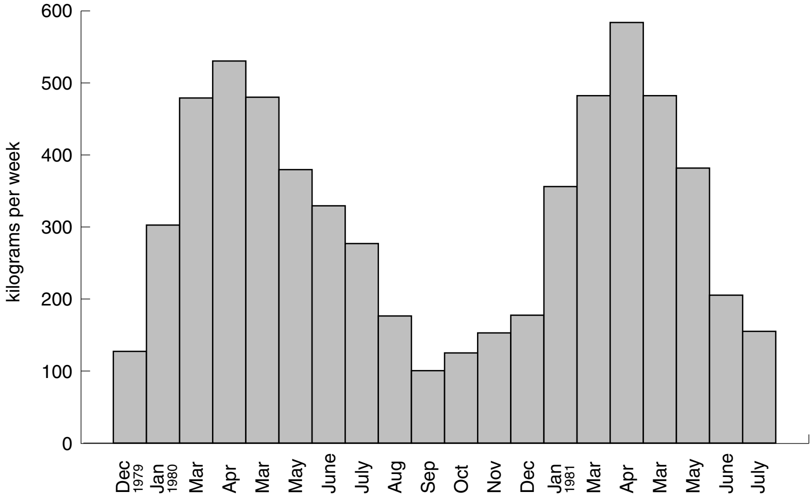


**Figure 1.** Monthly purchases (kilograms/week) of avocado by the Food Marketing Corporation, PNG, December 1979–July 1981 (Bourke et al. in press).

costs probably preclude the establishment of clonal orchards in the highlands, at least in the short term.

The above concerns do not detract from the value of the crop to the wellbeing of highland villagers, which is principally from home consumption and to a lesser extent from cash-crop marketing. The Salvation Army surveys in Eastern Highlands Province home gardens in 1999 show that producers furthest from major markets (Misapi and Kamila) were most likely to market fruit. Whether there is substantial demand for avocado in remote villages has yet to be established.

The main problems associated with local marketing and supply to coastal centres is the maturity of the fruit as apparent to purchasers. Fruits are often too soft and bruised, or too hard (suggestive of immaturity). There are also nonvisible factors such as seed size (relative to flesh recovery), internal disorders and unknown oil content. Obviously, avocados in hard, mature condition present well in markets under average road transport and packaging conditions in the highlands but they may meet buyer resistance.

## Plant Improvement

In addition to seed introductions over the last century, there have been some attempts at clonal introduction and screening of popular international cultivars into PNG. The Department of Primary Industry (DPI) introduced 14 virus-indexed clones from Australia in 1981. Ten survived quarantine (including the varieties Fuerte and Sharwil) and were planted at Laloki (Rogers 1992), where few, if any, survived. At least one subsequent introduction was made and trees were reputedly planted at Kuk, Wapanamunda, Aiyura and Keravat. These included Rincon, Ryan, Hazzard, Nabal and Carlon. The only trees surviving today appear to be Fuerte, Hass and possibly Edranol at the DPI's Wapanamunda station in Enga Province. These trees are currently in poor condition as a result of pink wax scale and inadequate soil drainage. Naki (1990) reported some propagation activity from the Wapanamunda nursery.

Additional work has been carried out on PNG local selections at Keravat and the PNG University of Technology, Lae. However, no clonal industry has been developed from the introductions or from local selections.

## Pests and Diseases

The main avocado pest of significance for production in the highlands is pink wax scale and associated sooty mould. These debilitate the trees and reduce productivity. Pink wax scale is particularly prevalent in the west of Eastern Highlands, Simbu and Western Highlands provinces. The shot-hole weevil (oribius weevil), *Oribius destructor*, causes significant leaf damage but this is not significant for overall productivity. The fruit spotting bug and fruit fly cause some damage to fruit quality (S. Sar, Wet Lowlands Mainland Programme, Bubia, pers comm.).

The main diseases are root rot and stem canker caused by *Phytophthora cinnamomi* and pink disease *Phanerochaete salmonicolor* (Philemon and Muthappa 1990; Kokoa 1991). *Phytophthora* root rot is fairly common in areas with poorly drained soils, and susceptibility to the disease increases as trees mature, so wet areas should not be planted. Seedling trees are much less susceptible than grafted trees.

## The Future and Possible Beneficial Interventions

In the space of some 50 years, the avocado 'industry' in the highlands has developed to provide substantial benefits for even the most remote villages. This has occurred through grower initiatives without any institutional interventions, apart from the original introduction and limited distribution of seed. There is evidence of grower selection, and fruit quality is expected to continue to improve because of this. The avocado is particularly important for villagers above 1800 metres asl, where banana production is very limited and other staples have a long gestation period. However, there are concerns for avocado production in those areas because of the relatively short harvest season and the risk of frost, particularly for juvenile trees.

The avocado is not a staple crop in PNG but is an important variation in the diet and is a high energy producer. Some possible interventions could improve the harvest. The cost would be not insubstantial but the benefits could be very rewarding. Possible beneficial interventions include the following.

- Introduction of the wasp parasitoid *Anicetus benificus* to eradicate pink wax scale. Pink wax is a serious problem with citrus and mango, also with ornamental and forestry species. Wasps have eliminated pink wax scale in northern Australia, with enormous benefits to growers.
- Introduction of an avocado gene pool appropriate for the needs of the villagers in particular but also for commercial clonal orchards in the long term. Appropriate Guatemalan and Guatemalan–Mexican hybrids could be brought in and used to supply seed to villages. Alternatively, villages could be supplied with nuclear quantities of grafted trees to assess and use as a source of seed. Cultivars with good quality, high oil content, significant protein, thick skins (better market-handling capacity), cold resistance and a long harvest season (collectively) would be of particular use. This range could include Bacon, Jim and Pinkerton. Others with potential for use in the main highlands, in addition to the existing Hass and Fuerte, are Edranol, Nabal, Reed, Sharwil, Gwen and Ettinger. Almost all of the above cultivars are unsuitable for lowlands production, and the past mistakes of planting such introductions in locations below 800 metres asl should be avoided.

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# Influence of Management Practices in Rainfed Rice Ecosystems on the Incidence of Rice Brown Planthopper (*Nilaparvata lugens*) in PNG

**K.S. Powell,* A. Saleu,† S. Poloma† and J. Engenae‡**

*Abstract*

Studies were conducted to quantify the population dynamics of rice brown planthopper (BPH) *Nilaparvata lugens* Stål (Homoptera: Delphacidae) and its natural predators—mirid bugs *Cyrtorhinus lividipennis* Reut. and *C. chinensis* Stål (Hemiptera: Miridae) and predatory spiders (Aranae)—under naturally infested rainfed conditions in Morobe Province, PNG. Populations of BPH and natural predators were monitored on 21 varieties of upland and irrigated rice, to quantify population dynamics and host-plant resistance levels in a series of field-based experiments during the 1997 and 1998 seasons. All but one of the experiments were maintained insecticide-free.

Host-plant resistance to BPH and insecticide application influenced population levels of BPH and natural predators. On moderate to highly resistant varieties, BPH and natural predator populations were relatively low in both insecticide-treated and insecticide-free situations. On susceptible varieties, both BPH and natural predator populations were relatively high in the absence of insecticide treatment. Populations of *Cyrtorhinus* spp. were reduced in insecticide-treated plots, allowing an insecticide-induced resurgence of BPH populations on susceptible varieties. The study showed the need for screening against BPH of both upland and irrigated rice varieties in PNG and for further investigations into the influence of natural predators on BPH population dynamics in a range of cropping systems. The effects of insecticide-induced BPH resurgence should also be investigated while the PNG government continues with its vision of reducing rice imports by developing large-scale rice production in the country.

RICE production is prominent in Southeast Asia. However, in the Pacific Islands, rice is grown on a relatively small scale compared with other crops, despite being a staple part of the diet of indigenous peoples. In 1999, Fiji was the largest producer of rice in the Pacific region (18,000 tonnes), whereas production in the Solomon Islands and PNG was 4500 and 600 tonnes, respectively (FAO 2000). Filipino missionaries in the Mekeo region of Central Province were the first to grow rice domestically in PNG, in 1891 (Bray and Romerosa 1983). Rice imports to PNG have increased dramatically over the past 100 years and successive administrations have commissioned a number of feasibility studies to investigate the potential for large-scale rice production to reduce the import bill. Four PNG provinces—Central, Morobe, East New Britain and Madang—have been ranked as having medium to high potential for small- to large-scale wetland rice production, either semi- or fully mechanised (Dearden and Freyne 1981; Angus et al. 1982; Bray and Romerosa 1983). Despite the potential

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for production, attempts to introduce rice into a number of provinces (Gulf, Highlands, East Sepik, Sandaun (West Sepik), Madang, Morobe, East New Britain, Central, New Ireland, Bougainville and Manus) have been largely unsuccessful. These attempts have included:

- government-subsidised schemes to encourage rice growing in Central, East Sepik and Sandaun provinces;
- five separate schemes introduced since 1921 in Bereina (Central Province) to encourage the development of semi-mechanised rainfed upland rice growing; and
- three schemes introduced since the 1960s in Maprik (East Sepik Province), in which growers relied totally on unmechanised production (Sloane 1993).

Rainfed rice production was at its peak in the Bereina region in 1971, when PNG reached 2.7% self-sufficiency, producing the equivalent of 1324 milled tonnes. Production has since rapidly declined to less than 0.3% self-sufficiency (Bray and Romerosa 1983). Attempts to integrate rice growing into indigenous PNG agriculture have largely failed due to sociological and economic factors including land tenure issues, continued cheap imports (primarily from Australia), varietal selection (based on agronomic performance rather than market-led criteria) and insect pests (Sloane 1993). Current rice production in PNG is confined to relatively small areas of rainfed lowland and upland production in East Sepik, Sandaun and Morobe province and semi-mechanised irrigated production in Central and East New Britain provinces. Rice is grown in these areas either as a monoculture or in a mixed cropping system.

One of the main pest constraints of rice in Asia and the Pacific region is the rice brown planthopper (BPH) *Nilaparvata lugens* Stål (Homoptera: Delphacidae). BPH causes damage directly through feeding (hopperburn) and indirectly by acting as a vector of grassy stunt and ragged stunt viruses. Severe yield losses in Fiji, PNG and the Solomon Islands have been attributed to BPH (Dyck and Thomas 1979). BPH was the most serious economic pest in the Guadalcanal region of the Solomon Islands in 1974, when rice production was at its peak, with losses of up to US$120,000 reported (MacQuillan 1974; Stapley 1975).

In the tropical lowland regions of PNG, with their high rainfall, BPH is potentially the most important pest threat to expanding rice production. Outbreaks of BPH in PNG have occurred on the New Guinea mainland and the islands of New Britain and New Ireland. Up to 100% loss through hopperburn has been recorded (Hale and Hale 1975). Recommendations for management of BPH at the subsistence level in PNG have not yet been established. Integrated pest management, using resistant varieties and natural biological control, is potentially an ideal method for controlling these insects in PNG, where farmers have limited access to capital for purchasing insecticides and application equipment. On resistant varieties, BPH cannot ingest and use phloem sap, so its ability to grow, develop and reproduce is reduced, resulting in low population levels and minimal economic damage.

The most important predators in rice ecosystems are spiders, such as the wolf spider *Lycosa pseudoannulata*, which can consume up to 15 hoppers per day (Shepard et al. 1987), and mirid bugs (*Cyrtorhinus* spp.) that feed preferentially on BPH eggs but can also feed on first instar nymphs (Ooi and Shepard 1994).

This paper presents BPH and natural predator population dynamics from field trials conducted under rainfed lowland conditions in Morobe Province, PNG. The relationship between BPH and natural predator densities in rice variety trials, with and without insecticide application, is discussed. This is the first published study to examine the relationship between host-plant resistance levels and population dynamics of a rice-pest–natural-enemy complex in PNG.

# Materials and Methods

## Site location

The research took place in the humid lowlands of Morobe Province. Experiments were conducted on the experimental rice demonstration farm of Trukai Industries, located at Bugandi High School in Lae (6°34'S, 147°02'E), from February 1997 – November 1998.

The altitude at the site was 33 metres above sea level and the soil type is described as a black clay (R. Clough, Trukai Industries, pers. comm. 1998). Rainfall records were available from 1987 and the monthly pattern is depicted in Figure 1. Total annual rainfall in 1997 was 2934 millimetres—well below the long-term average for the region. The low rainfall was attributed to the El Niño weather phenomenon, which severely affected the Pacific region in 1997–98. However, in the first seven months of 1998, nearly as much rain fell as in the whole of 1997.

## Experiment 1. Successive cropping trials

Fourteen rice varieties were screened in single demonstration plots over three overlapping seasons from

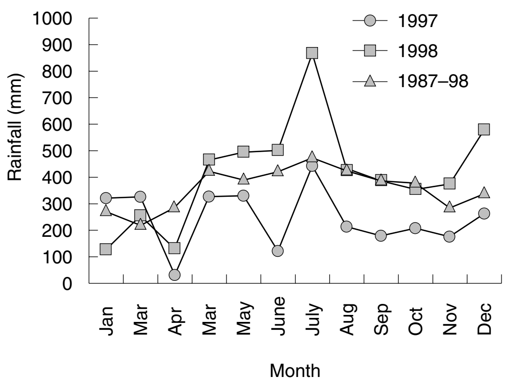



**Figure 1.** Monthly rainfall patterns at the experimental site during the 1997 and 1998 growing seasons compared with long-term average (1987–98).

February – August 1997 to select suitable varieties for inclusion in subsequent replicated trials (experiment 4). Control varieties were the locally grown varieties Finschhafen and Taichung Sen-10. Three weeks after sowing, rice seedlings were manually transplanted from the nursery into the field at a spacing of 0.25 metres between rows and 0.25 metres within rows for all trials (0.25 m × 0.25 m). Plot size was 1.75 m × 5 m and plots were arranged in two adjacent blocks of seven. Seedlings were planted on 21 February, 27 March and 4 May 1997, representing three overlapping seasons. Fertiliser, in the form of urea, was applied in split applications to all trials. The first application of 1.6 kilograms (kg) nitrogen per hectare was applied 30–32 days after sowing (DAS) whilst a second application was applied 49–55 DAS. Hand weeding was carried out once, at 32–39 DAS. Rice was hand harvested at 116–128 DAS and grain yield recorded. No insecticides were used, except in the third planting when carbaryl was applied once at 100 millilitres per 20 litres water in mid-July to control rice bug (*Leptocorisa* spp.). Carbaryl was applied when the crop had reached the milky stage, because rice bug populations had reached well over 150 bugs per square metre—the heaviest yet recorded in PNG (R. Clough, Trukai Industries, pers. comm. 1997). Insect and natural predator populations were only monitored for the second and third plantings. During the experimental period, monthly rainfall was unseasonally low in March and June, with July being the wettest month (Fig. 1).

## Experiment 2. Upland variety trial

Seven upland rice varieties were screened, including the control variety Niupela that is commonly used in PNG, in unreplicated plots over one season. Seeds were sown directly with a dibblestick on 20 January 1998. The crop was hand weeded at 28 DAS and harvested at 98 DAS on 28 April 1998. No insecticides were applied during the experimental period.

## Experiment 3. Irrigated variety trial

Seven irrigated rice varieties were screened in unreplicated plots over one season. Seeds were sown in a nursery on 23 January 1998 and transplanted at 32 DAS. Grain was hand harvested at 133 DAS. No insecticides were applied during the experimental period.

## Experiment 4. Replicated field trial

Trial seeds were sown on 5 August 1998 by dibblestick at 0.25 m apart with 0.25 m between rows. Six rice varieties were compared, based on selections from experiments 1–3, including three locally used control varieties (Niupela, Taichung Sen-10 and Finschhafen) and three BPH-resistant varieties from the International Rice Research Institute (IRRI) in the Philippines. A randomised block design with four replications was used with a plot size of 24 m × 6 m and between-plot pathways of 0.5 m. The trial was hand-weeded once and no fertiliser or pesticides were applied.

## Arthropod sampling techniques

Monitoring of BPH, *Cyrtorhinus* spp. and spiders was conducted weekly in all four trials using a mouth-operated suction sampler and random sampling of five tillers from 10 hills ($n = 50$) per plot. Field samples were stored in 70% ethanol and identified in the laboratory using a low-powered binocular microscope. The total density of adults and nymphs of *Cyrtorhinus* spp. per sample was calculated by combining *C. lividipennis* and *C. chinensis* data. Individual species of spiders were not identified but total spider density per sample was recorded.

## Statistical analysis

All plot means for insect and spider samples and grain yield from the replicated trial samples were subjected to analysis of variance.

# Results

## Experiment 1. Successive planting variety trials

*BPH susceptibility*

In the second and third plantings, the rice variety PSB12C-1 was consistently susceptible to high BPH populations, with more than 300 BPH per 50 tillers over a 5-week sampling period (Fig. 2). The incidence of BPH increased from the second to third seasons on varieties IR841-81-1-12, Finschhafen and Taichung Sen-10, which were all moderately susceptible to BPH. Four IRRI-sourced varieties (IR5314-14-43-2-3-3, IR74, IR65 and IR64) were moderately resistant over both seasons whilst six varieties (IR19661-23-3-2-2, IR25587-133-3-2-2-2, IR8608-75-31-1-3, BG379-2, IR17494-32-1-13-2 and RC20) consistently exhibited high resistance to BPH over both seasons.

*Natural predator levels*

Mirid bug levels were consistently higher on varieties with relatively high BPH populations and increased in the third planting when BPH populations also increased (Fig. 2). In contrast, mirid bug levels remained relatively low on those varieties highly resistant to BPH. Spider populations appeared to be relatively stable throughout the sampling periods on both BPH-resistant and BPH-susceptible rice varieties.

*Insecticide influence on BPH and natural predators*

Following the application of carbaryl in the third planting, a decline in both BPH and *Cyrtorhinus* spp. populations was initially observed but no noticeable decline in spider populations occurred. However, an insecticide-induced resurgence of BPH occurred after insecticide application on susceptible varieties, whilst mirid bug populations did not recover (Fig. 3).

*Grain yields*

On average, grain yields were reduced by 74% from the first to the second planting, and by a further 43% when comparing the second and third plantings (Fig. 4). Four varieties (IR17494-32-1-13-2, IR25587-133-3-2-2-2, IR19661-23-3-2-2 and BG379-2) maintained relatively high yields averaging over 4 tonnes per hectare (t/ha) over the three growth periods. All four varieties also showed high levels of resistance to BPH (Fig. 2). The variety IR5314-14-43-2-3-3 produced yields of over 2 t/ha over the first and second growth periods. The locally grown varieties (Finschhafen and Taichung Sen-10) and seven other varieties (IR8841-81-1-12, IR74, PSB-RC-1, RC20, IR8608-75-31-1-3, IR64 and IR65) yielded on average less than 2 t/ha over the second and third growth periods. In the third planting, the yield decline in some varieties was attributed to severe rice bug damage, with up to 99% unfilled grains (Table 1).

**Table 1.** Effect of *Leptocorisa* spp. on grain yields from rice variety trial (experiment 1: third planting).

| Rice variety | % Filled grains | Grain yield (kg/hectare) |
|---|---|---|
| IR64 | 1 | 255 |
| IR65 | 76 | 758 |
| IR74 | 46 | 1063 |
| IR841-81-1-12 | 15 | 780 |
| IR17494-32-1-13-2 | 49 | 1806 |
| IR5314-14-43-2-3-3 | 50 | 1290 |
| IR8608-75-31-1-3 | 1 | 67 |
| IR25587-133-3-2-2-2 | 38 | 1653 |
| IR19661-23-3-2-2 | 77 | 2627 |
| RC20 | 1 | 153 |
| PBS-RC-1 | 36 | 1109 |
| BG379-2 | 72 | 2814 |
| Taichung Sen-10 | 25 | 718 |
| Finschhafen | 82 | 550 |

## Experiment 2. Upland variety trials

*BPH susceptibility and natural predators*

Moderately severe BPH damage, which contributed to yield decline, was observed on varieties ER12 and ER13. These varieties had the highest levels of BPH (Fig. 5A) and correspondingly high levels of mirid bug incidence (Fig. 5B), whilst spider population levels remained stable on all varieties (data not presented).

*Grain yields*

Relatively low yields (less than 2 t/ha) were obtained for all varieties screened in this trial, with the exception of ER2, which yielded more than 5 t/ha (Table 2). The lowest yields were obtained for the ER3 variety, but this was attributed to Paraquat damage from a contaminated knapsack sprayer. All varieties, apart from ER2 and ER3, lodged badly and were susceptible to severe leaf folder damage, which also contributed to low yields. In general, the upland varieties screened in this trial were poorly adapted to conditions at Bugandi High School in Lae. Low rainfall in March may also have contributed to the poor yields of some varieties.

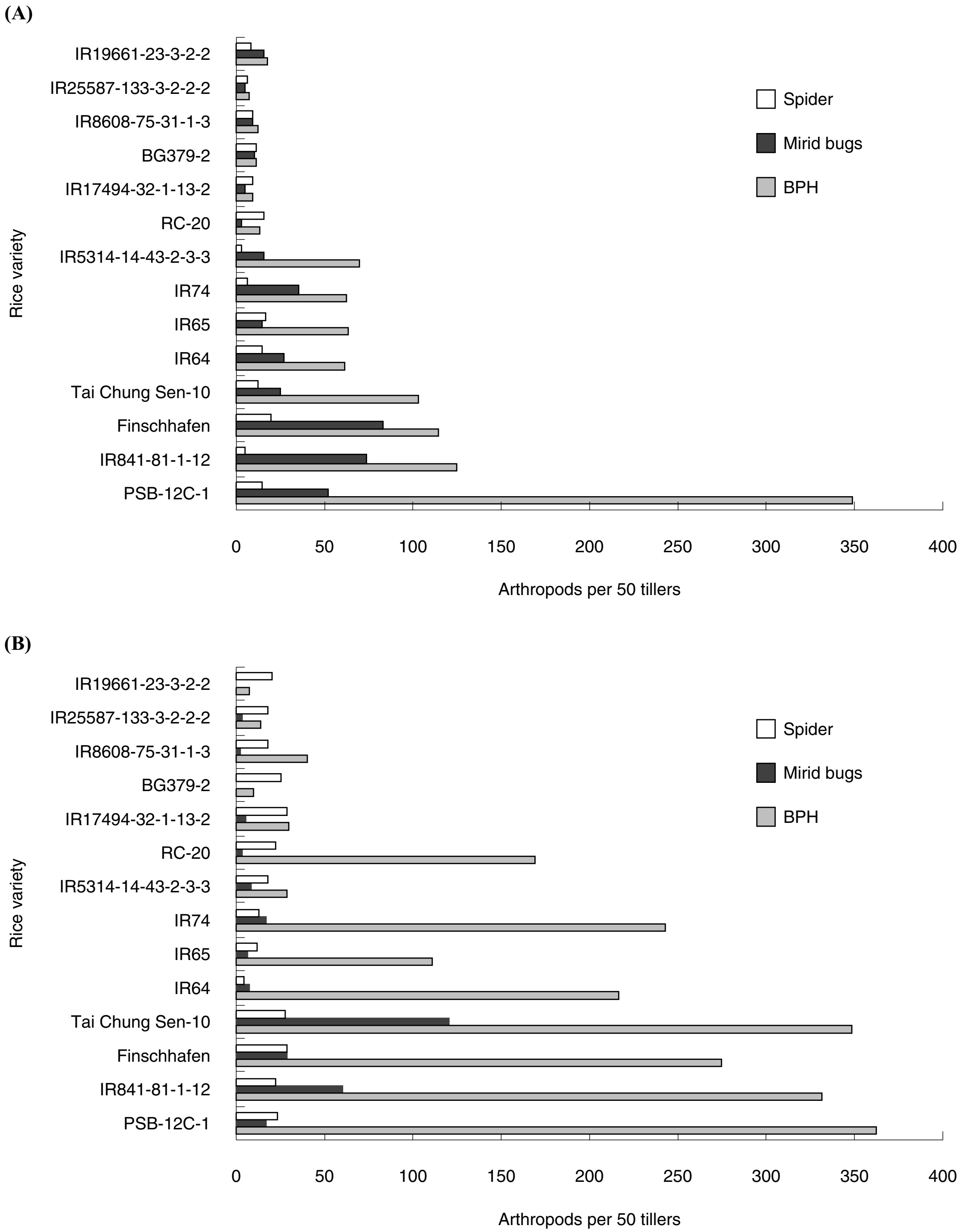



**Figure 2.** Rice brown planthopper (BPH) and its natural predator population levels, after five weeks sequential sampling on rice with varying degrees of host-plant resistance to BPH: (A) second planting; (B) third planting (experiment 1).

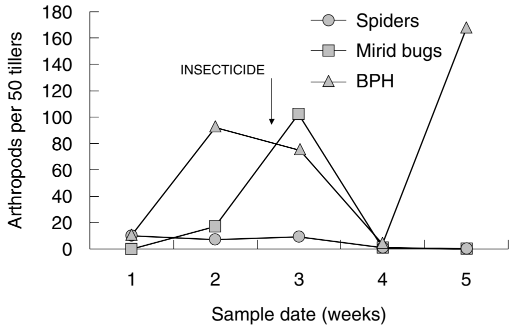



**Figure 3.** Effect of Carbaryl application on populations of brown planthopper (BPH) and its natural predators—mirid bugs and spiders (experiment 1: third planting).

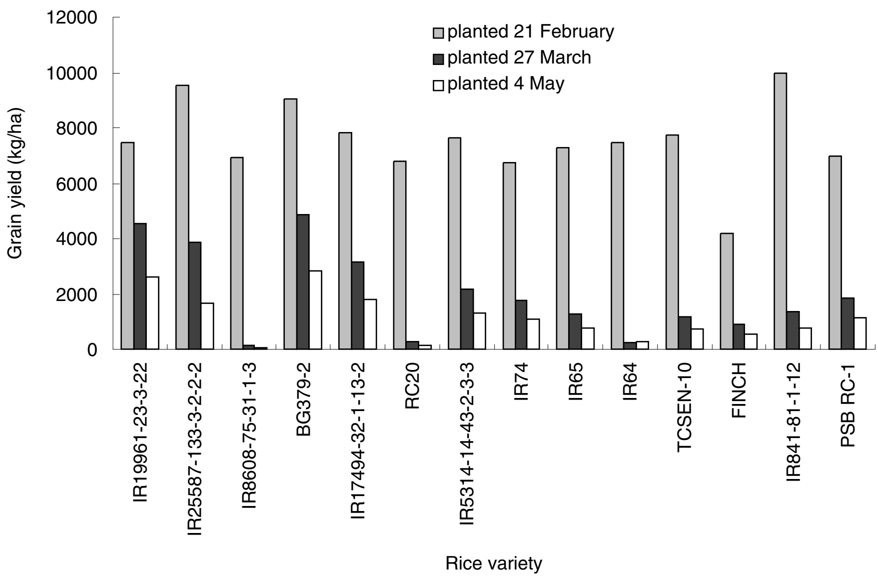
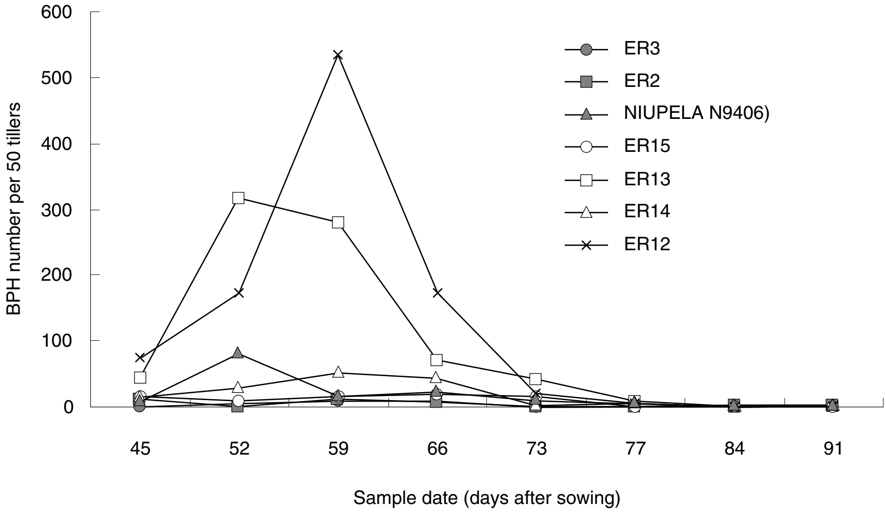



**Figure 4.** Grain yields of fourteen rice varieties grown over three overlapping periods (experiment 1).

(A)




(B)

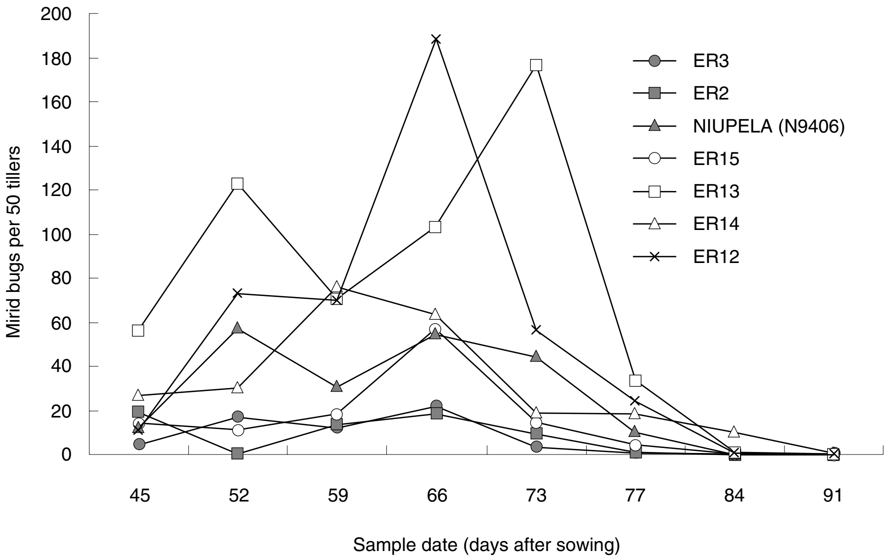



**Figure 5.** Population dynamics of (A) brown planthopper (BPH; *Nilaparvata lugens*) and (B) its natural predator mirid bugs (*Cyrtorhinus* spp.) on seven upland rice varieties (experiment 2).

**Table 2.** Grain yields from the upland rice variety trial (experiment 2).

| Rice variety | Grain yield (kg/hectare) |
|---|---|
| ER3 | 953 |
| ER2 | 5300 |
| Niupela (N9406) | 1395 |
| ER15 | 1053 |
| ER13 | 1184 |
| ER14 | 1316 |
| ER12 | 1974 |

**Table 3.** Grain yields from the irrigated rice variety trial (experiment 3).

| Rice variety | Grain yield (kg/hectare) |
|---|---|
| ER1 | 1209 |
| ER3 | 4146 |
| ER5 | 5760 |
| IR199661-23-3-2-2 | 2870 |
| IR8841-81-1-12 | 2190 |
| IR25587-133-2-2-2 | 2820 |
| BG379-2 | 2820 |

## Experiment 3. Irrigated variety trial

*BPH population levels*

Peaks in BPH population occurred twice over the sampling period (Fig. 6A). The first peak was observed at 57–64 DAS, with relatively high levels occurring on varieties ER3, IR199661-23-3-2-2 and IR8841-81-1-12. Other varieties were only able to support relatively low BPH levels of less than 20 insects per 50 tillers. The second peak in populations occurred at 120 DAS but only on variety IR8841-81-1-12, which appeared to be the variety most susceptible to BPH. The same variety also proved to be highly susceptible to BPH in experiment 1. BPH had little or no effect on yield of all varieties in the trial as BPH levels were relatively low throughout the trial period and visual symptoms of hopperburn were not observed.

*Natural predator population levels*

Spider populations maintained a relatively stable population throughout the trial on all varieties (data not presented). Peaks in mirid bug populations were observed at 57–64 DAS on most varieties (Fig. 6B). Further increases in density were observed at 78–85 DAS and 120–127 DAS on the IR8841-81-1-12 variety, corresponding with the population peaks of BPH. At 120 DAS, the mirid bug population could not suppress the BPH population sufficiently and resurgence occurred. However, these levels were recorded near to harvest and the presence of BPH at that time would have had minimal effect on grain yield.

*Grain yields*

The highest grain yields were produced by ER5 and ER3 varieties. The yields of ER1 and IR8841-81-1-1-12 were relatively low and the yields of the three remaining varieties were intermediate (Table 3).

## Experiment 4. Selected variety trial

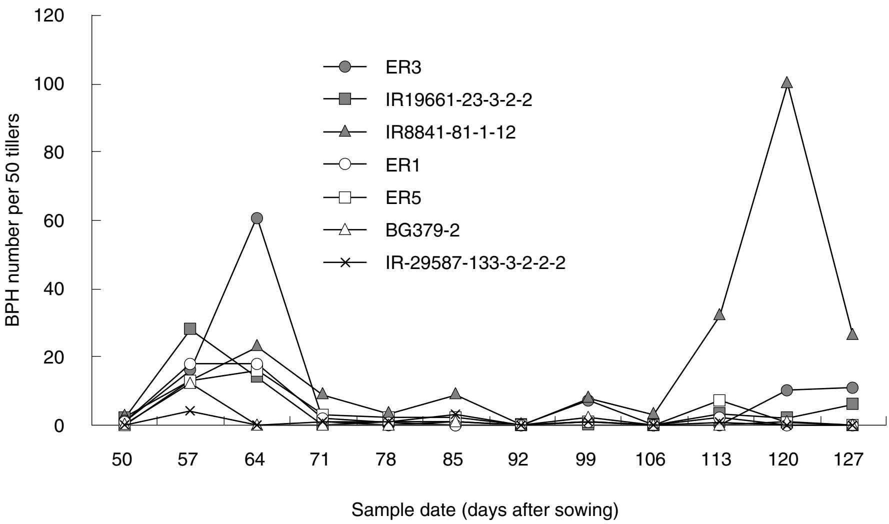
*BPH and natural predators*

The results of the replicated trial confirmed earlier findings (experiment 1) that Finschhafen and Taichung Sen-10 were relatively susceptible to BPH attack (Fig. 7A). The four remaining varieties were highly resistant, including the locally grown variety Niupela, confirming results from experiments 1–3. Taichung Sen-10 had 10-fold higher levels of BPH than IR25587-133-3-2-2-2 and BG379-2 over the 10-week sampling period. BPH levels rose significantly over the monitoring period peaking at 60–75 DAS on the two locally grown varieties (Finschhafen and Taichung Sen-10) but were relatively low and stable on the remaining varieties (Fig. 7A). Mirid bug populations were significantly higher on Finschhafen (Fig. 7B and Taichung Sen-10 (K. Powell, unpublished data), increasing in line with the BPH population. No hopperburn was observed in this experiment, suggesting that mirid bugs effectively controlled BPH.

*Grain yields*

Of the six varieties screened in the replicated trial, the lowest yielding variety was Finschhafen (5.4 t/ha) and the highest yielding varieties were IR25587-133-3-2-2-2 and ER3 (Table 4), which also produced relatively high yields in experiments 1 and 3, respectively. Yields from BG379-2 and Taichung Sen-10 were also reasonable. Niupela yields were relatively low, attributed in part to lodging by this variety, which was also observed in experiment 2. Lodging was not observed in any other varieties.

**(A)**




**(B)**

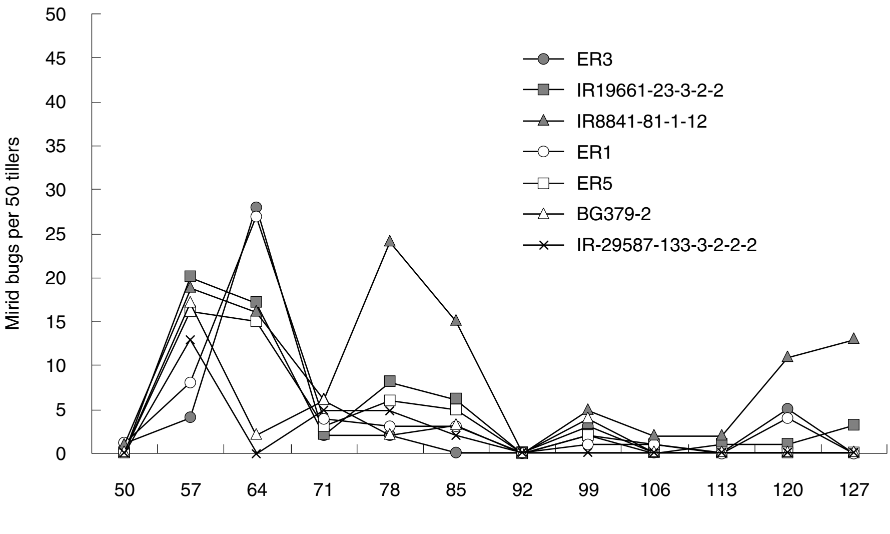
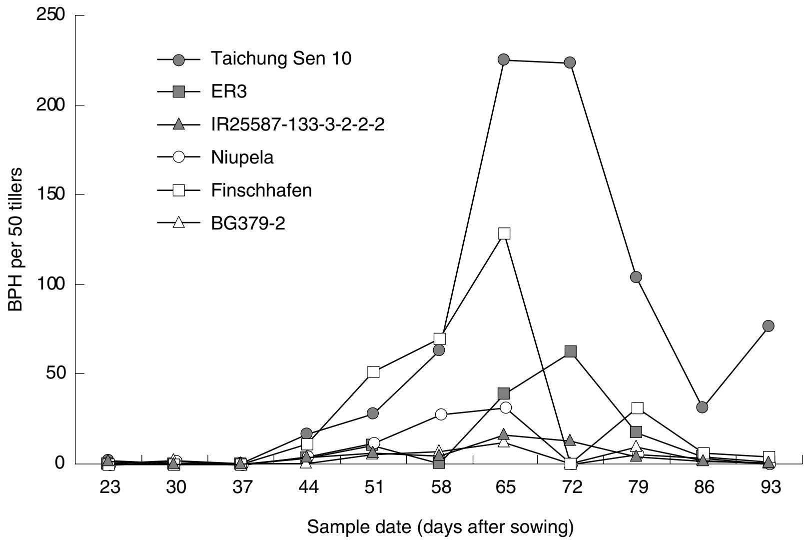



**Figure 6.** Population dynamics of (A) brown planthopper (BPH; *Nilaparvata lugens*) and (B) its natural predator mirid bugs (*Cyrtorhinus* spp.) on seven irrigated rice varieties (experiment 3).

**(A)**




**(B)**

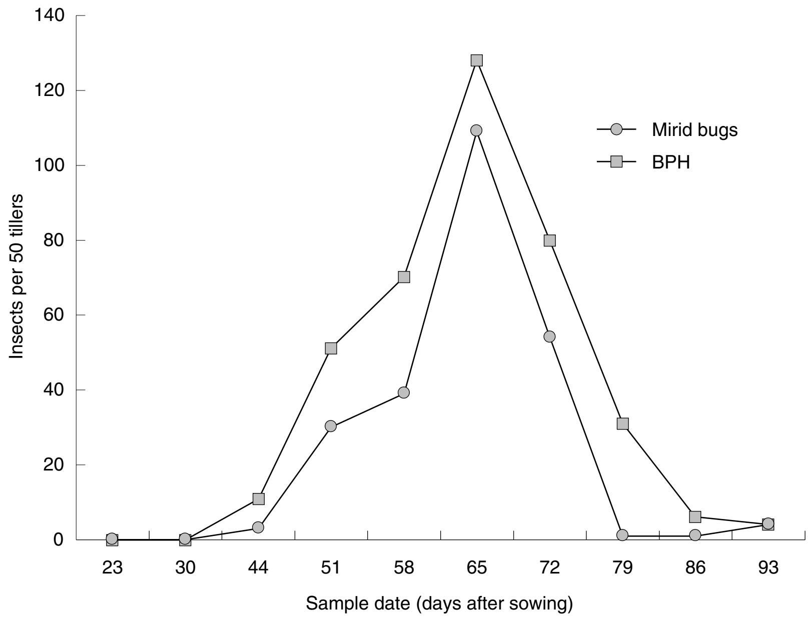



**Figure 7.** Population dynamics of brown planthoppper (BPH) on (A) six selected rice varieties, and (B) the susceptible local rice variety Finschhafen (experiment 4).

**Table 4.** Grain yields from the replicated rice variety trial (experiment 4).

| Variety | Mean grain yield (kg/hectare) |
|---|---|
| IR25587-133-2-2-2 | 6965 ± 500a |
| ER3 | 6382 ± 430ab |
| Taichung Sen 10 | 5514 ± 507bc |
| BG379-2 | 5431 ± 313bc |
| Niupela | 4833 ± 951cd |
| Finschhafen | 3750 ± 410d |

Notes: means followed by the same letter are not significantly different ($P < 0.05$) by ANOVA. Results expressed as means ± standard error.

# Discussion

## Rice production in PNG

PNG currently imports 160,000 tonnes of milled rice, representing 99% of domestic consumption, at an annual cost of 170 million PNG kina (Manning 1998).[1] To grow this quantity of rice in PNG would require 100,000 hectares of rainfed lowland rice or 200,000 hectares of upland rice to be in production (A. Carpenter, Rice and Grains Technical Advisory Committee, PNG, pers. comm. 1998). In the Kokopo and Rabaul districts of East New Britain Province more rice is consumed on a per capita basis than the world average, equalling and at one stage exceeding that of Japan (Bray and Romerosa 1983). In the urban regions of PNG rice is an intractable component of the diet representing on average 44% by weight of consumers' intake. As part of its natural agricultural policy, the PNG Government seeks to expand its area of production at the subsistence level to meet growing consumer demand. Based on experiences in the neighbouring Solomon Islands, insect pests are likely to be one of the major constraints to increasing the area of rice production to a sustainable level.

## BPH in the Solomon Islands

Domestic rice production in PNG only meets 1–2% of demand and importation is likely to increase with population growth (Sloane 1993). This is in contrast to the large-scale commercial production of rice under irrigation in the Guadalcanal region of the Solomon Islands, which allowed the country to achieve near self-sufficiency when rice production was at its peak. In forecasting future scenarios for large-scale rice production in PNG, comparisons are inevitably drawn with experiences in the neighbouring Solomon Islands. Commercial dryland rice production in the Solomon Islands started on a relatively large scale in 1965. At that time, in terms of the area of production, rice was the second most important crop (MacQuillan 1975a). The Solomon Islands was importing 98% of its rice in 1976, but by the early 1980s had attained near self-sufficiency. However, BPH became the most serious economic pest of rice in the Solomon Islands, and the major constraint to maintaining self-sufficiency in rice production was the breakdown in varietal resistance to BPH (MacQuillan 1974; Stapley 1975), with losses of up to US$120,000 in 1974. BPH was only a minor pest of rice under dryland conditions, but the switch to irrigated production in 1971 brought with it a change in the pest ecosystem and BPH rapidly changed from a secondary to a major pest (Stapley 1982; MacQuillan 1974). Initially, resistant varieties were used to control the pest but the development of a new Solomon Islands BPH biotype meant that insecticide use increased (Ho 1985).

## BPH incidence in PNG

This is the first study to compare the population dynamics of rice BPH and its natural enemies in PNG, on resistant and susceptible host-plant varieties in the field, under natural levels of infestation. Although the area of paddy rice harvested in PNG is currently only 350 hectares (FAO 2000), should large-scale production of rice be developed in the country, recommendations on management options for the control of BPH and other insect pests will be required. Surveys conducted throughout the country have recorded heavy incidence of BPH in Morobe and East New Britain provinces (Li 1985; K. Powell, unpublished data). BPH appears to be an insignificant economic pest in some relatively isolated regions of PNG (e.g. Finschhafen in Morobe Province), where local upland varieties have been used in a mixed-cropping, shifting-cultivation system for over a century. This may be due to the abundance and diversity of natural predators in this type of cropping system (Jahn and Chanty 1997) and the fact that subsistence farmers in the region never use insecticides.

1. In 1998, 1 PNG kina = approx. US$0.5 (A$0.8).

## Predators and BPH

Two main groups of natural predators—mirid bugs and spiders—were monitored in this study. Despite their importance as natural predators in the rice ecosystem, spider populations were relatively low in this study and did not appear to correlate with the BPH population or the use of the insecticide Carbaryl. Spiders are also less specific in their interaction with BPH than mirid bugs and will feed on a range of insect pests including leafhoppers and stem borers (Shepard et al. 1987).

Mirid bugs are geographically distributed across other Pacific rice-growing regions and earlier studies found them to be to be effective predators of BPH. Mirid bugs can become abundant in both wetland and dryland rice ecosystems infested with BPH and a single mirid bug can consume 7–10 eggs or 1–5 nymphs per day (Shepard et al. 1987). Stapley (1976) suggested that *C. lividipennis* contributed to BPH population suppression in its role as an egg and early instar predator, and that mirid bug populations migrated into the rice crop from grassy weeds in adjacent fallow fields. The use of a reservoir area to maintain mirid bug populations on grass weeds such as *Eleusine indica* was recommended by Stapley (1976). In the Solomon Islands, a ratio of BPH to mirid bugs of 20:1 was deemed necessary to successfully control BPH (Stapley 1975). Downham (1989) has shown that *C. lividipennis* population density is positively correlated with BPH populations.

## Host-plant resistance to BPH

The results presented here are the first documented study of host-plant resistance to BPH under field conditions in PNG. Six varieties in this study showed high to moderate susceptibly to BPH in rainfed lowland conditions at the Bugandi site, including the variety Taichung Sen-10 which is reported to be moderately resistant to BPH in Taiwan (R. Clough, Trukai Industries, pers. comm. 1998). The only comparable trials carried out in the Pacific Islands were conducted in the Guadalcanal region of the Solomon Islands when the resistance status of over 100 rice varieties to the Guadalcanal BPH biotype was assessed in field trials (Stapley et al. 1979). The development of resistant biotypes has been shown in the Solomon Islands, where resistance of rice varieties broke down in 1–3 years. Resistance of variety BG379-2, which has Ptb 33 parentage and is highly resistant to BPH, eventually broke down, with up to 60% hopperburn recorded (Ho and Taro 1985). The variety BG379-2 also showed high resistance to BPH in this study and it would be interesting to determine if the resistance is stable by testing this variety over a number of seasons under high BPH population pressure. Cohen et al. (1997) argued that high levels of resistance are not advantageous. They suggested that moderate levels of resistance or tolerance, such as those observed with the variety IR64, may be more sustainable in the long term as the level of resistance is durable and not reliant on single, major gene resistance.

## Host-plant resistance and natural predators

Using host-plant resistance to control BPH populations can reduce the levels and development of natural predators due to a reduction in the prey population (Heinrichs 1994). However, the use of resistant varieties is also likely to reduce the requirement for chemical insecticides to suppress BPH populations and hence indirectly conserve natural enemy populations. The use of resistant cultivars may also increase the efficacy of predation by natural enemies because the increased movement of the target pest on host plants may make detection easier. This has been observed in the case of the wolf spider *Lycosa pseudoannulata* against BPH (Kartohardjono and Heinrichs 1984). In our study, *Cyrtorhinus* spp. populations increased with BPH populations, particularly on the relatively susceptible varieties PSB-12C-1, Finschhafen, Taichung Sen-10, ER12, ER13 and IR841-81-1-12.

## BPH and successive plantings

In the Solomon Islands, yield declines of up to 19% that occurred over an 18-month period in 1983–84 were attributed to BPH (Beech 1985). Overlapping of rice crops in the Solomon Islands induced high densities of BPH and close cutting of paddy bunds reduced mirid bug and spider populations (MacQuillan 1974; 1975b). In our study, in experiment 1, yield declined over three overlapping growth periods for a number of varieties. Evidence that BPH was the primary cause for the decline could not be verified due to the high incidence of rice bug and rice leaf folder in the second and third growth periods. However, increases in BPH populations were observed on susceptible varieties after successive plantings.

## Insecticide-induced resurgence

The application of broad-spectrum insecticides can selectively destroy natural predators and increase

BPH densities a thousand-fold compared with no pesticide application, as BPH increases at a faster rate than most natural predators (Rombach and Gallagher 1994). Dyck and Orlido (1977) reported that a reduction in *C. lividipennis* after spraying with methyl parathion caused BPH resurgence. Gallagher et al. (1994) suggested that if pesticides are used on resistant varieties, breakdown in varietal resistance to BPH is likely to be accelerated as the relatively low numbers of natural enemies are destroyed, leaving nothing to control well-adapted BPH individuals. Our results indicate that Carbaryl application can initiate insecticide-induced resurgence under rainfed lowland conditions in PNG by reducing the density of mirid bug *Cyrtorhinus* spp. populations. Insecticide-induced resurgence was observed in trials in the Solomon Islands: *C. lividipennis* and *C. chinensis* controlled BPH in the absence of orthene insecticide on BPH-tolerant varieties but were unable to do so following insecticide application (Stapley et al. 1979). In trials conducted in Guadalcanal, MacQuillan (1975b) showed that insecticide application decreased adult and nymph populations of mirid bugs and depressed spider levels through direct contact and residual activity. A rapid increase in BPH densities in the absence of natural enemies was also enhanced by immigration of macropterous adults from surrounding rice paddies.

In trials conducted in Malaysia, mirid bug and spider populations were adversely affected by insecticide applications, resulting in resurgence of BPH populations (Ooi 1986) and exclusion cage studies have shown that, in the absence of natural predators, population outbreaks of BPH occur (Kenmore et al. 1984). Ooi and Shepard (1994) demonstrated a significant correlation between populations of *C. lividipennis* and BPH in the field in an insecticide-free environment in Malaysia. No correlation was observed between *Lycosa* spp. spider populations and BPH populations.

Insecticide-induced resurgence is not solely due to the effect of chemicals on natural enemies. Resurgence may also be attributed to the effects of an insecticide on plant growth or target insect biology, stimulating BPH reproduction (Chelliah and Uthamasamy 1986).

## Acknowledgments

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# Bulb Onions: the Challenge of Reducing Dependence on Imported Onions

**Geoff Wiles***

*Abstract*

The PNG Department of Agriculture and Livestock has set out to promote the production of bulb onions in PNG as a means of reducing dependence on imported onions. From 1988 to 1995, trials were carried out in a number of locations in the dry lowlands, the wet lowlands and the highlands of PNG. In all locations it is possible to produce bulb onions. In the dry lowlands, good crops of onions could be grown from sowings between February and June. These crops were produced under irrigation during the dry season. In the wet lowlands, production is extremely risky as the crop is easily damaged by heavy rain. In the highlands, all trials were grown as rainfed crops. It was clear that good onions could be produced, but results were not consistent. In wet weather, disease problems, especially purple blotch (*Alternaria porri)*, affected the crop. However, the crop could be produced year-round in the highlands, if excessively wet conditions did not occur. Wet weather during harvesting was liable to cause soft rots and make drying of the crop difficult. Irrigated dry season production of bulb onions in the highlands needs to be investigated. In the dry lowlands, smallholder farmers successfully grew crops of bulb onions using selected varieties (Gladalan Brown and Superex). In the highlands, some farmers have also managed to grow satisfactory crops of bulb onions, but onions are a more difficult crop to grow than many other vegetables. To date, there has been no significant reduction of imports as a result of local production. The varieties adapted to PNG conditions ('short day' varieties) also tend to store less well than the long day imported varieties. While PNG can successfully produce bulb onions both in the dry lowlands and the highlands, the crop requires careful management and year-round production may not be possible due to excessively wet weather during the rainy season and also to the photoperiodic sensitivity of the crop. If production is targeted at selected parts of the country and at optimal planting dates, then local production still has the potential to contribute significantly to the PNG onion supply.

BEFORE 1990, the Department of Agriculture and Livestock (DAL) had established that PNG was a significant importer of bulb onions. Onion imports were running at a level of about 2000 tonnes per year. At the same time, it was shown that onions could successfully be grown both in the dry lowlands (Bull and Bourke 1983) and in the highlands (Pitt 1987) of PNG. By 1990, DAL had decided to make a concerted effort to promote the production of bulb onions. Wiles (1991) reviewed previous work on bulb onions and outlined a strategy to develop onion production in PNG. This strategy combined an active extension program to provide information to prospective growers, and an ongoing research program focusing on six main areas:

- time of planting;
- cultivar evaluation;
- production methods (rainfed or irrigated; direct sown or transplanted);
- disease control (especially purple blotch);
- fertiliser requirements; and
- storage (selection of cultivars for storing).

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# Onion Research

## Research up to 1992

A review of onion research up to 1992 has been published by Wiles (1994). A number of new trials were conducted between 1990 and 1992. Most of these trials were for the purpose of cultivar evaluation, but some limited time-of-planting work was carried out in the highlands. The main conclusions of these and earlier trials were as follows.

- Onions can be successfully grown in the dry lowlands from February–June sowings.
- Five cultivars were recommended for lowland production (Gladalan Brown, Superex, Yellow Granex, Tropic Brown and Texas Early Grano).
- Late sowing (September) in the Port Moresby area led to premature bulbing in the seedbed (probably as a result of lengthening day length).
- Production in the wet lowlands (e.g. at Keravat or Bubia) can occasionally yield acceptable crops (LAES 1997), but heavy rainfall can result in total crop loss (LAES 1998).
- Gladalan Brown and Superex were also considered the best varieties for the highlands (Pitt 1987).
- Trials at Okapa showed that, in the highlands, good yields could be obtained from August and October sowing. Onions transplanted in late March yielded poorly, apparently because of drought stress.
- In the highlands and elsewhere, where humid conditions were experienced, onions were liable to attack by purple blotch (*Alternaria porri*). At higher altitudes (1600 metres above sea level and higher) downy mildew (*Peronospora destructor*) also attacked onion crops.
- The cultivars Red Creole and, to a lesser extent, Gladalan Brown, showed some tolerance to purple blotch. However Red Creole gave lower yields than Gladalan Brown and produced a high proportion of double bulbs.

## Research in the dry lowlands: 1993–95

Cultivar evaluation work continued at Laloki, Central Province, between 1993 and 1995. These trials evaluated locally available cultivars together with those available from the Horticultural Research Institute, Wellesbourne, United Kingdom, as part of an international program for screening tropical onions.

In 1993, three trials were planted. An elite trial compared a number of cultivars that had done well in previous trials (Sowei 1995). In this trial, the top nine cultivars (Rio Enrique, Gladalan Brown, Tropic Brown, Superex, Dessex, Yellow Granex, Pira Ouro, Texas Early Grano and Rio Bravo) did not differ significantly in marketable yield. Yields ranged from 27.0 to 42.3 tonnes per hectare (t/ha). A separate trial compared the yields of a number of cultivars with red bulbs (J. Sowei, DAL, pers. comm. 1994). The recommended yellow cultivar Gladalan Brown was included for comparison. Yields of this trial are presented in Table 1. Agrifound Dark Red performed particularly well in this trial. However, it also had the highest proportion of split and rotten bulbs.

Finally, there was a late (August 1993) sowing trial of 25 cultivars (J. Sowei, pers. comm. 1994). Because of premature bulbing and/or poor germination, only eight cultivars were actually transplanted, and only three of these yielded more than 10 t/ha: YHO 37—14.7 t/ha; Tropic Ace—14.4 t/ha; Gladalan Brown—12.7 t/ha. This sowing was clearly too late for optimal production, but, by comparing yields of Gladalan Brown over the three sowing dates (Table 2), some indication of the effect of sowing date on yield is available. Later plantings produced smaller bulbs and a much lower proportion of bulbs were of marketable quality. As previously noted, later plantings bulb quicker and have a shorter growing season.

In 1994, two further trials were planted at Laloki. The first trial compared elite lines from previous trials with other yellow onions not previously trialled (Kurika et al. 1997). The trial was transplanted on 11 July 1994. Harvesting began on 12 September and was completed on 10 October 1994. Marketable yields are presented in Table 3.

Some varieties that were trialled for the first time appeared promising. Storage observations showed considerable variation in storage losses: some Israeli and Brazilian varieties appeared to store better than those currently recommended. While Superex performed poorly in this trial, probably in part due to late sowing, it remains a good variety, especially for earlier plantings. Those cultivars selected for further trial are shown in Table 4.

In 1994, six red onion varieties were included in a trial with Gladalan Brown as a check variety. Planting dates were the same as for the previous trial. Most varieties were harvested on 10 October 1994, but Gladalan Brown and Agrifound Light Red were ready for harvest on 26 September 1994. Trial yields and percentage of bulbs in each grade are shown in Table 5. Only H-202 and H-226 gave yields approaching Gladalan Brown. Both were significantly better than Red Creole. Both of the Agrifound varieties were observed

**Table 1.** Red onion variety trial: marketable yield (tonnes/hectare).

| Cultivar | Marketable yield (t/ha) | % (by grade) | | |
|---|---|---|---|---|
| | | Marketable | Small | Split or rotten |
| Agrifound Dark Red | 23.80 | 65.5 | 17.5 | 17.0 |
| Gladalan Brown | 17.67 | 56.3 | 41.6 | 2.1 |
| Agrifound Light Red | 11.64 | 47.9 | 52.1 | 0.0 |
| Red Creole | 11.55 | 37.1 | 59.2 | 3.7 |
| Caraibe | 8.91 | 37.5 | 61.9 | 0.6 |
| Red Creole Select | 8.14 | 26.6 | 65.7 | 7.7 |
| Red Pinoy | 7.13 | 31.9 | 66.3 | 1.8 |
| Agrifound Rose | 0.00 | 0.0 | 96.5 | 3.5 |
| LSD (5%) | 8.55 | | | |
| Coefficient of variation | 52.4% | | | |

LSD = least significant difference
Note: trial sown 31 May, 1993 transplanted 3 August 1993, harvested November 1993.
Source: unpublished data of J. Sowei (Department of Agriculture and Livestock) and the author

**Table 2.** Comparison of performance of Gladalan Brown at three sowing dates in 1993 onion trials at Laloki Research Station.

| Transplantation date | Marketable yield (t/ha) | % marketable | Average weight (g) (all bulbs) |
|---|---|---|---|
| 22 June 1993 | 35.23 | 84.2 | 91.3 |
| 3 August 1993 | 17.67 | 56.3 | 60.1 |
| October 1993 | 12.71 | 52.2 | 69.0 |

Source: Sowei (1995)

to have light green foliage and appeared susceptible to purple blotch. These varieties also had a high proportion of rotten bulbs. Agrifound Dark Red and Red Creole had a high proportion of double (split) bulbs. Red Creole and Red Synthetic had more small bulbs than other varieties. H-226 had high dry matter and may have potential for storage.

A further variety trial was conducted in 1995. However, the management of the 1995 trial was unsatisfactory due to financial problems, and data cannot be considered reliable. Therefore recommendations for dry lowland production do not take account of the 1995 trial.

## Research in the highlands: 1993–94

Wiles (1994) provided a list of onion varieties that had shown promise in the 1991 screening trial at Aiyura. However, this trial was inconclusive and highlands recommendations continue to rely on trials reported by Pitt (1987) and work conducted by the Smallholder Market Access and Food Supply Project (SMAFSP) at Okapa (Wiles 1994). Time-of-planting work, which was attempted at the Highlands Agricultural Experiment Station (HAES), Aiyura, was largely inconclusive due to problems with disease (mostly purple blotch) and raising of seedlings.

**Table 3.** Marketable yield of onion bulbs: Laloki 1994.

| Cultivar | Yield (t/ha) | Cultivar | Yield (t/ha) |
|---|---|---|---|
| Tropic Brown | 44.97 | YHO 34 | 26.37 |
| Gladalan Brown[a] | 44.89 | Rio Bravo | 25.62 |
| Baia Periforme | 41.97 | Pira Ouro | 24.83 |
| H-486 | 41.49 | YHO 37 | 24.48 |
| Yellow Granex Imp. | 38.66 | H9 | 22.49 |
| Rio Enrique | 37.70 | Dessex | 21.05 |
| Pera IPA-6 | 37.29 | Hojem | 18.11 |
| Baia Dura | 32.68 | H8 (Barak) | 15.79 |
| Galil | 30.16 | Superex | 14.61 |
| YHO 30 | 28.66 | Ori | 4.89 |
| Rouge de Tana[b] | 26.73 | | |
| Mean | 29.47 | | |
| LSD (5%) | 12.50 | | |
| Coefficient of variation | 29.9% | | |

LSD = least significant difference
[a] Mean of two entries
[b] Red fleshed onion
Source: Kurika et al. (1997)

However, during the period under review, two trials are worthy of mention. A cultivar trial at Aiyura compared the performance of eight red cultivars with Gladalan Brown (B. Konabe, DAL, pers. comm. 1994). Yield data is shown in Table 6. This trial was planted at the beginning of the wet season and disease pressure was high. The percentage of marketable bulbs was low in all cultivars. The Indian cultivars (Agrifound cultivars, Poona Red, Pusa Red) were generally susceptible to disease and suffered a very high loss due to bulb rotting. All of the Agrifound Rose plants bolted, and some plants of Poona Red and Pusa Red also bolted. Red Creole, Red Creole Select, Red Pinoy and Caraibe all had more than 20% double bulbs. While this trial highlighted the difficulty of producing good onion crops during the wet season, it also showed significant cultivar differences in double bulb formation and susceptibility to bulb rotting.

The second trial of interest is a fertiliser trial with the cultivar Gladalan Brown conducted at three sites in Eastern Highlands Province: Aiyura, Baroda and Raipinga (B. Konabe, DAL, pers. comm. 1994). Unfortunately, data for the Aiyura site are meaningless as a result of theft. Fertiliser application rates of 0, 100 and 200 kilograms per hectare of nitrogen (N), phosphorus (P) and potassium (K) were compared in a factorial design study. N was applied as urea, P as triple superphosphate and K as muriate of potash. All fertilisers were incorporated in the soil before planting. Trial results are summarised in Table 7 and Figure 1. The Raipinga site was extremely deficient in P, but both sites showed strong P responses. At Baroda, but

**Table 4.** Cultivars selected for further trial.

| Cultivar | Description |
|---|---|
| Gladalan Brown | Recommended standard variety, reliable yielder, may have some resistance to purple blotch |
| Tropic Brown | Comparable yield to Gladalan Brown in most trials |
| Galil | Israeli hybrid, selected for earliness; acceptable yield |
| Baia Dura | Brazilian variety, good yield of medium bulbs; poor storage |
| Baia Periforme | Brazilian variety, good yield of medium to large bulbs; better storage than Gladalan Brown |
| Pera IPA-6 | Brazilian variety; good yield and may store better than Gladalan Brown |
| Rio Enrique | Hybrid from United States; medium bulbs, good yield; not suitable for storage |
| H-486 | Israeli hybrid; late maturing and appears to store well |
| Yellow Granex Imp. | Good yield, but some red off-types in this trial and appears susceptible to purple blotch |
| Superex | Disappointing in this trial, but has performed better from earlier (April) sowings; uniform and early maturing |
| Pira Ouro | Late maturing Brazilian variety; appears resistant to purple blotch and stores well |

**Table 5.** Marketable yield of red onion trial at Laloki Research Station, 1994.

| Cultivar | Yield (t/ha) | % bulbs (by grade) | | | |
|---|---|---|---|---|---|
| | | Marketable | Small | Split | Rotten |
| Gladalan Brown | 43.9 | 90.9 | 6.7 | 0.5 | 1.9 |
| H-202 | 35.9 | 87.8 | 8.9 | 0.6 | 2.8 |
| H-226 | 27.9 | 83.9 | 7.1 | 6.6 | 2.4 |
| Red Synthetic | 21.9 | 79.2 | 10.9 | 5.1 | 4.8 |
| Agrifound Light Red | 19.5 | 68.6 | 5.1 | 5.9 | 20.3 |
| Red Creole | 16.7 | 62.3 | 11.9 | 25.8 | 0.0 |
| Agrifound Dark Red | 15.2 | 43.1 | 1.4 | 45.2 | 10.3 |
| Mean | 24.4 | | | | |
| LSD (5%) | 12.0 | | | | |
| Coefficient of variation (%) | 33.1 | | | | |

LSD = least significant difference
Source: L. Kurika, Department of Agriculture and Livestock, pers. comm. (1994)

**Table 6.** Red onion variety trial yields at the Highlands Agricultural Experiment Station, Aiyura.

| Cultivar | Yield (t/ha) | | Percentage of bulbs (by grade) | | | |
|---|---|---|---|---|---|---|
| | Marketable | Total | Marketable | Small | Double | Rotten |
| Caraibe | 5.26 | 17.4 | 22.2 | 45.1 | 29.9 | 2.8 |
| Red Pinoy | 4.97 | 14.7 | 23.6 | 50.6 | 22.7 | 3.0 |
| Gladalan Brown | 4.37 | 10.5 | 29.0 | 47.1 | 7.6 | 16.2 |
| Red Creole Select | 4.30 | 15.1 | 18.6 | 35.6 | 25.3 | 20.5 |
| Red Creole | 3.89 | 19.1 | 18.9 | 42.0 | 31.7 | 7.4 |
| Agrifound Dark Red | 1.91 | 7.6 | 15.2 | 8.8 | 13.7 | 62.3 |
| Agrifound Light Red | 1.63 | 8.8 | 10.7 | 24.4 | 13.2 | 51.7 |
| Poona Red | 1.11 | 8.3 | 6.3 | 18.0 | 18.4 | 57.3 |
| Pusa Red | 0.83 | 8.4 | 4.1 | 44.7 | 22.4 | 28.8 |
| Mean | 3.41 | 12.7 | | | | |
| LSD (5%) | 5.06 | 6.39 | | | | |
| Coefficient of variation (%) | 52.7 | 29.5 | | | | |

Note: transplanted 2 November 1993 and harvested 6 April 1994.
Source: L. Kurika, Department of Agriculture and Livestock, pers. comm. (1994)

not at Raipinga, there was a significant response to K application. High rates of urea appeared to result in the death of some plants. Split application of N is preferable to avoid fertiliser burn. Nevertheless, N application appeared to increase bulb size at harvest.

## Support for Onion Production

In conjunction with research activities, onion extension activities were implemented. Based on the advice provided by Pitt (1987), activities initially focused on the highlands provinces and Division of Primary

**Table 7.** Onion fertiliser responses at Baroda and Raipinga, Eastern Highlands Province.

| Site | Nitrogen (N) | Phosphorus (P) | Potassium (K) |
|---|---|---|---|
| Baroda | High rates of N reduced the number of plants surviving; plants receiving some N (N1 or N2) produced larger bulbs. N1 plots yielded better than N0 or N2. | There was a response to P application up to the highest rate of P applied; P application increased both number and size of marketable bulbs. | There was a yield response to K application up to the highest rate of K applied; K application increased the number of marketable bulbs but had little effect on bulb size. |
| Raipinga | N response was similar to that at Baroda. | The response was similar to that observed at Baroda, though P0 plots produced extremely low or no marketable yields. | Application of K resulted in small decreases of marketable number, marketable weight and bulb size. |

Source: B. Konabe, Department of Agriculture and Livestock, pers. comm. (1994)

Industries (DPI) officers were trained in onion production techniques, including postharvest handling. Two advisory publications on onion production were produced by DAL (Wiles 1992a; 1992b), and the Fresh Produce Development Company (FPDC) provided training material for extension officers and subsequently produced a bulletin for farmers in the journal *Tok Pisin* (Sparkes, no date).

In the early 1990s, demonstration plots were established at the Highlands Agricultural Training Institute (HATI) (near Mt Hagen) and also in Southern Highlands Province. The varieties Superex and Gladalan Brown were promoted, though more emphasis was placed on the latter because of the high cost of hybrid seed. There were reports of successful small-scale farm production of onions from most highlands provinces, and productions of 27 tonnes (1991) and 24 tonnes (1992) was reported by extension staff. However, despite promising beginnings, onion production in the highlands has not become established on a large scale. This appears to be in large part due to the vagaries of the weather and build-up of diseases (especially purple blotch). Wet weather at harvest also resulted in problems with drying the crop and consequent postharvest rots. As a result, while growers have been able to grow good crops, results have not been consistent and some growers have experienced significant losses.

In the early 1990s, successful onion production was demonstrated in the Sogeri area of Central Province and at Tapini, in Goilala District. After 1993, when the third Laloki trial had been successfully completed, production in Central Province was given more attention (Sowei 1999). FPDC promoted onion production at a number of locations in 1994 (near Brown River, in the Sogeri area, and at Kerekadi near Tubuseria). Production on these sites was generally successful and encouraging. Based on these initially favourable results, FPDC has expanded its onion agricultural extension program to other areas of Central Province. Farmers in the Launakalana area (east of Kwikila) and in the Mekeo area have been shown how to produce onions and have received regular agricultural extension visits. Many of these farmers have been able to produce successful crops on a small scale. However, much of the produce has been absorbed by local sales and home consumption, and has not found its way onto the Port Moresby market. Furthermore, some farmers have experienced significant losses due to unseasonal rainstorms. The main points that have emerged from experience in Central Province are:

- successful production in the dry lowlands requires the crop to be grown in the dry season with irrigation, thus expansion of onion production needs to go hand in hand with expansion of irrigation;
- late rains in April and May can destroy onion seedbeds if they are not protected;
- rains at harvest time (October–November) can lead to storage rots if there are no covered drying facilities; and
- because of the above factors and the lower yields from late (after June) sowings, onion production in Central Province is strongly seasonal with the main harvest in September–October from June–July transplanting.

## Economics of Onion Production

Because of the slow rate of growth of onion production, FPDC felt the need to assess the economics of production and see whether it was able to provide satisfactory

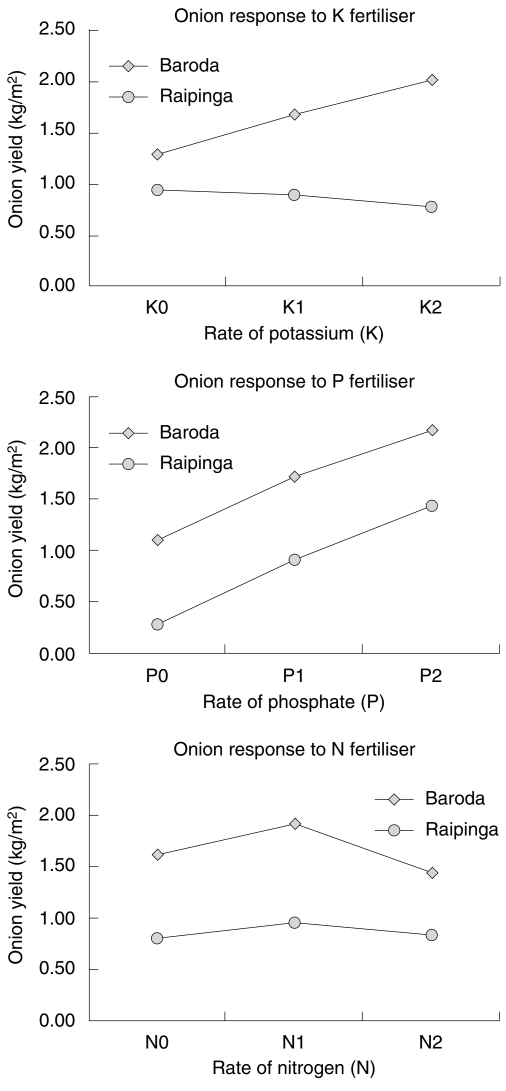


**Figure 1.** Fertiliser responses of bulb onions in trials at Baroda and Raipinga, Eastern Highlands Province, PNG.

returns to growers. Two commercial onion plantings, one on a private farm at Veimauri and one at the National Agricultural Research Institute (NARI) research station at Laloki, were closely monitored and the cost of all inputs, including labour, were recorded. Details of these two plantings were as shown in Table 8.

Costs and returns of the 1999 FPDC onion production trial in Central Province are shown in Table 9. Both crops achieved modest yields but, nevertheless, gross return amounted to about 50% of gross income. It appears that production of bulb onions gives an attractive return to the farmer. It is, however, labour intensive, especially the transplanting, weeding and harvesting.

## Discussion

Efforts to promote the production of bulb onions continued throughout the 1990s in both the highlands and the dry lowlands of PNG. However, while interest in the crop has expanded, increases in production have been modest. There is no evidence that local production has had any significant effect on reduction of imports (Table 10). Bulb onion is one (perhaps the only) crop where significant quantities of imported produce are sold on open markets. Availability of locally-grown onions, both in the formal retail sector and through open markets, remains very limited. The reason for this situation needs to be sought from both farmer and researcher experiences with the crop. The general perception is that bulb onions are a relatively difficult crop to produce. There appear to be good reasons for this perception. Since the difficulties associated with onion production in the lowlands and in the highlands are not the same, the two regions will be dealt with separately in this discussion.

In the highlands, onion production is clearly possible. However, both farmers and researchers have experienced crop failures. To date, all highland production has been under rainfed conditions, and the major constraint to production appears to be disease outbreaks during periods of wet weather. The red onion trial reported above is a good example of this. However, as a shallow-rooted crop, onions can also experience drought stress in the dry season, resulting in reduced yields. Wet weather at harvest time also leads to the development of storage rots. There appear to be two ways in which these constraints can be overcome:

- by developing ways to effectively control onion diseases either through resistant varieties or use of fungicides; and
- by growing onions as a dry season crop with the use of irrigation.

While differences in susceptibility to purple blotch were observed, no truly resistant cultivars were seen: all cultivars were attacked, some more severely than others. Currently farmers produce spring onions suc-

**Table 8.** Details of Fresh Produce Development Company commercial onion planting trials on 0.1-hectare plots.

| | Veimauri | Laloki |
|---|---|---|
| Date sown | 25 May 1999 | 27 May 1999 |
| Date transplanted | 12–21 July 1999 | 12–16 July 1999 |
| Date harvested | 7 October 1999 | 28 September 1999 |
| Gross yield | 2.76 tonnes | 1.98 tonnes |
| Postharvest losses | 0.5 tonnes | 0.28 tonnes |
| Land | Virgin ground | Old field (*Cyperus* infested) |
| Weed control | Chemical and manual | Manual |
| Irrigation methods | Sprinkler | Sprinkler and furrow |

**Table 9.** Bulb onion production budget for Central Province (0.1 hectares).[a]

| | Unit rate (PGK[b]) | Veimauri | | Laloki | |
|---|---|---|---|---|---|
| | | Quantity | PGK | Quantity | PGK |
| Income | | | | | |
| Onion sales (tonnes) | 2000 | 2.26 | 4520.00 | 1.70 | 3395.00 |
| Production costs: | | | | | |
| Tractor hire (hours) | 50.00 | 0.7 | 35.00 | 1.0 | 50.00 |
| Seed (kilograms) | 320.46 | 0.3 | 96.14 | 0.3 | 96.14 |
| Fertiliser (kilograms) | 1.40 | 100 | 140.00 | 100 | 140.00 |
| Chicken manure (bag) | 2.00 | 25 | 50.00 | 25 | 50.00 |
| Pesticides | various | at cost | 162.35 | at cost | 62.35 |
| Irrigation fuel (litres) | 0.67 | 50 | 33.50 | nr | nr |
| Miscellaneous costs (10%) | | | 51.70 | | 39.85 |
| Total (excluding labour and harvesting) | | | 568.69 | | 438.34 |
| Labour (person days) | | | | | |
| Field labour | 10.00 | 101.5 | 1015.00 | 119 | 1190.00 |
| Supervision | 20.00 | 10.0 | 200.00 | 10 | 200.00 |
| Total labour | | | 1215.00 | | 1390.00 |
| Harvesting costs | | | | | |
| Bags[c] | 1.10 | 100 | 110.00 | 50 | 55.00 |
| Transport to depot | 80.00 | | 80.00 | | |
| Total harvesting cost | | | 190.00 | | 55.00 |
| Total production cost | | | 1973.69 | | 1883.34 |
| Gross return | | | 2546.31 | | 1511.66 |

nr = not recorded
[a] Data provided by Paul Kitcher, Fresh Produce Development Company
[b] In 1999, 1 PNG kina (PGK) = approx. US$0.40 (A$0.60).
[c] Only produce sold to wholesalers was bagged.

**Table 10.** PNG onion importation, 1981–93 and 1996–98.

| Year | Onions imported (tonnes) | Value of imported onions (thousands of PGK) | Price (PGK/kg) | US$ per PGK | A$ per PGK |
|---|---|---|---|---|---|
| 1981 | 1629 | 612.0 | 0.38 | 1.47 | 1.32 |
| 1982 | 1691 | 333.2 | 0.20 | 1.34 | 1.30 |
| 1983 | 1745 | 243.5 | 0.14 | 1.14 | 1.36 |
| 1984 | 1704 | 627.9 | 0.37 | 1.06 | 1.27 |
| 1985 | 1989 | 358.0 | 0.18 | 0.99 | 1.28 |
| 1986 | 2288 | 507.6 | 0.22 | 1.04 | 1.45 |
| 1987 | 1993 | 572.8 | 0.29 | 1.14 | 1.57 |
| 1988 | 1951 | 632.6 | 0.32 | 1.21 | 1.58 |
| 1989 | 2031 | 689.6 | 0.34 | 1.16 | 1.42 |
| 1990 | 1849 | 674.1 | 0.36 | 1.05 | 1.47 |
| 1991 | 1937 | na | na | 1.05 | 1.36 |
| 1992 | 2292 | na | na | 1.01 | 1.38 |
| 1993 | 2100 | na | na | 1.02 | 1.47 |
| 1994 | na | na | na | 0.85 | 1.51 |
| 1995 | na | na | na | 0.75 | 1.09 |
| 1996 | 1932 | 1270.4 | 0.66 | 0.76 | 1.02 |
| 1997 | 2111 | 1441.8 | 0.68 | 0.70 | 0.97 |
| 1998 | 1429 | 1704.8 | 1.19 | 0.49 | 0.94 |

PGK = PNG kina; na = not available
Source: onion data for 1981–90 and 1996–98 provided by PNG National Statistical Office; onion data for 1991–93 compiled from Australian and New Zealand export data

cessfully in the highlands. Spring onions (botanically classified as Welsh onion (*Allium fistulosum*)) appear to be much more tolerant to purple blotch than bulb onions (*Allium cepa*). Preliminary work on purple blotch control at HATI suggested that Rovral fungicide may be more effective than those currently recommended, but more work is needed.

The possibility of irrigated onion production in the highlands needs to be investigated. It has proved successful in the dry lowlands, and in other tropical countries (e.g. Thailand) highland production is carried out successfully in the dry season with irrigation.

Research in the PNG highlands also showed that bulb onions respond to fertiliser application and that, as with other crops, application of phosphate fertilisers is necessary to attain good yields. However if recommended fertiliser rates are applied (see Sparkes, no date), then onion growth should be reasonably satisfactory, and other production constraints would be more important for short-term research needs.

In the dry lowlands we have been able to show that good onion yields can be obtained as long as certain practices are used:

- sowing should be between February and June;
- seedlings must be protected from heavy rain before transplanting;
- irrigation must be provided; and
- harvested bulbs must be protected from heavy rain.

The main constraint appears to be limited knowledge and practice of irrigation. There are also significant risks from end-of-season rainfall (in April–May) and from rain during the harvest season in October–November, which can make drying of the crop difficult. The narrow planting window means that farmers cannot supply onions over a long season unless they are able to store bulbs. This option is complicated by the fact that many of the present ‘short day’ varieties do not store well. However, some of the cultivars tested, especially those of Brazilian and Israeli origin, may have longer storage lives than the currently recommended cultivars.

## Conclusions

In summary, the effort to promote bulb onion production has failed to result in substantial increases in local production. However, it has resulted in greater awareness among farmers and extension officers on how best to grow the crop. At the same time, research has made significant headway in identifying the problems facing onion producers in PNG, and in refining production recommendations for growers. While success has proved elusive in the short term, the foundation has been laid for continuing efforts to expand onion production in PNG and reduce dependence on imports. If onion production is targeted at selected parts of the country and at optimal planting dates, local production still has the potential to contribute significantly to the supply of bulb onions.

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I would like to acknowledge support from former research staff at Laloki Research Station (Louis Kurika and John Sowei) and HAES, Aiyura (Brown Konabe), who provided data from onion trials conducted at their respective stations. I would also like to thank Paul Kitcher, Regional Horticulturist, FPDC, Port Moresby, for providing helpful comments on onion extension activities and information on the costs of onion production. Gus Maino (FPDC, Mt Hagen) kindly provided onion import data.

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# Appendix A

# Some Useful Sites on the World Wide Web

There are a number of useful web sites on the world wide web that contain information relevant to food and nutrition issues in PNG. A list of some of these sites is given here, together with brief notes. The address for these sites is given as a universal record locator (URL).

**The PNG Virtual Library**
http://coombs.anu.edu.au/SpecialProj/PNG/Index.htm
This is a useful entry site for information about PNG. There are connections to sites with information about agriculture, culture, environment, societies, the economy, mining, development issues and many other topics.

**Papua New Guinea 1996 Household Survey**
http://www.worldbank.org/lsms/country/png/pnghome.html
The 1996 Papua New Guinea Household Survey provides individual level and household level socioeconomic data from almost 1400 households. This survey was carried out as part of the World Bank Poverty Assessment.

**Dan Jorgensen's special section on the 1997 drought**
http://nexus.sscl.uwo.ca/anthropology/jorgensen
This page contains links to a number of other sites concerned with the 1997-98 drought.

**AusAID assessments of 1997 drought impact**
http://www.ausaid.gov.au/publications/pdf/pngdroughtrep.pdf
This site contains copies of the full reports on the impacts of the 1997 drought and frosts on rural PNG.

**Land Management Project, The Australian National University**
http://rspas.anu.edu.au/lmp
This site gives access to all of the information from the provincial Working Papers for the Mapping Agricultural Systems of PNG project. It is also possible to search the PNG Agricultural Bibliography (13,000 entries) from this site.

**Resource Management in Asia Pacific Project, The Australian National University**
http://rspas.anu.edu.au/rmap
This project conducts research on a number of resource management issues in PNG and elsewhere in the region. The web site gives links to project papers, seminar lists and conferences.

**Pacific Fruit Fly Web**

http://www.pacifly.org/Country_profiles/Png.HTM

A site hosted by the project on Regional Management of Fruit Flies in the Pacific (RMFFP), sponsored by the Australian Agency for International Development (AusAID), the United Nations Development Programme (UNDP) and New Zealand Official Development Assistance (NZODA), implemented by the Food and Agriculture Organization of the United Nations, and executed by the Secretariat of the Pacific Community (SPC).

**Rice Industries Ltd, Port Moresby**

http://www.trukai.com.pg

The predominant importer of rice into PNG and distributors of Trukai Rice.

**Papua New Guinea Coffee & Tea Store**

http://www.pngcoffee.com/

A web page advertising organically grown coffee and tea.

**Australian Centre for International Agricultural Research (ACIAR)**

http://www.aciar.gov.au/projects

ACIAR's projects page contains details of their international projects, including those in PNG.

**International Service for National Agricultural Research**

http://www.cgiar.org/isnar

The International Service for National Agricultural Research (ISNAR) assists developing countries to improve the performance of their national agricultural research systems and organizations.

**The AGRILIN Desktop Library, Union Catalogue of Agricultural Libraries**

http://www.agralin.nl/desktop/catalog

An extensive electronic bibliography of published papers on agriculture, from the University of Wagningen, the Netherlands.

**United Nations Food and Agriculture Food Insecurity and Vulnerability Databases and Links**

http://www.fivims.net

The Food and Agriculture Organization of the United Nations Food Insecurity and Vulnerability Information and Mapping Systems (FIVIMS) are networks of systems that assemble, analyse and disseminate information. They include the Global Information and Early Warning System (GIEWS), the Global Database on Child Growth and Malnutrition, (GDCGM) and the Key Indicators Mapping System (KIMS), tools for national and international FIVIMS partners to help present and map key indicators of food insecurity and vulnerability.

**Food and Agricultural Organization of the United Nations Special Programme for Food Security**
http://www.fao.org/spfs/
This site contains information about the Food and Agricultural Organization of the United Nations (FAO) Special Programme for Food Security in PNG.

**The Entomological Bibliography of New Guinea**
http://entomology.si.edu:591/entomology/NewGuineaBib/search.html
The Entomological Bibliography of New Guinea, including the Solomon Islands (10,500 citations), has been updated and moved to this new searchable interface.

**Papua New Guinea Eco-Forestry forum**
http://www.ecoforestry.org.pg
This is a new initiative that welcomes constructive comments and suggestions.

**The International Plant Names Index**
http://www.ipni.org/
The International Plant Names Index is a database of the names and associated basic bibliographical details of all seed plants. Its goal is to eliminate the need for repeated reference to primary sources for basic bibliographic information about plant names. The data are freely available and are gradually being standardised and checked. The index is the product of a collaboration between The Royal Botanic Gardens at Kew, The Harvard University Herbaria and The Australian National Herbarium.

**EcoPort: Ecology without boundaries**
http://www.ecoport.org
This is a large and growing database with a huge amount of information about crops, pests and diseases that FAO has set up. A lot of information about PNG food crops, pests and diseases can be found at this site.

# Appendix B

# Previous Conferences Devoted to Food Production or Human Nutrition in PNG (1970–99)

**R. Michael Bourke***

There have been a number of meetings devoted mainly to aspects of food production or human nutrition in PNG over the past 30 years. A list of these meetings is presented here in chronological order, together with publication details. The listing includes conferences, seminars and workshops. It does not include internal working meetings of PNG government departments.

It is likely that other meetings have been held, which have left no published record or which I have overlooked. These include, for example, a number of workshops on human nutrition, including one in Port Moresby in 1982 and one in Madang in 1999. There also may have been conferences or other meetings devoted to aspects of fishing. Papers have been presented and published on food production, subsistence farming systems or human nutrition at some other conferences, workshops and seminars. However, these have been excluded from this listing if the gathering was not devoted primarily to food production or human nutrition in PNG. An example of this is the Australian and New Zealand Association for the Advancement of Science (ANZAS) Conference held Port Moresby in 1970, which did not result in a published proceedings. Another example is a conference on Traditional Conservation in Papua New Guinea: Implications for Today held in Port Moresby in 1980, the proceedings of which were published by the Institute of Applied Social and Economic Research as Monograph 16 and edited by L. Morauta, J. Pernetta and W. Heaney. This volume contains a number of papers on aspects of subsistence food production.

Further information about these references may be obtained from the electronic bibliographic database called the Papua New Guinea Agricultural Bibliography (PNGAgBib), as discussed in Computer Managed Databases Relevant to Agriculture in PNG, by P. Vovola and Bryant J. Allen (another paper in these proceedings).

The helpful comments of Dr Alan Quartermain and Dr Robin Hide on the first version of this list is acknowledged with thanks.

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# Listing of previous conferences

Workshop on the development of legumes in Papua New Guinea, Port Moresby, 1974. Published as: Khan, T.N., ed., 1974. Proceedings of the seminar/workshop on the development of legumes in Papua New Guinea. Science in New Guinea, 2(1), 1–127.

Papua New Guinea Stockfeeds Conference, Lae, 1974. Published in 1975 as: Proceedings of Papua New Guinea Stockfeeds Conference. Department of Agriculture, Stock and Fisheries, Port Moresby, PNG.

Papua New Guinea Food Crops Conference, Lae, 1975. Published as: Bourke, R.M and Willson, K., eds, 1976. 1975 Papua New Guinea Food Crops Conference Proceedings. Department of Primary Industry, Port Moresby, PNG.

Tenth Waigani Seminar, Lae, 1976. Published as: Enyi, B.A.C. and Varghese, T., eds, 1977. Agriculture in the Tropics. University of Papua New Guinea, Port Moresby, PNG.

Highlands Grains Seminar, Mt Hagen, 1977. Individual papers on rice, maize, wheat, sorghum, rye, oats, lupins and soyabean were produced. The proceedings have not been published, but the papers were collated by Department of Primary Industry, Port Moresby, PNG.

National Nutrition Conference, Goroka, 1979. Published as: Eng, J., ed., 1979. 1979 National Nutrition Conference. $26^{th}$–$30^{th}$ March, 1979. Nutrition Section, Department of Health, Port Moresby, PNG.

Second Papua New Guinea Food Crops Conference, Goroka, 1980. Published as: Bourke, R.M. and Kesavan, V., eds, 1982. Proceedings of the Second Papua New Guinea Food Crops Conference. Department of Primary Industry, Port Moresby, PNG.

First Papua New Guinea Food and Nutrition Conference, Goroka, 1983. Published as: Levett, M.P., Earland, J. and Heywood, P., eds, 1992. Changes in Food and Nutrition in Papua New Guinea: Proceedings of the First Papua New Guinea Food and Nutrition Conference. Department of Primary Industry, Port Moresby, PNG.

Food Crops Research Advisory Meeting, Bubia Research Station, 1984. George, J. and Moles, D., eds, 1985. Food Crops Research Advisory Meeting, 2/3 October, 1984. Bubia Agricultural Research Centre, Lae. Department of Primary Industry, Port Moresby, PNG.

Agricultural Extension—Its Impact: Focus and Future, Mt Hagen, 1987. Published as: Silovo, S.L. and McKenzie, J., eds, 1988. Proceedings of the First Papua New Guinea Agricultural Extension Seminar. Department of Agriculture and Livestock, Port Moresby, PNG.

Potato/Sweet Potato Workshop, Mt Hagen, 1987. Published as: Pitt, A.J. and Yandanai, H.R., eds., 1988. Working Papers of the 1987 Potato/Sweet Potato Workshop. Department of Agriculture and Livestock, Port Moresby, PNG.

Maximising Animal Production in Papua New Guinea, Lae, 1988. Published as: Krebs, G.L., Cridland, S., Nunn, M.J. and Sims, L.D., eds, 1988. Proceedings of the Papua New Guinea Society of Animal Production, Volume 1, Inaugural Conference. PNG Society of Animal Production, PNG.

Smallholder Animal Production in Papua New Guinea, Mt Hagen, 1989. Published as: Malik, R.C., ed., 1989. Proceedings of the Papua New Guinea Society of Animal Production, Volume 2. PNG Society of Animal Production, PNG.

First Papua New Guinea International Fruit Conference, Rabaul, 1989. Published as: Bala, A.A., ed., 1991. Proceedings of the Papua New Guinea First International Fruit Conference. Department of Agriculture and Livestock and PNG Fruit and Vegetable Advisory Board, Port Moresby, PNG.

Workshop on Indigenous Conservation Farming Practices, Goroka, 1990. Published as: Indigenous Conservation Farming Practices: Report of the Joint ASOCON/Commonwealth Workshop, Goroka, Papua New Guinea, 3–7 December 1990. Asian Soil Conservation Network Report No. 7. Asia Soil Conservation Network, Jakarta, Indonesia.

Pests and Diseases of Food Crops—Urgent Problems and Practical Solutions, Port Moresby, 1991. Published as Kumar, R., ed., 1991. Proceedings of a Seminar on Pests and Diseases of Food Crops— Urgent problems and Practical Solutions. Agricultural Protection Division, Department of Agriculture and Livestock, Port Moresby, PNG.

Papua New Guinea National Nutrition Policy Workshop, Madang, 1992. Published in 1992 as Papua New Guinea National Nutrition Policy Workshop. Institute of National Affairs Discussion Paper No. 54. Institute of National Affairs, Port Moresby, PNG.

Animal Production Conference, Lae, 1993. Unpublished. Papua New Guinea Society of Animal Production.

First Taro Symposium, Lae, 1993. Abstracts and symposium recommendations only were published as: Jackson, G.V.H. and Wagih, M.E., eds, 1996. The Second Taro Symposium: Proceedings of an International Meeting held at the Faculty of Agriculture, Cenderawasih University, Manokwari, Indonesia, 23–24 November 1994, Appendix, 133–147. Cenderawasih University, Indonesia and PNG University of Technology, PNG.

Second Taro Symposium, Manokwari, Irian Jaya, 1994. Published as: Jackson, G.V.H. and Wagih, M.E., eds, 1996. The Second Taro Symposium: Proceedings of an International Meeting held at the Faculty of Agriculture, Cenderawasih University, Manokwari, Indonesia, 23–24 November 1994. Cenderawasih University, Indonesia and PNG University of Technology, Lae, PNG.

Workshop on Sustainable Land Management, Keravat, East New Britain Province, 1995. Published as: Howlett, D., ed., 1995. Proceedings of Pacificland Annual Meeting and Workshop on Sustainable Land Management. Department of Agriculture and Livestock, Port Moresby, PNG.

Third Taro Symposium, Manokwari, Irian Jaya, 1996. Unpublished.

First National Sago Conference, Lae, 1999. Published as: Sopade, P.A., ed., 1999. Sago Starch and Food Security in Papua New Guinea. The Proceedings of the First National Sago Conference. PNG University of Technology, Lae, PNG.

National Agricultural Research Institute (NARI) Cassava Workshop, Lae, 1999. Published as: Grant, I.McL. and Allen, M.G., eds, 2000. Proceedings of the Nari Cassava Workshop held at the Forest Research Institute, July 2nd 1999. NARI Proceedings Series, Proceedings 3. NARI, Lae, PNG.

NARI Poultry Workshop, Lae, 1999. Published as: Quartermain, A.R., ed., 2000. Proceedings of the NARI Poultry Workshop. NARI Proceedings Series, Proceedings 1. NARI, Lae, PNG.

Commercialisation of Vegetable Production Workshop, Vudal, 1999. See another paper in these proceedings, University of Vudal Workshop on Commercialisation of Vegetable Production, by Geoff Wiles and Peter Mwayawa.

Highlands Horticultural Workshop, Mt Hagen, 1999. See another paper in these proceedings, Towards an Understanding of Research and Extension Needs in the Highlands: the 1999 Highlands Horticulture Workshop, by B.J. Watson.

# Conference Summary and Recommendations for Policy and Programs*†

TEN working groups were appointed at the beginning of the Papua New Guinea Food and Nutrition 2000 Conference. Their task was to draw important policy and program recommendations from the papers presented and the discussion that followed them. The groups were assigned the following topics: food security, human nutrition, food shortages and the 1997 drought, sweet potato, other root crops, nonroot crops, animal production, resource management, information and extension, and food processing.

The main findings of the working groups were presented in the final session of the conference and are summarised here in a condensed form. They are addressed in more detail in many of the papers in these proceedings.

## Food Security

Food security exists when all people at all times, have access to safe and sufficient food that meets their dietary needs and food preferences for an active and healthy life. Food security is not the same as self-sufficiency in food. A nation, or a region, may be self-sufficient in locally produced food and yet many people may have inadequate food security. Conversely, a nation may be food secure, but may not be self-sufficient in all foods.

Food security is generally good in PNG. It has improved significantly over the past 100 years, and especially over the past 50 years. There are two major reasons for this:

- the introduction and adoption of new species, including sweet potato, cassava, Chinese taro and maize, which offer advantages over the older crops; and
- the development of a cash economy and the capacity of many people to purchase food with cash when their own subsistence supply is insufficient.

Despite the sweeping changes that have occurred in PNG, especially over the past half century, both rural and urban people are still vulnerable to short-term and long-term food supply problems. The main threats to food security in PNG are:

- high population growth rates—the present population will double in 30 years at existing growth rates—which means that food supply must also at least double in that time;
- land degradation—in particular the reduction of soil fertility—which is reducing food production;

* Summary of the concluding session of the conference chaired by Valentine Kambori, National Agricultural Research Institute (NARI), PO Box 4415, Lae, Morobe Province, PNG

† Compiled by Valentine Kambori, NARI from notes made by the 10 working groups and edited by the Proceedings editors, with assistance from Bryant Allen.

- the climate—most importantly high rainfall, and to a lesser extent periodic drought and frost—which will continue to influence the production of food; and
- low cash incomes—which in many places remain very low and are getting lower—giving people less chance of purchasing food when they need to.

There are also a number of other less certain influences on food security, including the developing HIV/AIDS epidemic and global climatic change.

Threats to food security are greater in some parts of PNG than others. For example, locations most vulnerable to population pressure on land and consequent degradation are small and very small islands with high population densities (over 100 people per square kilometre) and high altitude locations (above 2200 metres).

The capacity of people in PNG to counter some of these threats to food security is less now than it was 20 years ago. The major gains in food security in the last 100 years brought about by the adoption of new and superior food crops are unlikely to be repeated, as most of the possible introductions have now been made. As well, production of many cash crop commodities is stagnant and there is little adoption of new technologies.

There are two broad areas, however, through which food security in PNG could be enhanced. The first is carefully focused research on:

- the improvement of crop and animal production;
- resource management issues, including soil fertility maintenance;
- the agronomic and economic evaluation of alternative cash crops;
- the transport and marketing of locally produced foods, including root crops; and
- the international marketing of agricultural produce.

The second is improvement of the cash earning capacity of the poorest people, both urban and rural. Small improvements in cash incomes for very poor people will result in disproportionately large improvements in their food security, as well as in other aspects of their lives, including their ability to access health and education services. Factors that will enhance people's cash income include:

- maintenance of transport infrastructure, including roads, bridges, wharves and airstrips;
- maintenance of communications infrastructure, through which information can be distributed to rural areas, in particular radio, print media and telephone communications;
- delivery of information to villagers, particularly on subsistence food production, animal production and cash crops;
- improvement in the provision of financial services to rural people, including the ability to securely move small amounts of money around the country at low cost;
- securing public highways and ports against criminal activity, which seriously limits people's willingness to travel to markets to sell produce.

## Human Nutrition

Child malnutrition remains a major problem in PNG, with about 40% of children under 5 years of age affected. The causes of malnutrition and other nutrition-related health problems are complex and can be addressed only through cooperation and collaboration between all levels of government and the community. There are a number of factors that influence human nutrition. Some of the issues and possible solutions are as follows.

- Transport, communications and health services infrastructure needs to be developed and maintained.
- The general health and nutritional status of women is very important for the wellbeing of the whole family. In particular, infectious diseases such as malaria, sexually transmitted diseases and HIV/AIDS result in malnutrition in women, low birthweight babies and high death rates among birthing women.
- The health of both women and children is affected by the diet of mothers. A reduction in the number of children each woman has, and increased spacing between births, would improve the health of mothers and their children.
- Women have a very high workload, which affects their health. Improvement of village water and firewood supplies, including bringing them closer to villages, and increased backyard gardening would help to reduce the workload.
- Men need to be educated about the relationship between women's health, workload and the health of their children.
- An increase in the number of girls going to school would also help to improve women's health through improvement in the general levels of education and literacy among women.
- In communities where child malnutrition rates are high, mothers need to be educated in the importance of maternal health and nutrition and the provision of special weaning foods (the development of a cheap and readily available weaning food would assist in this goal).
- Village diets could be improved by encouraging and assisting households to produce more high-protein legumes and cereals, use more meat from small animals or fish, and earn more cash with which to purchase high-quality food.
- There is a lack of information about the levels of malnutrition in children (the last national survey was held in 1982–83) and new baseline data are required. However, the country's capacity to carry out surveys or to deliver advice on nutritional problems has been almost completely removed by the loss of most Provincial Nutritionist positions in more than half of the provinces in the country, and the lack of any professional nutritional training in PNG.
- To overcome these difficulties the government departments responsible for subsistence agriculture, health and education need to work together, at provincial and national levels.

## Crop Production

Crop production must be improved in PNG to meet the demands of a rapidly growing population. This section provides recommendations for how that might be achieved for individual crops.

### Sweet potato

- Sweet potato is the most important food in PNG, whether measured by production, number of people who depend on it as their staple food, or food intake.
- It contributes more calories to rural Papua New Guineans' diets than all other root crops, banana and sago combined. It is also an important cash crop.
- Important considerations for this crop are:
  - new cultivars need to be identified, evaluated and distributed to villagers;
  - the relationship between crop growth and soil moisture extremes is poorly understood; and
  - other important unresolved issues are an apparent yield decline over time, the role of various plant diseases and control of sweet potato weevil.

There has been a significant amount of research on sweet potato in PNG. A major review is needed on what is known about the crop, major problems, and research and development needs. New extension material should also be generated as a high priority (see The Status of Sweet Potato Variety Evaluation in PNG and Recommendations for Further Research by Paul Van Wijmeersch, and Review of Sweet Potato Diseases in PNG by Pere Kokoa, in these proceedings).

### Banana

- Banana is a widespread food in PNG and is the most important food in a number of locations, including some with both relatively low and very high annual rainfall.
- It was an important backup food during the 1997 drought when root crops failed completely.
- A number of significant pest and disease problems and other potential problems may arise if the quarantine barrier is breached (see Quarantine, below).

There has been only a limited amount of research on banana in PNG (see Review of Germplasm Collections and Agronomic Research on Bananas in PNG by R.N. Kambuou, in these proceedings). Previous research, development experience with the crop, and future research and development needs should be reviewed.

### Sago

- Sago is an important food, particularly in five lowlands provinces with permanent flooding. It is an important emergency or minor food in many lowland locations.
- It also has considerable potential for industrial starch production purposes and as domestically marketed food.

Some of the past research and development experience with sago was reviewed at the first National PNG Sago Conference in 1999 (see Sago Starch, Food Security and Nutrition in PNG: the Triple Web by P.A. Sopade, in these proceedings). It is anticipated that further recommendations for policy and programs will arise from the $7^{th}$ International Sago Symposium that will be held in Port Moresby in mid-2001.

### Cassava

- Cassava is a relatively minor food in PNG, but it is growing in importance, especially in locations where there is pressure on land or in difficult environments, such as locations with very high rainfall.
- It is currently a minor stockfeed, but there is potential for a greater role as a stockfeed.

The crop's status and previous research has been reviewed in a National Agricultural Research Institute Cassava Workshop. It is recommended that a limited research program be initiated on cassava, focusing on evaluating superior cultivars.

### Taro

- Taro (*Colocasia esculenta*) is grown widely in PNG. However, the significance of taro as a subsistence food has declined greatly over the past 60 years. Many former taro growers have switched to sweet potato or other food crops.
- Important considerations for this crop are:
  - it is now sold in significant quantities in fresh food markets at a higher price than the other root crops;
  - it suffers from a number of serious pest and disease problems, including taro leaf blight, taro beetle and viral diseases; resistance to some of these diseases is evolving and these strains need to be identified; and
  - it does not tolerate poor soils well, and yields are low where soil fertility has been reduced by land degradation caused by intensive land use.

There has been a reasonable amount of research on taro in PNG, but few of the findings have been applied by village growers. It is recommended that the current knowledge, previous research and the crop's status should be reviewed and that recommendations be made for further research and development activities.

### Yams

- Yams are widely grown in both the highlands and lowlands, but are a significant food source only in restricted locations in the lowlands.

There has been a limited amount of research on yams in PNG (see Yams and Food Security in the Lowlands of PNG by J.B. Risimeri, in these proceedings). Dr Margaret Quinn and colleagues have conducted important research as part of the East Sepik Rural Development Project but this work is unpublished. It is recommended that Dr Quinn's work should be edited and published.

A National Yam Workshop should be convened to review the status of the crop, previous research, future development and research needs.

### Other crops

- There are some 400 food crops grown or gathered in PNG, many of which are very minor or obscure.
- Many food crops have unrealised potential as subsistence foods, as food for the domestic market or as export crops.
- The groups with the greatest potential are indigenous vegetables, introduced vegetables, fruit and nuts.

- There are many individual crop species that have unrealised potential for further expansion. The fruit include potato, avocado, mandarin, orange, rambutan, mango, mangosteen and durian.
- There are several indigenous nut-producing species that deserve attention, including nut pandanus (*karuka*), *Terminalia* spp. (*okari* and sea almond), *Canarium* spp. (*galip*) and *Inocarpus fagifer* (Polynesian chestnut).
- Among numerous vegetable species, there are several that are important or potentially so, including potato, bulb onion (see Bulb Onions: The Challenge of Reducing Dependence on Imported Onions by Geoff Wiles, in these proceedings), *aibika*, amaranthus and various brassicas.

Further focused research and development attention needs to be given to a number of these species. A major review is recommended to determine research and development priorities, with a focus on vegetable production in the highlands, production of all fresh food for the Port Moresby market, selected lowland fruit and selected indigenous nut species.

## Animal Production

Animal production is important to food security in two ways. Firstly, animals provide an essential source of protein in the subsistence diet and are therefore important in a nutritional sense. Secondly, livestock is becoming increasingly important as a source of income for people in rural and peri-urban areas. There is a need for the whole process of research to develop packages that are relevant to small-scale producers and to engage as many farmers in participatory research processes as possible. There is also a lack of information concerning levels of farmer adoption, numbers and performance of village livestock. The key issues in improving animal production are as follows.

### Chickens

- Market opportunities exist for the sale of live chickens, which can fetch prices up to twice that of frozen chickens in supermarkets.
- The most active group in the live chicken market is the peri-urban community. No formal assessment of peri-urban chicken rearing activities has been made. A peri-urban chicken production survey should be conducted.
- The main issue in peri-urban chicken production is the high cost of feed and the cost of day-old chickens. Alternative feed sources should be investigated that will reduce the cost of production.
- Before further recommendations are made to village chicken (and also duck) producers the reasons why past recommendations have been largely ignored needs to be understood.

### Goats

- Goats have been identified as an animal that could potentially provide benefits to a large number of rural families, and whose integration with traditional gardening and tree crop systems would contribute to sustainable agricultural production.

- A gap exists in empirical knowledge on numbers and performance and the overall issue of adoption. This lack of knowledge could be remedied through a smallholder survey of goat numbers, productivity and management.

**Cattle**

- The smallholder cattle industry in PNG is in decline. The Australian Centre for International Agricultural Research Red Meat Study confirmed this, whilst at the same time acknowledging the great potential of the sector (see Potential for Producing More Meat from Small-Scale Livestock Production by A.R. Quartermain, in these proceedings).
- The key reasons for the decline have been identified as:
  - ineffective extension and technical support;
  - unavailability of appropriate management packages and training; and
  - lack of credit.
- These shortfalls are to be addressed in the national cattle research and development strategy. There is strong industry support for cattle research and development.

**Rabbits**

- Rabbits are an animal with the potential to be well integrated into subsistence farming systems and they are starting to receive interest, especially in marginal areas, mainly through the work of missions and nongovernment organisations.
- Although smallholder rabbit production has not been fully assessed in terms of viability and sustainability, the key issues appear to be optimum feed and management systems.

**Pigs**

- Village pigs continue to retain their nation-wide importance both culturally and as a source of animal protein.
- The key issue for village pig production is to develop options for cheaper and more cost-effective feeds using locally available feeds such as copra meal, fishmeal, and other readily available starch and energy feed sources.

**Fish**

- Inland fisheries have the potential to contribute to the animal protein requirements of rural inland communities.
- A small but well-established system of extension and fingerling production exists that is currently not widely used.
- Preliminary evaluations at the project sites indicate very high production per hectare.
- The activity needs to be brought under a formal and well-supported program to carry out appropriate assessments on productivity, and to identify constraints and opportunities for efficiency and appropriate extension.

### Alternative animal feeds

A search for alternative feeds for animals in PNG has identified cassava as a potential substitute for grain imports that would alleviate the vulnerability of PNG to world grain shortages. The main constraint is the lack of knowledge on cassava's viability and performance as a feed source. A full study, including a pilot program, would be part of a research and development program.

## Quarantine

There are serious threats, in the form of pests, diseases and weeds, to subsistence food production from outside PNG, in particular from Indonesia but also from other parts of the world. The introduction of coffee rust into PNG in 1986 illustrates the nature of this problem.

The most important present problems are:

- fusarium wilt (or Panama disease) in banana, which is already present inside PNG in Western Province, to which it is thought to have spread from Irian Jaya;
- blood disease in banana, which has recently appeared in Irian Jaya (at Timika) and, because it is easily and rapidly spread by insects, is a serious threat to banana production in PNG; and
- fruit fly, because it restricts PNG's ability to export fruit to Australian and Asian markets; the PNG Fruit Fly Project has confirmed PNG as the centre of diversity for fruit flies and found that new fruit flies are entering PNG, while existing flies are spreading to new areas (see Fruit Fly Research and Development in PNG by S. Sar et al., in these proceedings).

To tackle these problems, PNG should improve funding and training within its quarantine service and should continue to cooperate with the Australian Quarantine and Inspection Service in particular and other national services in Indonesia and Southeast Asia. Clear strategies to deal with introductions of plant diseases from Indonesia should be devised and made public.

Increasing international air travel by PNG citizens and the frequent and poorly controlled contacts between PNG villagers all around the coast and international logging ships are of concern.

## Resource Management

- Widespread evidence exists of soil degradation caused by the intensification of agriculture. Soil degradation is also occurring in some areas because of logging and mining.
- Other factors that are limiting the productivity of arable land are the spread of invasive exotic weeds and issues concerned with customary land tenure.
- The loss of soil fertility is apparent in the Wahgi valley, the Gazelle Peninsula and the most densely settled parts of Simbu Province. Elsewhere agricultural land is being used unwisely. If soil conditions are not monitored and appropriate control measures implemented, many areas of PNG will be much less productive in 20 years time.
- No national policy exists on the issue of sustainable resource use and there are no systems in place to effectively monitor and provide a regulatory framework that will ensure sustainable use of land resources.

- A national policy will address land management, land tenure (the problems of customary land not in productive agriculture use) and weed management.
- Specific approaches to land degradation problems will include the establishment of a monitoring system (probably based on geographical information systems (GIS)—PNG already has a lot of baseline information at the national level) and practical advice for villagers.

## Information and Extension

- The prevailing state of collapse in information and extension is a major weakness in research and development integration and a serious impediment to maintaining or improving food security in PNG.
- Major problems in the government extension services include:
  – duplication and overlapping programs;
  – the absence of a nationally integrated system that provides an effective link between all agencies (from research to development), including NGOs, church organisations, community groups and the private sector; and
  – the large backlog of relevant agricultural research that has never been reported in a form suitable for extension.
- Recent attempts to overcome this problem include the privatisation of extension services—the Asian Development Bank project in Morobe and Eastern Highlands provinces has a pilot project for outsourcing the provision of extension services to private agencies.
- There is a lot of information, much of which is held in computer-managed databases, about conditions that influence food production and nutrition in PNG. This includes information on the physical environment, including climate, soils, landforms and forests; village agricultural practices, cash cropping, crop growth potential and limitations; children’s nutritional status; and relevent published and unpublished reports, papers and books. More is known about the whole of PNG than for most other developing nations. However, the potential for these databases to inform planning, development and research has only been partially used. There is a need to train university students and professionals in the public and private sectors in accessing, manipulating and analysing this information, so that it can be used to develop sound policies and to implement effective development programs.

## Food Processing

Food processing and preservation have the potential to improve food security by extending the availability of seasonal food crops and by providing a source of cash income for people in rural and peri-urban areas. The most important issues are as follows.

- Food processing and preservation research in PNG has been limited and has not been undertaken as part of a formal, integrated research and development program.
- Work has been targeted towards the development of home and household food processing and preservation and the adoption of small-scale processing technologies.
- The uptake or impact of these development activities has not been systematically assessed or evaluated. Much of the research work remains unpublished and is not widely available within PNG.

- Commercial and industrial opportunities exist for the processing and preservation of traditional foods both for domestic consumption and international markets but not enough is presently known about demand and market potential.
- No national policy on food processing exists. A national policy on food processing should be established to ensure standards in the quality of processed food intended for human consumption and the introduction of food items that contain genetically modified organisms (GMOs).
- A national forum should be organised to review the state of knowledge in food processing and preservation (specifically related to past research work) and to assess opportunities and constraints regarding the development of a national research and development agenda that is relevant, focused, and has a sound socioeconomic rationale.

## Conclusion

A number of common themes emerge from these recommendations. They mainly involve what can be termed 'issues of governance', including:

- the importance of maintaining existing infrastructure, especially roads, schools and health facilities, and human resources in the form of skilled researchers, technical and field staff and experienced administrators;
- the need for cooperation and collaboration between government departments, both at the national level and between the national and provincial levels;
- the need for clearly stated policies to deal with many of the problems identified and practical and robust plans to implement them.
- the need for present day workers to access previous research findings and development experience, including reviews of what is known about issues and the publication of good quality research results that are currently unpublished.

Overall there is a critical need to upgrade the ability of government and other organisations to communicate information about agriculture, nutrition, health and resource management issues to rural villagers.