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CONTENTS

ENVIRONMENTAL IMPLICATIONS OF LIVESTOCK PRODUCTION IN PAPUA NEW GUINEA

Alan R. Quartermain[1]

ABSTRACT

Papua New Guinea (PNG) has a 5000 year history of the integration of livestock into subsistence food crop farming systems. The potential for significant environmental impacts only appeared with plantation agriculture and cattle ranching some 110 years ago. Even then, the impacts have been minimal but have been increasing over the last 30 years or so due to population pressures on agricultural land use. Global concerns over the sustainability of mixed crop-livestock systems are of relevance in PNG due to intensification of land use and reduction in the capacity of traditional responses to cope. The effective integration of livestock into cropping systems has been and will increasingly be one of the more important coping strategies. Mixed farming allows for the recycling of nutrients and the effective utilization of waste products from all sectors of the system. The likely future scenario is for increasing intensification together with increasing demand for livestock products. Options to meet these demands include more effective use of underutilized animal feed resources, including crop by-products, pasture improvement on existing grazing land, more effective use of fallows and multi-purpose tree species, and the efficient recycling of animal manures.

Key Words: *Livestock production; intensification; environmental impact; sustainability, animal manure.*

INTRODUCTION

For the purposes of this paper it is necessary to consider separately the impact of the introduction of livestock into the Papua New Guinea environment, the current situation and the environmental implications of the possible or likely development pathways for livestock production in the future. Livestock here includes those domestic animal species currently important for meat or egg production and those, such as the rabbit, showing some promise for the future.

Historical Impacts

Historically the impact of domestic animals has been small or localised. Prior to the introduction of new species by colonial administrations and settlers (effectively pre -1880), domestic animals were confined to pigs, dogs and chickens. Environmental disturbance was almost entirely the consequence of the hunting and gathering activities and the clearance of land for gardening by people. That the consequences of perhaps 40,000 years of human occupation and 10,000 years of gardening have been substantial is evidenced by species extinction, reduction in returns from hunting and the replacement of rainforest by anthropogenic grasslands (Flannery 1994, Vasey 1989, Lea 1976, Henty 1969). Loss of rainforest habitat became increasingly serious with the population increases and expansion of agriculture following the introduction of sweet potato some 400 years ago (Allen *et al.* 1995).

It might be expected that chickens have had little or no effect on the environment. Domestic pigs and pigs gone feral have an impact associated with human activities in that they continue to disturb fallow land and forest peripheral to gardens after the completion of the garden cycle. Dwyer (1978) documents the results of a detailed study on the changes in the distribution and abundance of rodent species resulting from reduction and increased patchiness of forest, increased grassland and local habitat disturbance due to the activities of pigs and humans at an altitude of 2000-2500 m. While it is not sensible to separate the effects of these two species, the suggestion is that pigs maintain the disturbance after completion of gardening or woodcutting. Pigs can subsist on the wide range of edible items found in the rainforest. However, provided the populations remain low due to nutritional and genetic factors, and to hunting pressure, the damage should remain minimal.

Dogs, introduced probably some 3,500 years ago, are only important in terms of their role in increasing the efficiency of hunting and this may have had local significance in prey depletion. Titcomb (1969) gives a fascinating account of the role of dogs in traditional Pacific societies. The hunting of feral pigs was an important activity where they inhabited secondary

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vegetation and the fringe zones of primary forest, especially at lower altitudes i.e. below 1200m. This is described for Maring speaking peoples of the lower Bismarck Ranges by Clarke (1971) and, for a contrasting society, the Siuai of Bougainville by Oliver (1955). Flannery (1994) suggests that wild dogs (presumed originally from domestic stock) were responsible for several mammalian extinctions in the high altitude grasslands.

European colonists found a foot-hold in Papua New Guinea in the drier or seasonally dry parts of the country. They carried with them their grazing domestic animals but the impact of these remained small. Historical accounts of early plantation or settled agricultural development (see the series of papers in Denoon and Snowden 1981) give little indication of the existing vegetation on the alienated or settled land. No doubt some was garden land and much was already grassland, but much also was primary or re-growth forest. Allen (1981) refers to crops planted by the German New Guinea Company in land newly cleared from rainforest and there are anecdotal accounts of alienation for plantations of suitable land that was not in use because of land disputes between adjacent groups or because of fear of sorcery.

Europeans introduced the full range of their available livestock - cattle and buffalo, sheep and goats, pigs, poultry and equines. The availability and introduction of tropical breeds of cattle and sheep (Holmes *et al.* 1976) assisted the establishment of these species and goats clearly became adapted (Quartermain 1982). Initially the introduced grazing animals were solely associated with plantation developments, either as draught animals or grazed under coconuts to keep the vegetation clear as well as produce meat. The later development of large-scale cattle ranches and the concerted effort to establish small-holder cattle projects in the early 1970s (Densley *et al.* 1978) took place mainly in areas with existing grassland in the Markham-Ramu valleys, Central Province savannas, the Eastern Highlands and the Sepik plains.

It is not possible here to go into the rise and fall and subsequent stabilisation of the cattle industry. Suffice it to say that the total herd numbers peaked in 1976 at 153,200 and declined to 80,100 by 1991. Accurate recent figures are not available but there has probably been only a little change overall since 1991, but current numbers may have declined further to about 70,000 head. Sheep and goat numbers have grown over the last years but remain modest, perhaps 15-20 thousand of each species (Quartermain 2002), although there has never been a systematic count. These smaller grazing or browsing animals are kept in very small flocks utilising fallow or waste land. Their environmental impact is negligible. It has been estimated (see Table 8.1 of Levett and Bala 1995) that there are 445,635 ha of grazeable grassland out of a total grassland area of 550,097 ha. The current cattle herd would utilise about 128,000 ha only. The potentials for expansion are discussed later. While it could be concluded that grazing areas are under-utilised, especially on customary land, individual cattle projects may still be overstocked with the grassland subject to ongoing degradation.

Global Concerns

On a global scale there have been major concerns for many years over certain aspects of the environmental impact of livestock production systems. A major international study on livestock and the environment was recently commissioned by a consortium of agencies and governments (de Haan *et al.* 1997, Steinfeld *et al.* 1997) and this was followed up by an international conference (Nell 1998). The concerns were classified into three categories corresponding with grazing, mixed farming and industrial production systems. None of the concerns to do with the sustainability of pastoral systems - overgrazing, land degradation and desertification, deforestation for ranching and conflict with wildlife conservation - are of major relevance in Papua New Guinea. Likewise, problems of soil and water pollution resulting from waste disposal from intensive industrial production systems, mainly of pigs and poultry, are not yet of concern in Papua New Guinea and may not ever become serious since there are adequate technologies available for the safe disposal or utilisation of such wastes on the scales likely to be found appropriate. Wider concerns over the production of green-house gases, the transfer of nutrients from areas of feed production to those of high livestock concentration and losses of domestic animal genetic diversity are of relevance in Papua New Guinea but there are no immediate problems that should or can be addressed.

Concerns associated with mixed farming systems are however of immediate relevance in Papua New Guinea. Most farming in the world is carried out in mixed crop - livestock systems, covering 2.5 billion ha of land and producing 54 percent of the world's meat and 90 per cent of the milk. Over the last decade, the growth in meat production from these systems has been about two percent per year which is below the likely growth in demand for meat at about three percent per year. Resource use in the systems is often required to be self-sustaining as nutrients and energy flow back and forth between crops and livestock. This flow is mainly comprised of crop residues or surpluses and animal manures or draught animal power. While most farming systems in Papua New Guinea are not integrated in this way or to this degree, the concerns are the same. These concerns arise from increasing difficulty for a system to meet the demands for productivity being made and to cope with the resultant

nutrient depletion. This becomes particularly serious when cropping is expanded at the expense of livestock with the resultant losses in the benefits of mixed farming detailed below.

Pressures on Papua New Guinea Cropping Systems

Most traditional Papua New Guinea crop production systems rely on long fallow periods to restore and maintain soil fertility and soil structure and reduce the levels of pests and diseases. Typically and ideally for food crops a piece of land is cleared and cropped for one to three years before the vegetation is allowed to revert, preferably to rainforest, for periods up to or in excess of 20 years. It is not the purpose of this paper to go into detail concerning the incredible variety of systems which exist currently in Papua New Guinea. The Agricultural Systems Project has identified, mapped and described a total of 287 systems, published in a series of working papers covering all 19 provinces. The basic methodology and text summaries for the systems are given in two volumes by Bourke *et al.* (1998). What is important here is that the traditional systems have come to a greater or lesser extent under pressure and have been modified to cope. (Allen et al. 1995; Bourke and Allen 1995, Levett and Bala 1995, Vasey 1981, Wood and Humphreys 1982).

The main pressures can be summarised as follows -

1. Population increase - agriculture is supporting some 80 percent of the population which is doubling approximately every 30 years. This pressure is only minimally mitigated by rural to urban migration.

2. Alienation of land for cash cropping - mainly plantation mode tree crops. This has been an ongoing process since European colonisation. There are also social problems and gardening on unsuitable land caused by increasing distances between village settlements and food gardens due to the establishment of plantation type agricultural activities (coffee and cattle projects) near to village residences (Grossman 1984).

3. Keeping up with the Jones - the so-called Jones Effect (Watson 1997) - which attempted to explain social and production changes following the introduction of sweet potato but has its modern counterpart in increasing demand or desire for the products of an affluent society, including greater meat consumption.

Responses to the Pressures

Papua New Guinea farmers have responded to these pressures in a number of ways which can be summarised as follows –

1. Expansion onto previously unused (for agriculture) land as a result of reduction in inter-group hostility or the introduction of new technology. However, note the previously mentioned conversion of these lands for plantation cropping and also that most unused or lightly used land is unsuitable for agriculture because of excessive rainfall, inundation or steep slopes. The extent of the unused land can be clearly seen in the map of land use intensity (Figure 1).

2. Widespread replacement of traditional crops, particularly taro, by more productive or adaptable introductions including sweet potato, cassava, chinese taro (Xanthosoma), potato, maize and peanut.

3. Replacement of existing cultivars by more productive or adaptable cultivars.

4. Longer sequences of cropping before going into the fallow, often with the addition of a new crop to the sequence.

5. Shorter fallow periods with a resultant increase in the extent of grass rather than woody fallows. This is particularly serious in the lowlands where grass fallows appear less effective in fertility restoration than in the highlands.

6. Inovative technologies - a number of techniques are used by Papua New Guinea farmers to help maintain soil fertility in the face of intensification of land use. These include short fallows of two to 12 months between crops in the sequence; complete tillage; mounding; making of beds; mulching; composting; planted tree fallows (particularly Casuarina); legume rotations (peanut, winged beans); animal manure (see below); placing of pigs in gardens (see below); burning; and soil retention barriers.

Of major concern are the longer cropping sequences and shorter fallows. The ratio of cropping period to total cycle length is a measure of land use intensity used in the Agricultural Systems Project, the R value following Ruthenburg (1976). R value classes have been mapped (Figure 1) to indicate where in Papua New Guinea farmers have needed or been able to intensify production. Bougainville, the northern Gazelle Peninsula and the central highland valleys stand out.

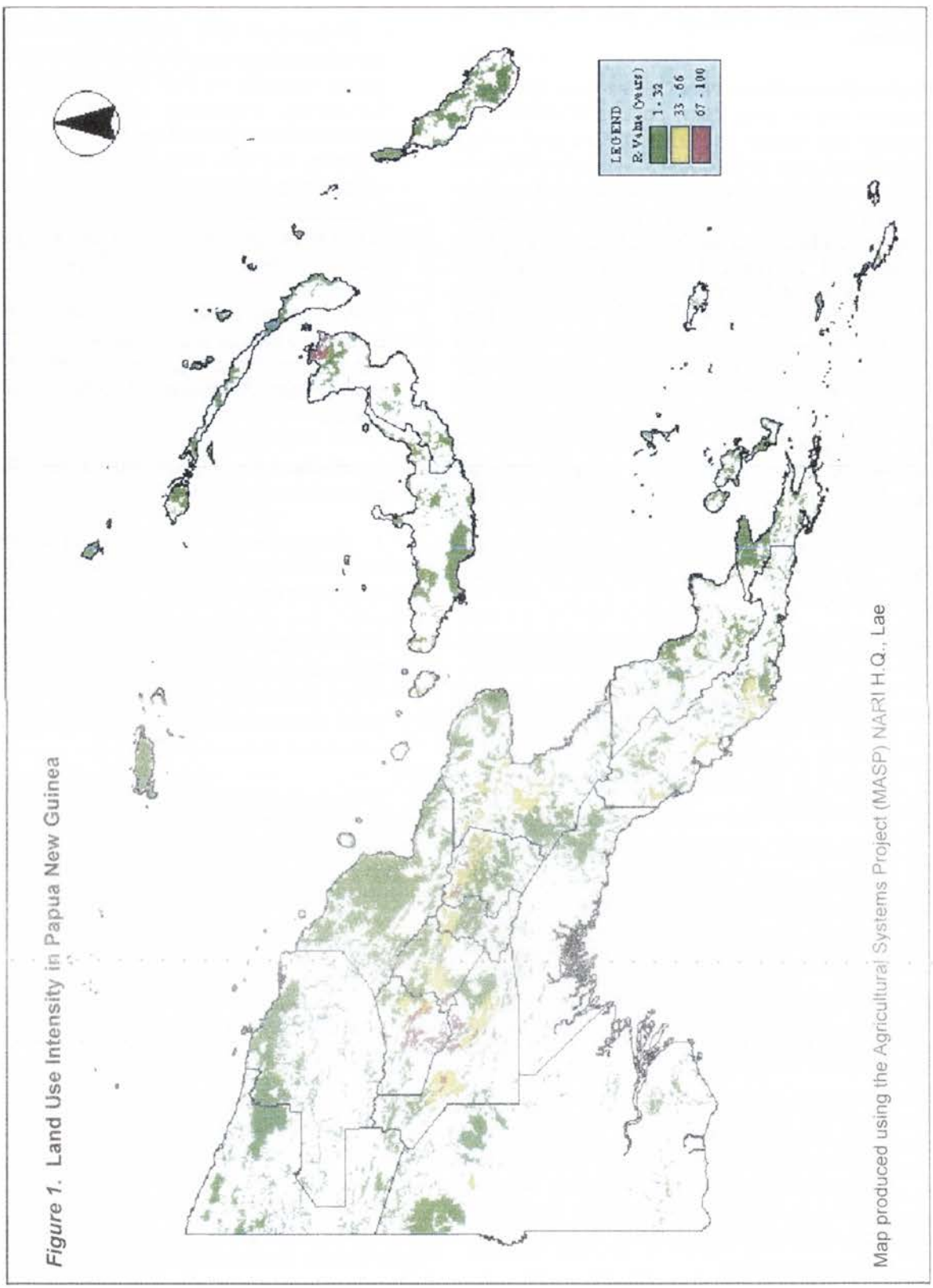

Figure 1. Land Use Intensity in Papua New Guinea

Roles for Livestock

It is necessary now to return to the main theme of this paper and discuss the role of livestock production in mitigating the adverse effects of intensified cropping. Quartermain (1975) produced a general account of roles for animals in food crop production systems in which he discussed the use of manures, crop residues, fallows and night pens, and the use of animals for weed control and as power units. Livestock make the best use of crop residues, by-products, wastes and surpluses compared to the alternatives of burning or direct incorporation into the soil. In mixed systems they can supply a high proportion of the soil nutrients required to sustain cropping through the use of manure either deliberately or from animals grazing or browsing on crop land between crops or in fallows. Manure improves soil structure through the addition of organic matter which may also be beneficial in maintaining the health and bio-diversity of soil micro-flora and fauna (de Haan *et al.* 1997). Animal manure increases the nutrient retention or cation exchange capacity of the soil and improves its physical condition, water holding capacity, structural stability and organic matter content.

In many systems in Papua New Guinea, pigs are allowed to forage in the fallows. The benefits or otherwise of this with respect to the fertility restoring role of the fallow are not clear. Pigs certainly have a sanitation role in consuming diseased un-harvested plant material and a range of garden pests. Rappaport (1968) describes how the Tsembaga people use pigs to benefit the secondary forest that is developing on abandoned garden sites by uprooting much of the herbaceous component and thinning the arboreal component. Rooting eliminates weeds and seedling trees, softens the ground and makes nutrients more readily available if the site is to be re-used for the next crop in the sequence. Some groups of people (including the Tsembaga and other Maring speaking peoples) practice the deliberate placing of pigs in gardens between crops during the cropping sequence. This practice has been mapped by the Agricultural Systems Project and a map showing the systems in which the practice was recorded is given as Figure 2. Peoples for whom this is significant include the Goilala, Anga, northern Simbu, Maring, southern Enga and the Huli.

The only other system in Papua New Guinea in which livestock are integrated with cropping is the grazing of cattle in coconut plantations. There are some 265,000 ha of coconut plantings in Papua New Guinea but about 40 percent of this is inter-planted with cocoa (Nevenimo 1989). Locations without intercropping tend to be those with poorer soils or a climate unsuited to cocoa such as in much of Central, Morobe and Milne Bay Provinces. Nevertheless, grazing under coconuts may remain or can be made economically viable with the advantages of reduced understory maintenance costs, higher nut recovery and a more efficient re-cycling of nutrients. However, currently probably less than 10 percent of the national cattle herd is grazed under coconuts.

Research work in Papua New Guinea has unequivocally demonstrated the benefits of the use of animal manures for crop production. A bibliography of published work is given in Appendix 1. It is probably unnecessary to do any more work to further demonstrate the obvious benefits. What is needed is consideration of how to use the limited material likely to be available in the most effective manner with the least cost in handling. Nutrient balance in a system (essentially the balance of gains and losses of N, P and K) is the over-riding crucial factor in determining the environmental impact of that system (Blackburn 1998). While mixed farming does not generate nutrients, except through the fixation of N by planted legumes, it does allow for nutrient transfers both spatial and temporal from one part of a system to another, accelerates nutrient turn-over and reduces nutrient losses. Mixed farming allows the use of waste products from one sector as inputs to another sector, e.g. by-products and manure.

Future Developments in Livestock Production

It is timely to give consideration to likely future developments in livestock production, giving attention to the mitigation of any possible adverse environmental effects and capturing the benefits of mixed farming. The integration of crops and livestock may be the only way to achieve or sustain intensification of food production and satisfy the demand for meat which might be expected to continue to grow at a rate of at least five percent per year commensurate with a population growth rate of 2.0 - 2.5 percent and anticipated increases in affluence. Mixed farming diversifies risk, uses labor more efficiently, generates increased cash income and adds value to low value or surplus feed. The environmental benefits could include the maintenance of soil fertility, replenishment of soil nutrients, possible reduction in erosion and reduced pressure to shorten the fallow period. The utilisation of the fallow by livestock can add value to the system and help justify the maintenance of a mosaic of vegetation types including multi-purpose tree species (MPTS) and edible soil retention barriers. Livestock can help prevent the collapse of intensive or intensifying cropping systems.

Research and development is now required to determine the best ways of achieving the benefits of mixed farming. Little need be said in this context

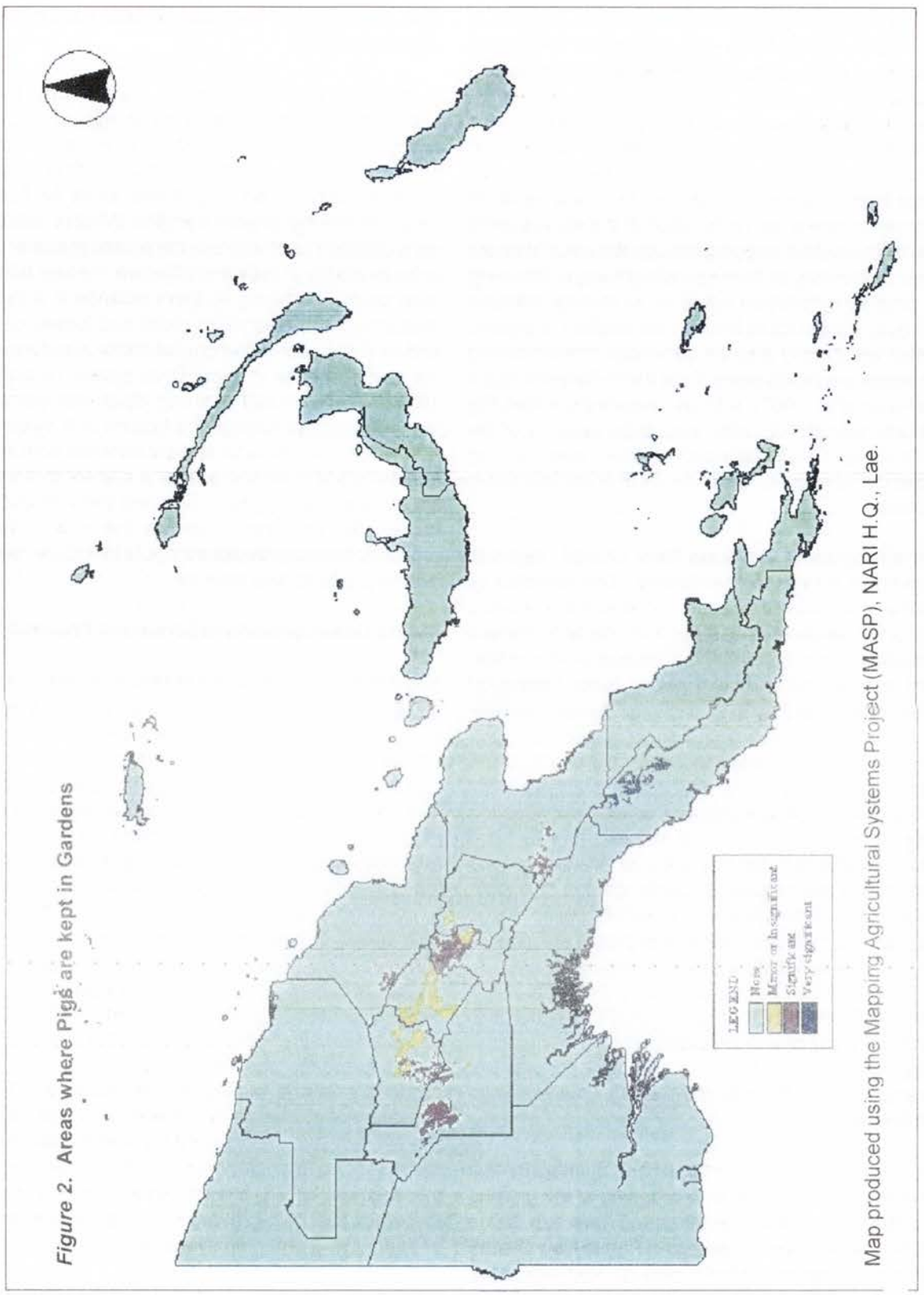

Figure 2. Areas where Pigs are kept in Gardens

regarding the intensive production of pig meat and poultry products except that the production systems must make maximum use of the available crop by-products, that local small-scale production is more likely to result in manure being used on gardens than larger-scale intensive peri-urban production and that one-way transfer of nutrients from arable feed grain, grain legume or root crop production areas to areas of livestock concentration is avoided as far as possible. The household production of meat from the smaller domestic animals such as rabbits, ducks and chickens can result in utilisable manure, but only from the poultry species if suitable night-housing systems are adopted. Sheep and goats are the species of choice for more intensive utilisation of waste lands and fallows. As indicated, pressure to reduce the fallow length can be mitigated if livestock can make economic use of this phase in the cycle, especially where grass fallows are now the norm. Fallows can be improved for livestock use through the planting of MPTS or the sowing of grazeable legumes. Research has been and is being done in Papua New Guinea on MPTS, including species suitable for livestock feeding. The situation as in 1992 and proposals for on-going work were reviewed by the Forest Research Institute (Nir and Srivastava 1992) and by Brook (1992). Research work is on-going in the National Agricultural Research Institute and the Papua New Guinea University of Technology.

There remains the need to consider further expansion of cattle production from natural grasslands (albeit anthropogenic) or sown pastures. It is most unlikely that primary forest would be clear felled for the establishment of cattle ranches. Any use of forest land for agriculture would be for the establishment of tree crop plantations. Due to a general shortage of good agricultural land not already in the garden cycle, any future development is likely to be crop oriented. However, as mentioned earlier, the estimated 445,000 ha of grazeable grassland is under-utilised and the theoretical national herd could be increased to some 300,000 head. In addition to the open grassland, there are up to 150,000 ha of coconut plantation not under-planted with cocoa, some 26,000 ha of smallholder oil palm and 22,000 ha of rubber which could be considered for sheep and goat production if not for cattle. The establishment of sown pastures in the near future may be restricted to the Markham-Ramu valleys where there may be some 60,000 ha of grassland still available for development. Overall growth in cattle production is constrained by, above all, accessibility to markets and long-term land tenure. Social inequalities and other problems caused by the establishment of cattle projects on grass fallow land have already been mentioned and are discussed fully by Grossman (1984) for a specific Eastern Highlands situation. Other constraints to pasture development include high interest rates, short lending terms and low returns on capital investment.

The grazing of natural grasslands should not cause any environmental problems provided that stocking rates are controlled to levels that allow the maintenance of good grass cover and prevent weed invasion. The sustainability of pastoral systems in Papua New Guinea is almost entirely a function of stocking rate and intensification of production should be undertaken using by-products (e.g. palm kernel meal) as supplementary feeds while maintaining low stocking rates. Details of such production systems cannot be discussed further here but clearly the location of sources of supplementary feeds is another constraining factor for cattle production. Avoidance of the use of alpine grasslands and those on steep slopes should help the maintenance of bio-diversity and indigenous grassland eco-systems.

Finally there are potential benefits to the environment from the promotion of livestock production not previously mentioned. Increased animal production could reduce pressure on hunted game in a reversal of the historical process in which reduced returns from hunting were an encouragement to domestic animal production. The promotion of the use of MPTS could reduce the pressure on the forest for firewood while the use of animal manures and research into biological control measures for weeds, pests and diseases should reduce pressures to use artificial fertilisers and agri-chemicals. The further development of livestock production should be undertaken with the maximum possible degree of local-level participatory planning to ensure the likelyhood of harmony with the total environment.

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APPENDIX 1

REFERENCES ON THE USE OF ANIMAL MANURE ON FOOD CROPS PAPUA NEW GUINEA

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DISTRIBUTION AND ALTERNATIVE HOSTS OF TARO BACILLIFORM BADNAVIRUS IN SAMOA

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ABSTRACT

The distribution and alternate hosts of Taro bacilliform badnavirus was investigated through field surveys for infected taro plants on Upolu and Savaii islands in Samoa during 2001. Investigations into alternative hosts were carried out through field surveys for symptoms of infection on non-taro plants growing within or around taro farms on Upolu Island. In both cases, and in addition to visual observation for symptoms of infection by the virus, plant specimens were collected and subjected to PCR-based diagnostic tests for the virus. Results for the distribution of Taro bacilliform virus revealed that the virus occurs on both Upolu and Savaii Islands. The findings further showed that the virus is presently more widespread than was found by an earlier investigator. Alternative host studies revealed that Xanthosoma sp., Alocasia macrorrhiza, and Commelina benghalensis are natural hosts of the virus.

Key words: *Alocasia macrorrhiza,* alternative host, *Commelina benghalensis*, geographical distribution, Samoa, *Taro bacilliform virus, Xanthosoma* sp.

INTRODUCTION

Taro bacilliform badnavirus (TaBV) infects taro, causing slight stunting, chlorosis of marginal leaf veins, and downward curling of leaf blades (Yang *et al.* 2003). The virus is transmitted by mealybugs (Gollifer *et al.* 1977). Findings of recent investigations by the present authors have revealed that the virus is also seed- and pollen-transmitted (Macanawai *et al.* in press, 2005). According to Brunt *et al.* (1990), Taro (*Colocasia esculenta* L.) is the natural host of TaBV. There is no information in the literature to suggest that infection by TaBV alone has significant effect on the yield of taro. However, the virus is viewed as an important quarantine pest (Zettler *et al.* 1989), as concurrent infection of taro plants by TaBV and Colocasia bobone disease virus (CBDV) leads to the lethal 'alomae' disease complex (James *et al.* 1973; Rodoni 1995), severe cases of which can result in total crop loss (Jackson 1980; Onwueme 1999). Alomae disease is present in Papua New Guinea and the Solomon Islands (Gollifer *et al.* 1977; Jackson 1980).

TaBV was first reported in C. esculenta from the Solomon Islands (Kenten and Woods 1973). It has since been recorded, also in taro, in several pacific island countries; including Papua New Guinea, Fiji, Vanuatu (Gollifer *et al.* 1977), and Samoa (Jackson 1979).

In Samoa, TaBV was first recorded in 1978 (Jackson 1979), but during a survey that Jackson conducted on Upolu and Savaii islands in 1979, he found the virus only on Upolu Island, and only at one location at Tanumalala village, about 32 km south-west of Apia (Jackson 1979).

The first objective of the present investigation was to review the status of the geographical distribution of TaBV in taro in Samoa. The second objective was to determine whether TaBV has alternate and natural hosts in Samoa. Alternative hosts are important in the epidemiology of several plant diseases. For instance, weeds may act as reservoirs of pathogens (Duffus 1971; Aftab *et al.* 2001). Therefore, the identification of alternative hosts would facilitate the development of more effective disease management strategies.

MATERIALS AND METHODS

Surveys for distribution of TaBV

Seventy-six taro farms (55 farms in 41 villages on Upolu Island and 21 farms in 21 villages on Savaii Island) were surveyed during 2001 (Fig. 1). Taro plots carrying three to four month old plants, mainly variety 'PSB-G2' (Philippine Seedboard-Gabbi 2), were selected at random and visually examined for plants exhibiting

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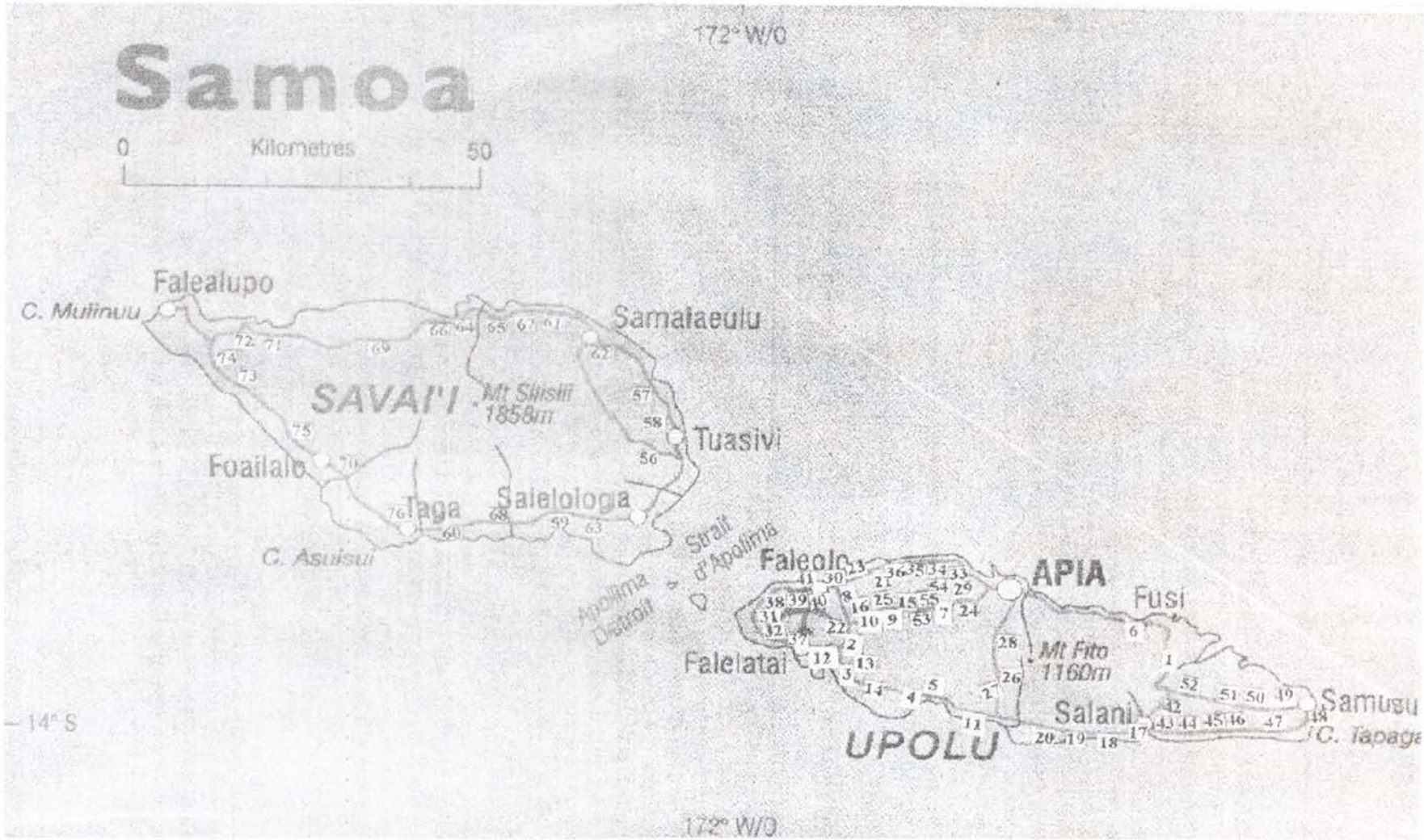
Fig. 1. **Map of Samoa showing numbered locations of taro farms surveyed for *Taro bacilliform virus* during 2001. (Source: Map adapted from Anonymous, 1997).**



symptoms of infection by TaBV. Between 75 and 500 randomly selected plants per plot were examined. Other taro cultivars ('Niue', 'Palau 4', 'Palau 10', 'Palau 20' and 'Pwetepwet'), which were present in the survey areas, were also sampled for TaBV symptoms. After visual examination, a 6 cm x 6 cm leaf section was removed for laboratory analysis from each plant that showed symptoms of infection. The leaf sections were cut into thin strips, dried under silica gel, and sent to Queensland University of Technology (QUT), Brisbane, Australia, where they were tested for TaBV by polymerase chain reaction (PCR) tests.

On Savaii Island, no taro plants showing symptoms were encountered during the survey. However, leaf specimens for diagnostic tests were randomly collected from symptomless taro plants.

Surveys for alternative hosts of TaBV

This investigation on alternate hosts of TaBV was conducted during 2001 on Upolu Island, around the villages of Falesiu-uta and Falesiu. Non-taro plants, such as small weeds, shrubs/trees, and crop plants, which were growing within or bordering each of six farms that were known to carry TaBV-infected taro plants (variety 'PSB-G2'), were visually examined for TaBV-like symptoms. In addition to visual examination, one to three youngest expanded leaves were collected from each species for laboratory analysis for TaBV, irrespective of whether the plants displayed symptoms of virus infection or not. Leaf samples were then prepared as described above for taro leaves, and sent to QUT for PCR analysis for the presence of TaBV.

RESULTS

Distribution of TaBV

Taro plants with TaBV-like symptoms were recorded on eight farms in four villages on Upolu Island (Table 1). Five of the eight farms were located around Falesiu-uta village, where the cultivars 'PSB-G2', 'Palau 4', Palau 20' and 'Pwetpwet', manifested the symptoms. In addition to 'PSB-G2', cultivar 'Palau 10' was found with TaBV-like symptoms in the village of Falesiu. Other observations of TaBV symptomatic plants were from Nuu and Manono on cultivar 'PSB-G2'. In all cases, leaf specimens from all symptomatic plants tested TaBV-positive by PCR-based tests.

No TaBV symptomatic taro plants were observed on any of the farms surveyed on Savaii Island. However, the virus was diagnosed by PCR tests in symptomless specimens collected from Paia village (cultivar 'PSB-G2') and Aopo village (cultivar 'Niue').

Alternative hosts of TaBV

Thirty-five plant species belonging to eighteen families were sampled and tested for TaBV. Of these, TaBV-like symptoms were observed on benghal dayflower (Commelina benghalensis L.), tannia (Xanthosoma sagittifolium (L.) Schott), and giant taro (Alocasia macrorrhiza Linnaeus). PCR tests confirmed all the symptomatic plants as TaBV-positive (Table 2).

DISCUSSION

The present study has recorded, for the first time, the occurrence of Taro bacilliform virus in the Samoan island of Savaii. In terms of overall distribution in Samoa, the investigation revealed that TaBV occurs in more locations than was observed in a 1979 survey by Jackson (1979). Furthermore, the detection of TaBV in symptomless taro plants from Savaii suggests the occurrence of latent infections. Yang *et al.* (2003) have indicated that many infections of TaBV appear to be latent. This suggests that the virus may be occurring in more areas than was recorded in the present study, especially on Upolu Island where specimens were collected only from symptomatic plants.

TaBV is a quarantine pest (Zettler *et al.* (1989), even though infection by the virus alone is not known to cause any significant yield loss in taro. Nevertheless, the virus could become extremely important because the lethal 'alomae' disease is thought to be caused by concurrent infection of taro by CBDV and TaBV (James *et al.* 1973; Rodoni 1995). Therefore, the presence and apparent increase in geographical spread of TaBV in Samoa constitutes a risk of alomae attack in this country. At present, CBDV has not yet been detected in Samoa, and efforts must be made to keep it away. Furthermore, precautions should be taken to curb further spread of TaBV within the country.

The presence of TaBV in C. benghalensis, A. macrorrhiza and X. sagittifolium in the field shows that the natural host range of this virus is not restricted to C. esculenta, as suggested by Brunt *et al.* (1990). This finding suggests that these, and possibly other non-taro plants may be potential reservoirs for the virus in the natural cropping environment. This information could be of significance in the management of TaBV.

ACKNOWLEDGEMENTS

We acknowledge the Australian Centre for International Agricultural Research (ACIAR) for funding the research, The University of the South Pacific's School of

Table 1. **Results from survey of taro farms for geographical distribution of Taro bacilliform virus (TaBV) in Samoa during 2001.**

Locations of taro farms surveyed on Upolu Island (villages)	Status of TaBV	Locations of taro farms surveyed on Upolu Island (villages)	Status of TaBV	Locations of taro farms surveyed on Savaii Island (villages)	Status of TaBV
Falevao (1)*	-	Valuu-tai (30)	-	Fusi (56)	-
Gagaifo (3)	-	Manono (31)	+	Asaga (57)	-
Saanapu (4, 14)	-	Siufaga (32)	-	Saasaai (58)	-
Lotofaga (5, 43, 52)	-	Vaitele-uta (33)	-	Palauli (59)	-
Fusi (6)	-	Puipa'a (34)	-	Gataivai (60)	-
Aleisa (7)	-	Afega (35, 45)	-	Safai (61)	-
Leulumoega (8, 16)	-	Saleimoalevi (36)	-	Samalaeulu (62)	-
Tanumalala (2, 10, 22)	-	Felelatai (37)	-	Salelologa (63)	-
		Manono-uta (38)	-	Sasina (64)	-
Tafitoala (11)	-	Satui Malufilufi (39)	-	Paia (65)	+
Safaatoa (12)	-	Fuaiolo'o (40)	-	Letui (66)	-
Tafagamanu (13)	-	Satapuala (41)	-	Avao (67)	-
Faleasiu-uta (9, 15, 25, 53, 55)	+	Lotofaga-uta (42)	-	Satufia-uta (68)	-
		Vavau (44)	-	Aopo (69)	+
Salani-tupai (17)	-	Saleapaga (46)	-	Salailua (70)	-
Vaovai (18)	-	Lalomanu (47)	-	Vaisala (71)	-
Saleilua (19)	-	Mutialele (48)	-	Papa (72)	-
Siumu (20, 26, 27)	-	Samusu-uta (49)	-	Falelima (73)	-
Siusega (24, 29)		Tiavea-uta (50)	-	Neiafu-uta (74)	-
Faleasiu (21)	+	Afulilo (51)	-	Samatau (75)	-
Nofoalii (23)	-	Nuu (54)	+	Taga (76)	-
Vailima (28)	-				

+ TaBV detected; - TaBV not detected

* Numbers in parenthesis represent the location of each farm surveyed in each village as shown in Fig. 1

Agriculture at Alafua Campus in Samoa, for providing research facilities, and the Ministry of Agriculture, Forests, Fisheries & Meteorology, Samoa, for providing support with the field surveys. We also thank Samoa taro farmers for allowing their farms to be surveyed, as well as Dr. G. Hafner and Mr. L. Devitt of QUT, for PCR-based diagnostic tests.

Table 2. **Result of field survey for alternative hosts of Taro bacilliform virus (TaBV) in Samoa.**

Scientific name	Common name	Virus-like symptom observed	TaBV status
Bidens pilosa	Spanish needle	Interveinal chlorosis	-
Hyptis pectinata	Comb bushmint	None	-
Mikania micrantha	Mile-a-minute	Interveinal chlorosis	-
Ageratum conyzoides	Goat weed	None	-
Emilia sonchifolia	Consumption weed	None	-
Crassocephalum crepidioides	Thick head	Interveinal chlorosis	-
Eleutheranthera ruderalis	Ogiera	Interveinal chlorosis	-
Synedrella nodiflora	Cinderella weed	Interveinal chlorosis	-
Paspalum conjugatum	Sour grass	None	-
Digitaria ciliaris	Bamboo grass	None	-
Digitaria setigera	Bristly crabgrass	Leaf chlorosis	-
Lantana camara	Lantana	Interveinal chlorosis	-
Cassia tora	Wild peanut	None	-
Stachytarpheta urticifolia	Blue rat's tail	None	-
Euphorbia hirta	Garden spurge	None	-
Phyllanthus amarus	Carry me seed	Interveinal chlorosis	-
Spermacoce assurgens	White broomweed	None	-
Oxalis barrellieri	Barrelier's woodsorrel	Interveinal chlorosis	-
Peperomia pellucida	Shiny bush	None	-
Alocasia macrorrhiza	Giant taro	Chlorosis of marginal veins	+
Xanthosoma sagittifolium	Tannia	Chlorosis of marginal veins	+
Momordica charantia	Bitter gourd	Interveinal chlorosis	-
Solanum nigrum	Black nightshade	None	-
Physalis angulata	Wild cape gooseberry	None	-
Cyperus rotundus	Nutgrass	None	-
Commelina benghalensis	Benghal dayflower	Leaf chlorosis	+
Passiflora foetida	Stinking passionflower	Interveinal chlorosis	-
Spathodea campanulata	African tulip tree	Interveinal chlorosis	-
Castilla elastica	Mexican rubber tree	Leaf chlorosis	-
Ficus elastica	Indian rubber tree	Leaf chlorosis	-
Macaranga harveyana	*Macaranga	None	-
Flueggea flexuosa	*Flueggea	Leaf chlorosis	-
Derris malaccensis	New Guinea creeper	None	-
Erythrina indica	Coral tree	None	-
Musa sapientum	Banana	Veinal chlorosis	-

+ TaBV-positive, - TaBV-negative, * No English common names available

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ANALYSIS OF ESSENTIAL OIL COMPOSITION OF SOME SELECTED SPICES OF PAPUA NEW GUINEA

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ABSTRACT

Some selected spices from Papua New Guinea were analyzed to determine the chemical compositions of their respective essential oil contents. These included black and white pepper (Piper nigrum: *Piperaceae*); *cardamom* (Ellataria cardamomum: *Zingiberaceae*); *ginger* (Zingiber officinale: *Zingiberaceae*); *patchouli* (Pogostimon cablin: *Lamiaceae*); *nutmeg* (Myristica fragrans: *Myristicaceae*); *and the leaf and stalk of lemon grass* (Cymbopogon citratus: *Poaceae*). *The essential oils were obtained by exhaustive hydro-distillation and analyzed by a combined gas chromatography-mass spectrometry (GC-MS) method. The results indicated that d-3-carene (34.0 %), limonene (18.3 %) and b-caryophyllene (15.7 %) were the major components of black pepper* (*Piper nigrum*); *d-3-carene (23.7 %), limonene (23.7 %), b-caryophyllene (17.6 %) and b-pinene (16.9 %) were the major components of white pepper* (Piper nigrum); *1,8-cineole (44.4 %) and á-terpinyl acetate (39.7 %) were the major components of cardamom* (Ellataria cardamomum); *citral (18.4 %), a-zingiberene (16.8 %) and camphene (11.2 %) were the main constituents of ginger* (Zingiber officinale); *the patchouli alcohol (71.8 %) was the main constituent of patchouli* (Pogostimon cablin); *a-pinene (22.6 %), sabinene (15.8 %) â-pinene (15.2 %) and myristicin (13.2 %) were the main components of nutmeg* (Myristica fragrans) *and* citral *was the main component in the leaf (91.0 %) and stalk (90.7 %) of lemon grass* (Cymbopogon citratus).

Keywords: *spices, essential oils, Piper; Ellataria, Zingiber; Pogostimon, Myristica, Cymbopogon, citral, floral diversity.*

INTRODUCTION

Essential oils are volatile organic compounds that are the major constituents in spice products and give rise to the perceived flavour and fragrance characters. These chemical compounds have a high vapour pressure and therefore are highly volatile, hence exist as vapour at ambient temperature and pressure. The analysis of these compounds in flavour and fragrance industries has served as the benchmark to ascertain the qualities of these products.

As an ongoing research program aimed at identifying the chemical compositions of the different volatile organic compounds in the floral diversity of Papua New Guinea (PNG) (Rali *et al.* 2003), we report here the chemical compositions within the matrix of the essential oil extracts obtained from some of the selected spice crops of PNG. The spices studied were black pepper (*Piper nigrum* L: Piperaceae); white pepper (*Piper nigrum* L: Piperaceae); Cardamom (*Ellataria cardamomum* White et Mason: Zingiberaceae); ginger (*Zingiber officinale* Roscoe: Zingiberaceae); patchouli (*Pogostimon cablin* Pellet: Lamiaceae); Nutmeg (*Myristica fragrans* Houtt: Myristicaceae); and the leaves and stalks of lemon grass (*Cymbopogon citratus* [DC] Stapf: Poaceae).

MATERIALS AND METHODS

The spice products were a donation from the New Guinea Spice Ltd of Rabaul, East New Britain Province, while patchouli and lemon grass samples were obtained from Tabubil in the Western Province. These samples were brought back to the laboratory while fresh and the essential oils extracted by exhaustive hydro-distillation, using an all-glass apparatus standard distillation setup. The oils obtained were dried over anhydrous sodium sulphate (Na_2SO_4) and analyzed using gas chromatography coupled to a mass spectrometer (GC-MS). The individual oil constituents were tentatively identified by their respective retention times and confirmed by comparison to the mass spectral data and that of the authentic reference compounds or with published data.

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RESULTS AND DISCUSSIONS

The results of the chemical analysis of essential oils extracted from some selected spices of PNG are presented in Table 1. The major constituents of both the black and white pepper (*Piper nigrum*) were d-3-carene, limonene, b-caryophyllene and b-pinene. However the composition of these essential oils were observed to vary in various proportions of composition in the individual types as presented in Table 1.0. Earlier reports by Martins *et al.* (1998) on the essential oil composition of black pepper reported a composition of limonene (18.8%), â-caryophyllene (15.4%), sabinene (16.5%) and â-pinene (10.7%). A further detailed phytochemical studies on the essential oil and other secondary metabolites in this species and others from the genus *Piper* were recently reviewed (Parmar *et al.* 1997). The oil extracts were previously reported to exhibit antimicrobial activity (Dorman & Deans, 2000; Hammer *et al.*, 1999). The oil obtained from *Piper nigrum* has been widely appreciated in culinary preparations.

Eleven components of cardamom oil were detected (Table 1). The major constituents were 1,8-cineole (44.4 %) and á-terpinyl acetate (39.7 %). In previous studies, Hussain *et al.* (1988) reported 74 % composition of 1,8-cineole contents while another study by Pieribattesti *et al.* (1986) reported 54.4 % 1,8-cineole and 24.0 % á-terpinyl acetate. Atta-ur-Rahman *et al.* (1999) further reported 1,8-cineole and á-terpinyl acetate compositions to be 30.7 % and 30.6 % respectively, and the oil was observed to inhibit the growth of the fungal species *Aspergillus flavus*. The cardamom seeds and oil have application in food flavouring in the forms such as whole, decorticated seeds, and grounded powder.

The chemical composition of essential oils from the rhizomes of ginger (*Zingiber officinale*) has been well documented including its health (Wilkinson 1999) and antimicrobial properties (Hammer *et al.* 1999; Hili *et al.* 1997; Habsab *et al.* 2000). The analysis of the rhizome oil extracts from this study indicated citral content (18.4 %) and á-zingiberene (16.8 %) to be the major components followed by camphene (11.2 %). In comparison with the oil yield and chemical compositions in the rhizomes from the published data (MacLeod and Pieris, 1984; Smith and Robinson, 1981; Kami *et al.* 1972), a variation in oil yield and chemical compositions in the extracts can be observed. Such difference can be attributed to earlier postulation that the oil yield and compositions are influenced by geographical locations, climate conditions and the age of the plant at harvest (Miyazaki and Taki 1955).

The major components identified for nutmeg (*Myristica fragrans*) seed oil were a-pinene (22.6 %), sabinene (15.8 %), b-pinene (15.2 %) and myristicin (13.2 %). A previous study, (Masada 1975) reported á-pinene (26.7%), â-pinene (20.7%), sabinene (14.5%), limonene (9.4%) and terpinen-4-ol (4.4%) as the main constituents. Recently, Atta-ur-Rahman *et al.* (1999) reported 37constituents representing 99.3% of the total nutmeg essential oils. The major component identified was terpinen-4-ol making up 31.3%.

Citral, the common indicator compound in lemon grasses (*Cymbopogon citratus*) is a mixture of two inseparable isomeric sesquiterpene aldehydes of geranial and neral (De Silva 1959). A previous study on citral content in lemon grass from Port Moresby was reported by Sino *et al.* (1992) to be 68 %. In this study, the samples from Tabubil had a higher citral contents in the leaf (91 %) and stalk (90.7 %). Such difference in citral yield can be attributed to geographical locations, weather patterns and conditions and age of grass as influential factors in the citral yield and quality of oil (Miyazaki and Taki 1955). This result is particularly encouraging because of the vast opportunity it has in the potential for cultivation and commercial production of this oil, which has applications in the synthesis of various flavour and fragrance substitutes, vitamin A and ionones (Kingston 1962).

The composition of various indicator chemical markers from this study are within established marketable values. For example, oil and citral contents in lemon grass (Table 1) suggests the possibility of cultivating this species for the commercial production. It is further recommended that detailed chemical study be pursued to establish the commercial potential for these and other spice products, hence establish adequate scientific basis on which to develop the untapped economic potential in the spice industry in PNG.

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Table 1. **Compositions (% area) of the essential oil extracts from the selected spices of Papua New Guinea**

Constituents	Black Pepper	White Pepper	Cardamom	Ginger	Patchouli	Nutmeg	Lemon grass leaf	Lemon grass stalk
a-thujene	-	-	-	-	-	4.0	-	-
a-pinene	7.4	8.9	1.5	3.5	-	**22.6**	-	-
b-pinene	**11.3**	**16.9**	-	-	-	**15.2**	-	-
sabinene	-	-	1.2	-	-	**15.8**	-	-
myrcene	2.7	2.6	1.4	2.2	-	2.1	8.9	2.7
r-cymene	2.6	1.9	0.8	-	-	2.6	-	-
limonene	**18.3**	**23.7**	3.4	1.7	-	3.4	-	-
1,8-cineole	-	-	**44.4**	4.8	-	-	-	-
linalool	-	-	2.1	-	-	-	-	-
terpinen-4-ol	-	-	2.0	-	-	9.6	-	-
a-terpineol	-	-	2.7	-	-	0.7	-	-
linalyl acetate	-	-	0.8	-	-	-	-	-
geranyl acetate	-	-	-	9.2	-	-	-	-
a-terpinyl acetate	-	-	**39.7**	-	-	-	-	-
camphene	-	-	-	**11.2**	-	-	-	-
a-phellandrene	3.5	2.3	-	-	-	-	-	-
b-phellandrene	-	-	-	3.9	-	1.6	-	-
g-terpinene	-	-	-	-	-	3.6	-	-
neral	-	-	-	6.4	-	-	**33.5**	**29.2**
geraniol	-	-	-	8.9	-	-	-	2.7
geranial	-	-	-	**12.0**	-	-	**57.5**	**61.5**
AR-curcumene	-	-	-	1.8	-	-	-	-
E,E-a-farnescene	-	-	-	6.4	-	-	-	-
a-zingiberene	-	-	-	**16.8**	-	-	-	-
b-bisabolene	-	-	-	2.9	-	-	-	-
germacrene-D	-	-	-	2.0	-	-	-	-
b-sesquiphellandrene	-	-	-	6.4	-	-	-	-
d-3-carene	34.0	23.7	-	-	-	-	-	-
a-terpinolene	0.6	-	-	-	-	0.8	-	-
d-elemene	1.9	-	-	-	-	-	-	-
b-caryophyllene	**15.7**	**17.6**	-	-	-	-	-	-
a-caryophyllene	0.8	0.9	-	-	-	-	-	-
caryophyllene oxide	1.3	1.5	-	-	-	-	-	-
a-guaiene	-	-	-	-	7.6	-	-	-
seychellene	-	-	-	-	3.9	-	-	-
a-patchoulene	-	-	-	-	1.7	-	-	-
d-guaiene	-	-	-	-	9.9	-	-	-
pogostol	-	-	-	-	5.1	-	-	-
patchouli alcohol	-	-	-	-	**71.8**	-	-	-
a-terpinene	-	-	-	-	-	2.5	-	-
saffrole	-	-	-	-	-	2.3	-	-
myristicin	-	-	-	-	-	**13.2**	-	-

Note: - = not detected

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REVIEW OF SWEET POTATO DISEASES AND RESEARCH IN PAPUA NEW GUINEA

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ABSTRACT

Diseases that have been recorded on sweet potato in Papua New Guinea are reviewed. Although many diseases of sweet potato caused by fungi, bacteria, viruses, phytoplasmas and nematodes have been recorded, very little work to date has been done on important diseases in the country. Sweet potato scab and, to a lesser extent, virus, little leaf and nematode problems received some attention in the past.

The distribution of most of the important diseases appear, to be widespread or increasing, but the impact of the diseases on cultivation of sweet potato is sporadic or location specific. The importance of each disease depends on the production system and the intended use of the crop. Intensive cultivation of sweet potato associated with land shortage and increasing population pressure, and improved transportation, are some factors that will contribute to an increase in disease spread and severity of sweet potato diseases in the future.

The cultural techniques for cultivating sweet potato are diverse and have a great influence on disease development and spread. These techniques have changed or are changing in some parts of the country.

Disease surveys and epidemiology are priority areas for research in future to develop suitable disease control strategies in various production systems.

***Key words**: sweet potato, Ipomoea batatas, disease, pathogen, fungi, bacteria, viruses, phytoplasmas, nematodes and Papua New Guinea.*

INTRODUCTION

1. Background

Sweet potato (*Ipomoea batatas* (L.) Lam.) is attacked by a wide range of diseases caused by fungi, bacteria, viruses, phytoplasmas and nematodes. However, most of the pathogens recorded in Papua New Guinea (PNG) are fungi, followed by plant parasitic nematodes (Appendix 1.). Only a few diseases caused by bacteria, viruses and phytoplasmas have been recorded. The type of fungal diseases and their importance as pathogens is indicated in Tables 1&2.

Diseases are a major constraint to production of sweet potato in other parts of the world, particularly in temperate regions (Clark and Moyer 1988). Only a few of the most serious diseases of sweet potato are present in PNG and the diseases appear to cause significant crop damage only in certain parts of the country. One of the main reasons for this is that a large number of sweet potato varieties are grown together with other crops in traditional food gardens using various cultivation techniques. However, this appears to be changing in some parts of the country, particularly in the highlands, which will encourage the build up of diseases to cause serious crop losses.

This paper presents a review of sweet potato diseases that have been recorded, and past research that has been carried out on some of the diseases in the country. The main objectives of the review are: (i) to identify the types of diseases and microorganisms that have been recorded on sweet potato, (ii) to determine what work or research has been carried out on diseases of sweet potato, (iii) to identify important diseases and their impact on sweet potato production and (iv) to identify and prioritise future research on diseases of sweet potato in PNG.

2. Diseases Caused by Fungi

2.1 Sweet Potato Scab (*Elsinoe batatas* Jenkins and Viegas)

The fungus *Elsinoe batatas* causes sweet potato scab. The disease is widely distributed throughout PNG wherever sweet potato is grown. The disease attacks only the stem and leaves. Infection causes

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Table 1. Important diseases of sweet potato.

Type	Disease	Pathogen
Field	Sweet potato scab	*Elsinoe batatas*
	Stem and leaf blight	*Alternaria alternata*
	Black rot	*Ceratocystis fimbriata*
	Stem rot	*Fusarium lateritium*
	Vine dieback	*Phomopsis ipomoeae*
	Scurf	*Monilochaetes infuscans*
Storage	Surface rots	*Fusarium oxysporum*
		Fusarium solani
	Java black rot	*Botrydioplodia theobromae*
	Rhizopus rots	*Rhizopus nigricans*
		Rhizopus oryzae
		Rhizopus stolonifer
	Scurf	*Monilochaetes infuscans*

Table 2. Minor diseases of sweet potato.

Type/Occurrence	Disease	Pathogen
Field	Vine and tuber rot	*Sclerotium rolfsii*
	Leaf spots	*Pseudocercospora timorensis*
		Cercospora bataticola
		Phyllosticta sp.
		Alternaria bataticola
		Ascochyta convolvuli
		Phomopsis ipomoeae-batatas
Storage	Charcoal rot	*Macrophomina phaseolina*
	Vine and tuber rot	*Sclerotium rolfsii*
	Blue mould rot	*Penicillium* spp.
	Punky rot	*Trichoderma koningii*
	Foot rot	*Plenodomus destruens*

small lesions or spots to develop on stem, petioles and veins on the underside of the leaf. Infected stems and leaves become distorted and reduced. Cool and wet weather conditions seem to be most favourable for the development and spread of the pathogen.

Sweet potato scab is considered the most serious of all foliar diseases of sweet potato (Clark and Moyer 1988). Yield reductions due to scab have been reported in the highlands of PNG. Goodbody (1983) reported yield loss of 57 %, while Floyd (1988) recorded 19 % loss in total tuber yield. Kokoa (1991b) reported yield differences in three varieties with different degrees of resistance or susceptibility. The most susceptible variety had 27 % loss in tuber weight. Kanua and Floyd (1988) found significant differences in scab incidence between varieties at or across experimental sites but could not relate these to differences in tuber yield. It was suggested that the method of scoring scab was not suitable to detect effects of the disease on the actual yield loss.

The disease is however, not considered a major constraint to sweet potato production. Subsistence farmers in PNG grow more than one variety of sweet potatoes in their gardens (Bourke 1982; Bourke 1985). It is most likely that a mixture of both resistant and susceptible varieties are cultivated together in a single garden which may reduce the infection and spread of the pathogen. It is possible that yield losses in susceptible varieties can be compensated for by mixed cropping of susceptible and resistant sweet potato

varieties. Field screening of sweet potato accessions in field collections at Kuk Agricultural Research Station (KARS), Aiyura Experiment Station, Laloki Research Station and Keravat Lowlands Agricultural Experiment Station (LAES), showed a large number of varieties with different degrees of resistance or tolerance to scab (Kokoa, P. unpublished (d); Kokoa *et al.* 1991a&b; Van Wijmeersch, P. unpublished; Philemon, E. C. unpublished). Scab assessment carried out at KARS showed that 590 of the 986 accessions were highly resistant and 116 were moderately susceptible to scab (Kokoa unpublished (b); Kokoa *et al.* 1991a&b). Philemon, E. C. (unpublished data) reported 285 of the 518 varieties had symptoms of scab at Laloki Research Station.

Several studies have been carried out on chemical control of the disease in the highlands of PNG (Goodbody 1983; Floyd 1988; Kokoa, P. unpublished (c)). These studies showed that fungicides (benomyl, dithane, mancozeb, Bordeaux mixture) could be used effectively to control the disease in the field. However, chemical control has never been recommended to the farmers who usually grow sweet potato in mixed cropping situations because it is inappropriate, especially for economic reasons. However, a farmer may be advised to use fungicide sprays if a highly susceptible variety is monocropped for commercial purposes.

2.2 Alternaria Stem and Leaf Blight (*Alternaria alternata* (Fr.) Keissler)

Stem and petiole blight caused by *Alternaria alternata* was first recorded in PNG from gardens in Nebilyer Valley of the Western Highlands province in early 1987 (Kokoa, P. unpublished (a); Kokoa 1991a&c; Kokoa 1991; Kokoa 2002). About eight months later the disease was recorded at KARS and in the Tambul area. Disease surveys carried out showed that within two years the disease had spread on infected vines to other areas of Western Highlands, Simbu, Southern Highlands and Eastern Highlands provinces. There have not been any follow-up surveys to monitor and determine its spread in the highlands region since the 1989 disease surveys.

Field and laboratory observations were carried out at KARS to study the development of disease symptoms. Initially, the disease produces small, black, oval or circular lesions about 1 mm in length on stems and petioles. The lesions, initially superficial, become depressed as they increase in size. Individual lesions, especially on stems, can develop up to 50 mm long depending on the variety and the weather conditions. The lesions girdle stems and petioles as they enlarge and gradually cause death of shoots (dieback) or collapse of individual leaves. Dieback symptoms usually become more severe in drier weather conditions when lesions completely girdle stems and petioles. Cracks are observed along the stems engulfed or bleached by the lesions, especially during drier weather conditions (Kokoa 2002).

Pathogenicity tests were carried out in a screenhouse at KARS in 1988 to test pathogenicity of fungi frequently isolated from stem and petiole lesions (Kokoa, P. unpublished (a); Kokoa 1991a&c; Kokoa 2002). Isolates of *A. alternata* sp., *Phomopsis* sp., *Fusarium* sp. and a species of *Colletotrichum* were used in the experiment. The results of the tests showed that *A. alternata* was the main pathogen causing the stem and leaf blight on sweet potato in the highlands of PNG. The other fungi were either saprophytes or secondary pathogens.

In 1989, sweet potato varieties in the KARS sweet potato germplasm collection were screened to determine the number of varieties with the disease symptoms (Kokoa, P. unpublished (a); Kokoa 1991a). It was found that the disease did not attack many varieties of sweet potato in the collection. This could mean that resistant or tolerant varieties were already present in the field. Follow-up work on the disease was never carried out because KARS was closed down at the end of 1990.

2.3 Fusarium Stem Rot (*Fusarium lateritium* Nees:Fr.)

Symptoms of stem rot causing wilt and death of vines were first reported from a polycross seed nursery at KARS in 1986 (Kokoa, P. unpublished (b); Kokoa 1991; Kokoa 1991d; Kokoa 2002). Infection of stems caused leaf chlorosis and wilt in some of the varieties which were staked to induce flowering. Under favourable weather conditions the stems become necrotic and this eventually leads to death of stem portions above the lesions. Vascular discolouration is noticed on affected stems. Under favorable weather conditions, the pathogen produces fruiting bodies (sporodochia) on necrotic tissues.

In 1988, similar disease symptoms were observed on a variety (Gorokagi) in the plant pathology working collection at KARS and at Bromil in Gumine district of Simbu province (Kokoa, P. unpublished (b); Kokoa 1991; Kokoa 1991d; Kokoa 2002). Gorokagi was one of the common varieties in the gardens at Bromil. An unknown species of *Fusarium* was isolated from affected stems and petioles. Cultures of the isolate were sent to the Fusarium Research Laboratory at the University of Sydney where it was identified as *Fusarium lateritium* (Kokoa, P. unpublished (b); Kokoa 1991; Kokoa 1991d; Kokoa 2002). It was the first record of the species on sweet potato in PNG. Pure cultures of the pathogen were used in pathogenicity tests in the laboratory and screenhouse at KARS.

Results of the inoculation tests showed that *F. lateritium* was pathogenic and identified to be the causal agent of stem rot at KARS and Bromil. Initially, *Fusarium oxysporum* f. sp. *batatas*, the causal agent for vascular wilt of sweet potato, was suspected as the cause of the stem rot because of the intense discolouration of the vascular tissues. Waller (1984) isolated *Fusarium oxysporum* from discoloured vascular tissues of vines but could not prove it was the vascular wilt pathogen.

2.6 Postharvest Diseases

Postharvest diseases (also known as storage rots) are very important in the temperate countries where tubers are stored for long periods of time (Clark and Moyer 1988). It is quite different in PNG where sweet potato is not usually stored for a long period of time after harvest (Siki, B. F. unpublished). Storage rots become a major constraint when tubers must be stored or are in transit to markets in Lae or Port Moresby. Incidence of storage diseases can be reduced by minimising injury to tubers during harvest and transport of tubers. For long distance shipment of tubers, curing and cool storage would be ideal but small farmers cannot afford or have access to such facilities.

Sweet potato is attacked by several fungal pathogens after tubers are harvested and stored. Some of the most important storage rot pathogens have been recorded in PNG (Shaw 1984; Drum 1984; Muthappa 1985, 1987; (Kokoa 1986a & b; Kokoa and Kuruma 1987a & b; Kokoa 1991). A survey carried out in 1985 by Gosford Horticultural Postharvest Laboratory in New South Wales found surface rot (*Fusarium* spp.), black rot (*Ceratocystis fimbriata*) and *Rhizopus* rot (*Rhizopus nigricans*, *Rhizopus oryzae*) as being the predominant postharvest diseases or storage rots in the country (Morris, S. C. unpublished). Disease surveys conducted between 1985 and 1989 also showed that *F. oxysporum*, *F. solani*, *C. fimbriata* and species of *Rhizopus* were frequently isolated from or observed on necrotic tissues of tubers (Kokoa 1986b; Kokoa and Kuruma 1987a & b; Kokoa 1991). The fungi are very aggressive colonizers of wounds and are widespread in the highlands of PNG where sweet potato is intensively cultivated. Infection usually takes place primarily through; wounds inflicted during or before harvest, particularly injury caused by insects and rodents. Sutherland (1986) gives a good account of sweet potato weevil damage on sweet potato stems and tubers which the present author believes to be the main entry point for the secondary fungal pathogens such as *C. fimbriata*.

Black rot is an important field and storage disease in the tropics (Clark and Moyer 1988). In PNG black rot appears to be an important storage disease. Various disease surveys show that black rot is prevalent in higher altitude areas where sweet potato is intensively cultivated (Waller 1984; Kokoa 1986b; Kokoa and Kuruma 1987(a & b); Kokoa 1991). In areas of the highlands like the Lower Jimi Valley the disease is less common and scurf (*Moniliochaetes infuscans*) is predominant on necrotic stem and tuber tissues (Kokoa and Kuruma 1987a; Kokoa 1991). The black rot pathogen infects virtually all underground parts (root, tuber, stem) of sweet potato, mainly through wounds caused by sweet potato weevil (*Cylas formicarius*) on stems, people during progressive harvesting, especially where tubers are detached, nematodes and rodents (rats, bandicoots). Infection causes rots of tissues which in turn may reduce the market appeal of the tubers, or tubers are completely decayed if other secondary pathogens also colonise the wounds.

3. Diseases Caused by Phytoplasmas

3.1 Sweet Potato Little Leaf or Witches' Broom

Sweet potato little leaf was first reported in PNG by Van Velsen from LAES (Van Velsen 1967). He carried out transmission studies using tuber core-grafting and concluded that little leaf was due to viral infection and a soil borne disease. Disease symptom remission in response to tetracycline (antibiotic) treatment and electron microscopy showed that a mycoplasm-like organism (MLO) was the most probable cause of sweet potato little leaf in PNG (Pearson and Keane 1980; Pearson 1980; Pearson *et al.* 1984). Up to the early 1980s the disease was only reported from Keravat, Lae, Dogura in Milne Bay and Central Province (Van Velsen 1967; Newton and Jamieson 1968; Pearson 1980; Pearson 1981; Pearson and Jackson 1983; Lenne 1991). Initially, the disease appeared to be confined to certain coastal areas of Central province with a marked dry season (Pearson and Keane 1980; Pearson 1981). However, the disease or symptoms of the disease have been observed or confirmed in other parts of the country, including the main highlands of PNG, particularly in recent years (Levett and Thistleton unpublised; Davis *et al.* 2001). The present author also reported very high incidence of the disease in certain parts of Milne Bay province in 1998. The effects of the 1997 El Nino drought could have contributed to the high incidence of the disease in traditional food gardens. Wiles (personal communication) observed symptoms of the disease on Lihir Island in New Ireland Province. Results of the disease survey carried out by Davis *et al.* confirmed little leaf on sweet potato in Milne Bay and Western provinces. The survey also confirmed the presence of little leaf pathogen on *Ipomoea pes-caprae* subsp. *brasiliensis* from Taupota village in Milne Bay province (Davis *et al.* 2001.

Velsen (1967) described that plants or vines affected by the disease have small leaves, short internodes, a proliferation of axillary shoots, resulting in plant having more upright growth, and some general leaf chlorosis. He also reported that latex content of vines and roots was greatly reduced in diseased plants. It has been observed that plants growing under normal conditions rarely show symptoms. Symptoms of the disease are more obvious when plants are under conditions of stress like lack of nutrients or soil moisture. Because of this, the disease has been reported to be more serious in Central Province, particularly during the dry season (Pearson and Keane 1980; Pearson *et al.* 1984; Philemon, E.C. unpublished data). Affected plants have reduced tuber size and tubers may not form at all if vines are severely affected at early growth stages. Van Velsen (1967) reported mean tuber yields of 28 grams and 618 grams for diseased and healthy vines respectively.

Little leaf is easily spread by farmers through infected vines or tubers, particularly when the symptoms of the disease are not visible to the naked eye. Work done in the Solomon Islands (Dabek and Sagar 1978) showed that a leafhopper could transmit the disease but this could not be verified in PNG. Cultural control methods can be used effectively to reduce severe crop losses or restrict disease spread (Pearson 1981; King, G. unpublished). Use of planting material derived from tissue cultured plants seems to be the safe way of restricting the spread of little leaf and reducing tuber loss. The major obstacle is the fast rate of reinfection of pathogen-indexed planting material in the field. This means that clean planting material has to be supplied to farmers on a regular basis through an effective propagation and delivery system. Work carried out at Laloki Research Station in 1985-1986 (Philemon, E.C. unpublished data) indicated that there could be varieties with some degree of resistance or tolerance to little leaf. However, further work is required to identify varieties that may show resistance or tolerance to the disease in farmers' fields, so that these can be used in future research on the disease.

Much of the past work was concentrated on determining the causal agent of little leaf in the country with very little work done on crop loss assessment and development of suitable methods of control. Priority areas for research in future should include: (i) a national survey to assess the distribution and impact of the disease (crop loss assessment) in subsistence food gardens; and (ii) investigations to develop appropriate disease control or management strategies.

4. Diseases Caused by Viruses

According to Clark and Moyer (1988), diseases caused by viruses are probably the most poorly understood. Viruses are important pathogens in virtually all areas of the world where sweet potato is cultivated and have been reported to cause significant crop losses (Haha 1978; Lenne 1991). Crop losses up to more than 50 % as reported by Lenne (1991) indicate that virus diseases are a serious constraint to production. Yield decline in sweet potato has been reported in PNG and it is possible that viruses may contribute to the general decline in tuber yield in parts of the country (Kokoa and Thistleton, 1987; Lenne 1991). Otherwise, sweet potato viruses appear at present to pose no major threat to production of sweet potato in the country but the problem needs to be properly investigated.

Symptoms related to viral infections have been observed on sweet potato throughout the world but the actual causal agents have never been identified nor characterised in most countries (Clark and Moyer 1988; Lenne 1991). Virus-like symptoms are widespread in the highlands of PNG but of relatively low incidence. Observations at KARS in the 1980s appear that symptom expression could be influenced by environmental factors and the host genotype. Although there are many viruses that have been recorded on sweet potato (Clark and Moyer 1988; Brunt *et al.* 1990; Beetham and Mason 1992), Lenne (1991) reported 16 in her definitive list of viruses on sweet potato worldwide. Viruses or virus-like symptoms recorded on sweet potato in PNG are listed in Appendix I. Some of the viruses are widely distributed throughout the world while others are restricted to regions or countries. Sweet potato feathery mottle virus (SPFMV), which is probably the best-known virus, has a worldwide distribution, while sweet potato caulimo-like virus (SPCLV), one of the lesser known sweet potato viruses, is found in few countries including PNG (Clark and Moyer 1988; Brunt *et al.* 1990; Lenne 1991; Beetham and Mason 1992). Sweet potato ring spot virus (SPRV) that causes chlorotic spotting has limited geographical distribution and is probably restricted to PNG (Lenne 1991; Beetham and Mason unpublished).

Sweet potato viruses are easily spread by infected planting material. Sweet potato is vegetatively propagated using terminal shoots and this is probably the common means of dissemination of sweet potato viruses in the country. Insect vectors (aphids and whiteflies) also spread sweet potato viruses (PANS 1978; Clark and Moyer 1988; Brunt *et al.* 1990; Beetham and Mason 1992). Of the known or confirmed viruses in PNG, only SPFMV is known to be transmitted by an aphid (*Aphis gossypii*). A few other viruses are known to be transmitted by whiteflies especially *Bemisia tabaci*. Both insect vectors are present in the country but it seems that there is no information on transmission of the other known PNG viruses by aphids or whiteflies.

Virus diseases are difficult to control and no single method of control is effective. Planting material from tissue cultured plants (virus indexed) provides only a short-term solution to the spread of sweet potato viruses because of the problem of re-infection in the field. The long-term strategy should be aimed at reducing yield loss through the combined use of host plant resistance and tissue culture techniques. The success of such practice depends on the types of viruses, the magnitude of the re-infection problem in the field and other factors or issues. The sweet potato yield and/or quality decline over time is a complex phenomenon due to a varied complex of interacting factors such as; mutations, viruses and other pathogens (Clark *et al.* 2002). Because of this, the yield decline reported in PNG needs to be properly investigated through a multidisciplinary research approaches.

4.1 History of Viral Tests

4.1.1 There is very little information available on sweet potato virus diseases in PNG. This is simply because no plant pathologist or qualified virologist has ever done any detailed studies on virus diseases of sweet potato. Other reasons are that viruses, unlike other plant pathogens, are very difficult and expensive to work with and virus-indexed sweet potato is not always available for research purposes. Much of the earlier work reported results of virus identification carried out overseas, mainly by the Glasshouse Crops Research Institute (GCRI) in the United Kingdom (Shaw 1984; Waller 1984; Clark and Moyer 1988; Brunt *et al.* 1990; Lenne 1991). It was only in the mid-1980s that some experimental work on sweet potato virus diseases was actually carried out at KARS (Shrestha, H. M. unpublished; Levett and Thistleton, unpublished). This was followed by field trials carried at Laloki Research Station under the ACIAR Project 88/12: Virus-free germplasm of sweet potato (Kambuou *et al.* 1989; Beetham and Mason, 1992) and LAES (Van Wijmeersch *et al.* 1999). Akus (1995) carried out field evaluation of varieties at Aiyura Highlands Agricultural Experiment Aiyura in the 1980s and found different degree of resistance to virus infection based on field symptoms.

4.1.2 Shrestha, H. S. (unpublished) working on sweet potato at KARS during 1985 - 86 carried out limited work on sweet potato viruses. He was recruited under the UNDP/FAO-SPC Project on Strengthening Plant Protection and Root Crops Development in the South Pacific. He was originally recruited to set up a sweet potato breeding project. However, because of virus findings by the Agricultural Field Trials, Studies, Extension and Monitoring Unit (AFTSEMU) of the Southern Highlands Rural Development Project (SHRDP) he decided to spend part of his time investigating the virus problem. It was planned that he would make comparisons of yields of field material (dirty) and clean (pathogen-tested) material but this work was not commenced before he left the country prematurely. Limited virus transmission work (graft inoculation) done by the author using *Ipomoea setosa* and infected (field) sweet potato accessions observed virus-like symptoms (inter-veinal chlorosis) on most *I. setosa* inoculated seedlings. Samples of infected *I. setosa* were sent to Rothamsted Experimental Station and GCRI in the United Kingdom where sweet potato feathery mottle virus (SPFMV) was identified in several sweet potato accessions from KARS (Brunt *et al.* 1990).

4.1.3 The Australian Centre for International Agricultural Research (ACIAR) funded a regional research programme to evaluate the use of pathogen-tested planting materials for production throughout the Pacific region. The Institute of Horticultural Development (IHD), formerly known as the Plant Research Institute (PRI) at Burnley, in Australia provided technical expertise required in the project. Two of the overall objectives of the project were to supply pathogen-tested (PT) sweet potato varieties and conduct field experiments in collaborating countries to compare yield of PT and infected material and, assess the reinfection rate in PT material.

4.1.4 The collaborating countries were Tonga, Solomon Islands, Western Samoa and PNG. Selected varieties from each country were pathogen-indexed at Burnley and returned to the countries of origin for multiplication and agronomic field trials. The PNG programme was initiated by Malcolm Levett during 1984 and ended in 1990. Fifty-five accessions were sent from Laloki germplasm collection and, 36 accessions were virus indexed and returned to Laloki tissue culture laboratory as PT material.

4.1.5 Two agronomic trials were carried out at Laloki Research Station in which yields of two varieties (L9, L11) from dirty (field) and clean or PT planting materials were compared. The first trial was completed in June 1988 (Kambuou *et al.* 1989) and the second trial completed towards end of 1990. The results were somewhat inconclusive or inconsistent mainly because there were no significant yield differences between treatments in L11 and the main factor (viruses) likely to cause any differences in yield between treatments was not detected in the materials

using a serological method. Even if there had been significant yield differences, there was no way of differentiating the effects of viruses from those caused by little leaf which is prevalent in Central Province. Based on the results of Laloki work, it was recommended that agronomic and disease assessments should continue for another 2 to 3 generations.

4.1.6 The Africa, Caribbean and Pacific (ACP) council of ministers meeting in 1987 approved the Pacific Regional Agricultural Program (PRAP) to be funded by the European Union. PRAP Project 4, which concentrated on selection, trial and dissemination of sweet potato varieties in the Pacific region, started in June 1990 and ended in December 1998 (Van Wijmeersch 2001). Under the project 1167 varieties were evaluated for lowland conditions at LAES. At the end of the project 79 varieties were recommended as PRAP 1st Class (53 PNG, 26 overseas) and 14 as PRAP 2nd Class (6 PNG, 8 overseas). All the selected varieties for lowlands conditions (except for five varieties) were PT at IHD through the PRAP project, and the earlier ACIAR Project 88/12.

4.1.7 Two trials were conducted at LAES between December 1997 and November 1998 (Van Wijmeersch *et al.* 1999). There were significant yield differences between varieties and the types of planting materials (pathogen-tested and non-pathogen tested) used. The pathogen-tested material gave an average yield increase of 66 % over the non-pathogen-tested material. The higher yield in pathogen-tested material was attributed to the increase in the number of marketable tubers. There was significant interaction between variety and type of planting material. Most of the varieties recorded significant increases in yield and improved market appeal (less cracking). The results also showed that re-infection could take longer than was observed at Laloki Research Station.

There is a need for research to identify major viral diseases through detailed field surveys and characterisation of the viruses. Further work on yield losses in the lowlands and highlands is required. Pathogen indexed sweet potato is available at LAES tissue culture laboratory which can be used for yield loss studies. Recommended varieties must be multiplied in tissue culture and distributed to farmers in different parts of the country through the provincial agriculture extension system.

5. Diseases Caused by Bacteria

There are five bacterial pathogens of sweet potato of which three are of economic importance (Clark and Moyer 1988; Lenne 1991). These are bacterial soft rot (*Erwinia chrysanthemi* pv. *zeae*), bacterial wilt (*Ralstonia solanacearum*, formerly *Pseudomonas solanacearum*), and soil rot or pox (*Streptomyces ipomoeae*). Only three genera of bacteria have been recorded on sweet potato in PNG. *Pseudomonas cichori* and an unknown species of *Bacillus* were isolated from stem and petiole lesions caused by *A. alternata* (Kokoa 1991; Kokoa, 2002). These are most likely secondary or saprophytic bacteria colonising wounds. The causal agent of bacterial soft rot was found to be associated with tuber rot in the highlands (Muthappa 1987). Bacterial soft rot has been reported to be one of the important bacterial diseases of sweet potato in the United States of America (Clark and Moyer 1988).

Very little research has been done on bacterial soft rots of sweet potato in PNG. Although there are no serious bacterial diseases in the country, further surveys of bacterial soft rot must be carried out to assess its importance as a postharvest pathogen, particularly in the highlands.

6. Diseases Caused by Nematodes

Twenty two different genera of plant parasitic nematodes have been reported to be associated with sweet potato in PNG (Bridge and Page 1982; Kokoa 1986a&b; Levett, *et al.* 1987; Kokoa 1991; Kokoa 1991a). At least five species are considered to cause significant damage to the sweet potato (Bridge and Page (1982). They are root-knot nematodes (*Meloidogyne incognita*, *Meloidogyne javanica*, *Meloidogyne hapla*,) the spiral nematode *(Helicotylenchus mucronatus)* and an undescribed species of *Radopholus*. The general symptoms of damage caused by nematodes are leaf chlorosis, root and tuber malformation and possibly yield loss (Bridge and Page 1982).

Results of several surveys carried out in the 1980s indicated that nematodes are widespread, but serious damage to roots was reported only in some areas of the highlands like Upper Mendi, Tari Basin and Gumine district where fallow periods are short due to high population pressure on land use (Bridge and Page 1982; Kokoa 1986b). Sixteen yield loss assessment trials were carried out by AFTSEMU in the Southern Highlands in the 1980s using carbofuran and methyl bromide. D'Souza (1986) showed that yields at ten

sites varied from 3.1 to 13.0 t/ha without nematicides and 5.9 to 16.3 t/ha with nematicide. The mean yield loss of 28 % using carbofuran to control nematodes was considered to be inconclusive. D'Souza *et al.* (1986) found no significant yield response to carbofuran when applied to control root-knot nematode (*Meloidogyne* sp.) in a field trial. Thrower (1958) did not consider root-knot nematodes to be a serious pest of sweet potato in East New Britain Province. Hartemink *et al.* (2000) concluded that nematode infestation was one of the contributing factors to decline in sweet potato yield.

Nematode problems are evident in certain areas of the highlands of PNG like Dirima and Bromil in Gumine District of Simbu province. However, in future, increasing land shortage and shortened bush fallow may lead to widespread nematode disease problems. Farmers can use cultural methods to reduce the levels of infestation in the gardens. These include crop rotation with non-host and resistant varieties. Bridge and Page (1982) reported five varieties as being poor hosts for the highlands race of *M. incognita*. Shiga and Takemata (1981) reported 69 varieties from PNG as resistant to root-knot nematodes. Field trials carried out in Gumine District of Simbu province showed 14 varieties of sweet potato with different reactions to infection caused by root-knot nematodes (Kokoa *et al.* 1991; Kokoa, P. unpublished (e). The local varieties (Table 3) appear to have less root distortion, tuber cracking and root necrosis than the introduced varieties. The only exception is Bogigi which was the most susceptible variety to root-knot nematode infection. These results may help to explain different types of resistance in sweet potato as reported by D'Souza (1986). The high number of resistant varieties from PNG may be attributed to high selection pressure, especially in the highlands.

The results of the survey carried out by Bridge and Page (1982) showed that nematodes are an important constraint to production of food crops and made recommendations for future research. Crop loss assessment and screening varieties for resistance are priority areas of research. Field trials to estimate yield loss should be carried out in areas like Bromil in Gumine district where nematode populations are extremely high in traditional food gardens. This should be followed by screening local and introduced varieties from many parts of the highlands for resistance or tolerance to nematodes, particularly against species of *Meloidogyne* and *H. mucronatus*.

CONCLUSION

A wide range of diseases has been recorded or identified on sweet potato since the 1940s. Many of the diseases are widespread but a small number of diseases such as Alternaria stem and leaf blight

Table 3: Reactions of sweet potato varieties to root-knot infections.

Cultivar	Root distortion and swelling	Adult female in root cortex	Tuber cracking	Root necrosis
*Spagi	Low	Absent	High	Low
*Ongi	Low	Absent	Low	Low
*Morogi	Low	Absent	Low	Low
*Triplangi	Low	Absent	Low	Low
*Dumagi	Low	Absent	Low	Low
*Bogigi	High	Present	Low	Low
Gorokagi	Moderate	Absent	Moderate	Moderate
Naveto	Moderate	Present	Low	Moderate
Serenta	Moderate	Absent	High	High
Ma'alu	Moderate	Present	High	High
NG7570	Moderate	Absent	High	High
Merican	Low	Absent	Moderate	Moderate
Munduena	Moderate	Absent	Low	Moderate
Markham	Moderate	Absent	Low	Moderate

* local varieties

appear to be confined to the highlands region. Past work has been concentrated on identification of diseases and their distribution through disease surveys. Very little research was carried out in the past to quantify the effects of important disease problems and to develop suitable control methods for farmers to use. The present situation remains the same with a limited number of plant pathologists actively engaged in crop pathology research.

The effect or impact of disease problems on sweet potato production appears minimal except in certain areas of the country where serious damage has been reported. However, this may change in the future, particularly in areas of the country which are at present densely populated and experiencing problems related to decline in soil fertility and acute land shortage.

At present no plant pathologist is working specifically on sweet potato diseases. Future work should concentrate on surveys to update the current status of some of the disease problems highlighted in this review. This should be followed by research to assess economic crop losses in farmers' fields and disease epidemiology to assist in developing disease management strategies.

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APPENDIX 1.

Microorganisms Recorded on Sweet Potato in Papua New Guinea

(i) Records of Fungi

Alternaria alternata - Stem and petiole blight (Kokoa unpublished (a); Kokoa and Kuruma 1987; Kokoa 1991; Kokoa 1991a&c; Kokoa *et al.* 1991; Lenne 1991; Kokoa 2001; Kokoa 2002)

A. alternata - Stem rot (Kokoa unpublished (a); Kokoa and Kuruma 1987; Kokoa 1991; Kokoa 1991a&c; Kokoa 2001; Kokoa 2002)

Alternaria bataticola - Leaf spot (Waller 1984; Levett and Thistleton unpublished; Lenne 1991; Kokoa 2001; Kokoa 2002)

Alternaria solani - Stem and petiole rot (Lenne 1991; Kokoa 2001)

A. capsici-annui - Leaf and stem blight (Kokoa 2002)

A. sesami - Kokoa 2002)

A. solani - Leaf and stem blight (Lenne 1991; Kokoa 2002)

A. teniuissima - Leaf and stem blight (Kokoa 2002)

Alternaria sp. - Dieback (Joughin and Thistleton 1987)

Arthrobotrys sp. - Stem rot (Kokoa 1991; Kokoa 2001)

Ascochyta bataticola - Leaf spot (Waller 1984; Muthappa 1987; Lenne 1991)

Ascochyta convolvuli - Leaf spot (Waller 1984; Muthappa 1987; Levett *et al.* 1987; Levett and Thistleton unpublished; Lenne 1991; Kokoa 2001)

Aspergillus sp. - Tuber/ stem rot (Drum 1984; Muthapp, 1987; Levett and Thistleton unpublished; Kokoa 1991; Morris, S.C. unpublished; Kokoa 2001)

Aspergillus flavus - Tuber rot (Shaw 1984; Kokoa 2001)

Aspergillus ostianus - Tuber rot (Shaw 1984; Kokoa 2001)

Aspergillus repens - Tuber rot (Shaw 1984)

Aspergillus terreus - Tuber rot (Shaw 1984; Kokoa 2001)

Aspergillus versicolor - Tuber rot (Shaw 1984; Kokoa 2001)

Athelia rolfsii - Collar rot (Shaw 1984); Muthappa 1987; Kokoa 1991, 2001)

Botryodiplodia theobromae - Java black rot (Shaw 1984; Drum 1984; Muthappa 1985, 1987; Kokoa and Kuruma 1987; Levett and Thistleton unpublished; Kokoa 1991; Lenne 1991)

B. theobromae - Java black rot (Kokoa and Kuruma 1987)

Botryosporium longibrachiatum - Stem rot (Shaw 1984)

Ceratocystis fimbriata - Black rot (Waller 1984; Drum 1984; Isamay *et al.* unpublished; Muthappa 1985, 1987; Kokoa and Kuruma 1987; Levett *et al.* 1987; Levett and Thistleton unpublished; Kokoa 1991; Kokoa 1991a; Morris, S. C. unpublished; French undated; Kokoa 2001)

Ceratocystis fimbriata - Unstated (Shaw 1963)

Ceratocystis fimbriata - Tuber rots (Shaw 1984; Joughin and Thistleton 1987)

C. fimbriata - Vine/stem rot (Levett *et al.* 1987)

C. fimbriata - Tuber rot (Morris, S. C. unpublished)

Ceratocystis paradoxa - Tuber rot (Waller 1984; Kokoa 2001)

Ceratostomella fimbriata - Unstated (Shaw 1963, 1984)

Cercospora sp. - Leaf spot (Pearson 1979)

Cercospora bataticola - Leaf spot (Muthappa 1987; Levett and Thistleton unpublished; Kokoa 2001)

Cercospora timorensis - Leaf spot (Shaw 1963, 1984; Bourke 1985)

Choanephora sp. - Tuber rot (Drum 1984; Muthappa 1987; Kokoa 2001)

Cladosporium sp. - Tuber/ stem rot (Shaw 1984; Drum 1984; Kokoa 1991; Kokoa 2001; Kokoa 2002)

Colletotrichum spp. -Tuber/ stem rot (Waller 1984; Kokoa 1991c; Kokoa 1991; Kokoa 2001)

Corticium rolfsii - Collar rot (Shaw 1984)

Corynespora cassiicola - Leaf spot (Shaw 1984; Muthappa 1987; Kokoa 1991; Kokoa 2001)

Cylindrocarpon destructans - Leaf spot (Shaw 1984; Lenne 1991; Kokoa 2001)

Cylindrocarpon destructans - Tuber rot (Waller 1984)

Dendrophoma sp. - Stem rot (Kokoa 1991; Kokoa 2001)

Diaporthe phaseolorum - Tuber rot (Shaw 1984)

Didymella sp. - Leaf spot (Muthappa 1987; Kokoa 2001)

Elsinoe batatas - Scab (Shaw 1963; Pearson 1979; Bourke 1982; Shaw 1984; Waller 1984; Bourke 1985; Isamay *et al.* unpublished; Kokoa and Kuruma 1987; Levett *et al.* 1987; Levett and Thistleton unpublished; Muthappa 1987; Kokoa 1991; Kokoa 1991b Lenne 1991; Van Wijmeersch and Guaf 1993; Akus 1995; French undated; Kokoa 2001)

Epicoccum sp. - Stem and root rot (Kokoa 1991; Kokoa 2001)

Eupenicillium cinnamopurpureum www.ecoport .org accessed on 7/6/03 (citing French 1996)

Eurotium repens - Tuber rot (Shaw 1984; Kokoa 2001)

Fusarium sp. - Stem rot (Kokoa 1991; Kokoa 1991d; Kokoa 2001)

Fusarium sp. - Dieback (Joughin and Thistleton 1987)

Fusarium sp. - Tuber/root rot (Drum 1984; Muthappa 1985, 1987; Kokoa and Kuruma 1987; Kokoa 1991a)

Fusarium spp. - Surface/end rot (Muthappa 1985; Levett and Thistleton unpublished; Joughin and Thistleton 1987)

Fusarium spp. - Stem rot (Kokoa 1991a&c, Kokoa 1991d)

Fusarium lateritium - Stem rot (Kokoa unpublished (a); Kokoa 1991; Kokoa 2001; Kokoa, 2002)

F. lateritium - Stem and leaf blight (Kokoa unpublished (a); Kokoa 1991; Kokoa 1991a; Kokoa 2002)

Fusarium oxysporum - Stem rot/leaf spot (Kokoa unpublished (a); Bourke 1985; Muthappa 1987; Levett *et al.* 1987; Levett and Thistleton unpublished; Kokoa 1991; Kokoa 1991a; Kokoa 2001; Kokoa, 2002)

F. oxysporium - Stem rot (Kokoa unpublished (a); Waller 1984; Levett *et al.* 1987; Kokoa 1991; Kokoa *et al.* 1991; Kokoa 2002)

F. oxsporum - Tuber rot (Shaw 1984; Levett and Thistleton unpublished; Muthappa 1987; Waller 1984; Kokoa 1991; Morris, S. C. unpublished)

F. oxsporum - Root rot (Bourke 1982; Waller 1984; Muthappa 1987; Kokoa 1991)

F. oxsporum - Root rot (Morris, S. C. unpublished)

Fusarium moniliforme - Tuber rot (Levett and Thistleton unpublished; Morris, S. C. unpublished)

Fusarium pallidoroseum - Stem rot (Kokoa 1991; Lenne 1991; Kokoa 2001)

Fusarium solani - Tuber/root rot (Waller 1984; Levett *et al.* 1987; Levett and Thistleton unpublished; Kokoa 1991; Lenne 1991)

F. solani - Stem and tuber rots (Levett *et al.* 1987; Kokoa 1991; Kokoa 1991a; Levett and Thistleton unpublished; Kokoa 2001; Kokoa 2002; Morris, S. C. unpublished)

F. solani - Seed rot (Shrestha, H. M. unpublished)

Fusarium subglutinans - Stem/ root rot (Kokoa 1991; Kokoa 2001; Kokoa 2002)

Geotrichum candidum - Tuber rot (Morris, S. C. unpublished; Kokoa 2001)

Glomerella cingulata - Leaf spot (Waller 1984; Lenne 1991; Kokoa 2001)

G. cingulata - Stem rot (Waller 1984)

Leptosphaeulina sp. - Leaf spot (Waller, 1984; Kokoa, 1991; Kokoa 2001)

Leptosphaerulina trifolii - Leaf spot (Waller 1984; Kokoa 2001)

Macrophomina phaseolina - Charcoal rot (Drum 1984; Muthappa 1985, 1987; Levett and Thistleton unpublished; Kokoa 2001)

Monilia stophila - Tuber rot (Morris, S. C. unpublished; Kokoa 2001)

Moniliochaetes infuscans - Scurf (Muthappa 1987; Kokoa and Kuruma 1987 Joughin and Thistleton 1987; Levett and Thistleton unpublished; Kokoa 1991; Kokoa 1991a; Kokoa 2001)

M. infuscans - Scurf (Morris, S. C. unpublished)

Mucor sp. - Tuber and stem rot (Muthappa 1987; Kokoa 1991; Kokoa 2001)

Nectria sp. - Stem and tuber rot (Kokoa and Kuruma 1987)

Nectria sp. (see *Tricoderma koningii*) - (Shaw 1984)

Nigrospora sp. - Stem/ root rot (Kokoa 1991; Kokoa 2001)

Nigrospora sphaerica - Leaf spot (Lenne 1991; Kokoa 2001)

Penicillium sp. - Stem and tuber rot (Muthappa 1985, 1987; Levett and Thistleton unpublished; Kokoa 1991; Kokoa 2001)

Penicillium citrinum - Tuber rot (Shaw 1984; Kokoa 2001)

Penicillium crustosum - Tuber rot Shaw 1984; Kokoa 2001)

Penicillium funiculosum - Tuber rot (Shaw 1984; Kokoa 2001)

Penicillium frequentans - Tuber rot (Shaw 1984; Kokoa 2001)

Penicillium glabrum - Tuber rot (Shaw 1984; Kokoa 2001)

Penicillium islandicum - Tuber rot Shaw 1984; Kokoa 2001)

Penicillium simplicissimum - Tuber rot Shaw 1984; Kokoa 2001)

Periconia sp. - Stem rot (Kokoa 1991; Kokoa 2001)
Periconia sp. - Stem and tuber rot (Kokoa and Kuruma 1987)
Pestalotiopsis royenae - Leaf spot (Lenne 1991; Kokoa 2001)
Pestalotiopsis versicola - Leaf spot (Lenne 1991; Kokoa 2001)
Phaeoisariopsis bataticola - www.ecoport.org accessed on 7/6/03 (synonym of *Cercospora bataticola*)
Phoma sp. - Stem and root rot (Kokoa 1991; Kokoa 2001)
Phoma exigua - Stem and petiole/leaf rot/blight (Kokoa 1991; Kokoa 1991a; Kokoa 2001; Kokoa 2002)
P. exigua - Leaf spot (Waller 1984)
Phoma leveilleri - Leaf spot (Waller, 1984; Kokoa 2001)
Phoma sorghina - Leaf spot (Muthappa 1987; Levett and Thistleton unpublished; Kokoa 2001)
Phomopsis batatas - Tuber rot (Muthappa 1987; Levett and Thistleton unpublished; Lenne 1991; Morris, S. C. unpublished; Kokoa 2001)
P. batatas - Tuber rot (Morris, S. C. unpublished)
Phomopsis ipomoeae - Leaf spot (Waller 1984; Levett *et al.* 1987; Lenne 1991; Kokoa 1991; Kokoa 2001; Kokoa 2002)
Phomopsis ipomoeae - Stem rot and dieback (Waller 1984)
Phomopsis ipomoeae - Stem and leaf blight (Kokoa 1991a)
P. Ipomoeae - Root rot (Waller 1984)
Phomopsis ipomoeae-batatas - Leaf spot (Waller 1984; Lenne 1991; Kokoa 2001)
Phomopsis ipomoeae-batatas - Stem rot (Shaw 1984; Joughin and Thistleton 1987)
P. ipomoeae-batatas - Dieback (Waller 1984; Muthappa 1987; Kokoa 1991)
P. ipomoeae-batatas - Tuber rot (Muthappa 1987)
Phyllosticta sp. - Leaf spot (Muthappa 1987; Kokoa and Kuruma 1987; Levett and Thistleton unpublished; Kokoa 1991; Kokoa 2001)
Phyllosticta batatas - Stem rot (Shaw 1984)
Plenodomus destruens - Foot rot (Kokoa 1991; Kokoa 1991a; Kokoa *et al.* 1991c)
Pseudocercospora timorensis - Leaf spot (Shaw 1984; Waller 1984; Levett *et al.* 1987; Muthappa 1987; Kokoa and Kuruma 1987; Kokoa 1991; French undated; Kokoa 2001)
Pythium sp. - Stem rot (Kokoa 1991; Kokoa 2001)
Pyrenochaeta terrestris - Stem rot (Waller 1984)
Ramularia sp. - (Leaf spot (Muthappa 1987; Levett and Thistleton unpublished; Kokoa 2001)
Rhizoctonia solani - Stem rot and root rot (Kokoa 1991; Kokoa 2001)
Rhizopus sp. - Tuber rot (Levett and Thistleton unpublished)
Rhizopus spp. - Storage rots - (Shaw 1984)
Rhizopus spp. - Tuber and stem rot (Drum 1984; Muthappa 1985; Kokoa 1991; Kokoa 2001)
Rhizopus oryzae - Tuber rot (Morris, S. C. unpublished; Kokoa 2001)
Rhizopus nigricans - Soft rot (Shaw 1963; Shaw 1984; Morris, S. C. unpublished)
Rhizopus stolonifer - Soft rot (Shaw 1984; French undated)
Rhizopus stolonifer - Tuber soft rot (Muthappa 1987; Lenne 1991; Morris, M. C. unpublished)
Sclerotium rolfsii - Collar/ vine rot (Shaw 1984; Muthappa 1987; Kokoa 1991)
Trichoderma sp. - Tuber and stem rot (Kokoa 1991; Morris, S. C. unpublished; Kokoa 2001)
Trichoderma hamatum - Tuber and stem rot (Kokoa 1991; Kokoa 2001)
Trichoderma harzianum - Tuber rot (Shaw 1984; Kokoa 2001)
Trichoderma koningii - Tuber and stem rot (Shaw 1984; Kokoa 1991; Kokoa 2001)
Trichoderma neolongitrachiatum - Tuber rot (Morris, S. C. unpublished; Kokoa 2001)
Verticillium sp. - Stem rot (Kokoa 1991; Kokoa 2001)

(ii) Records of Phytoplasmas

Mycoplasma like-organism - Little leaf (Van Velsen 1967; Shaw 1984; Pearson 1979, 1982; Pearson and Keane 1980; Pearson *et al.* 1984; Muthappa 1987; Levett and Thistleton unpublished; Philemon unpublished, Lenne 1991)
Phytoplasma - Little leaf (Davis, *et al.* 2001 in press)

(iii) Records of Viruses

Sweet potato caulimo-like virus - Chlorotic spots (Waller 1984; Levett and Thistleton unpublished; Clark and Moyer 1988; Brunt and Crabtree 1990; Kokoa 1991; Kokoa 1991c; Lenne 1991; Beetham and Mason, 1992; Kokoa 2001; Beetham and Mason unpublished)
Sweet potato feathery mottle virus (SPFMV) Chlorotic vein clearing - (Levett and Thistleton unpublished; Brunt and Crabtree 1990; Kokoa 1991; Lenne 1991; Beetham and Mason, 1992)
Sweet potato leaf curlvirus (SPLCV) - Chlorotic vein clearing and leaf curl - (Shaw 1984; Muthappa 1987; Lenne 1991; Kokoa 2001)
Sweet potato reo-like virus - General leaf chlorosis (Beetham and Mason, 1992; Beetham and Mason unpublished)
Sweet potato ring spot virus (SPRV) - Chlorotic vein clearing and leaf rugosity (Brunt *et al.* 1990; Beetham and Mason, 1992; Kokoa 2001; Lenne 1991; Beetham and Mason unpublished)
Potyvirus - Symptomless (Shaw 1984; Kokoa 2001)
Virus (suspected) - Leaf chlorosis and vein clearing (Kokoa 1991)

(iv) Records of Bacteria

Bacillus sp. - Stem and petiole rot (Kokoa 1991; Kokoa 2001; Kokoa 2002)
Erwinia sp. - Tuber rot (Muthappa 1987; Levett and Thistleton unpublished; Kokoa 2001)
Erwinia chrysanthemi - Tuber rot (Muthappa 1987; Levett and Thistleton 1987; Kokoa 2001)
Pseudomonas cichorii - Stem and petiole rot (Kokoa 1991; Kokoa 2001; Kokoa 2002)

(v) Records of Nematodes

Aphelenchoides sp. - Roots (Kokoa 1991; Kokoa 2001)
Aphelenchoides bicaudatus - Soil (Kokoa 1991; Kokoa 2001)
Aphelenchoides spp. - (Bridge and Page 1982; Kokoa 2001)
Aphelenchus spp. - (Bridge and Page 1982)
Aphelenchus avenae - (Bridge and Page 1982; Kokoa 2001)
A. avenae - Soil (Kokoa 1991)
Cephalenchus sp. - Vine and tuber rot (Levett 1987)
Coslenchus sp. - (Bridge and Page 1982; Kokoa 2001)
Criconematid sp. - (Bridge and Page 1982; Kokoa 2001)
Criconemella sp. - (Bridge and Page 1982; Kokoa 2001)
Criconemella sp. - Roots and soil (Kokoa 1991)
Criconemella onoensis - (Bridge and Page 1982; Kokoa 2001)
Crossonema civellae - Soil (Kokoa 1991; Kokoa 2001)
Discocriconemella sp. - (Bridge and Page 1982; Kokoa 2001)
Discocriconemella sp. - Soil (Kokoa 1991; Kokoa 2001)
Gracilacus aonli - (Bridge and Page 1982; Kokoa 2001)
Helicotylenchus sp. - (Bridge and Page 1982; Kokoa 2001)
Helicotylenchus sp. - Vine and tuber rot (Levett 1987)
Helicotylenchus sp. - Roots (Kokoa 1991; Kokoa 2001)
Helicotylenchus sp. - Soil (Levett 1987; Muthappa 1987; Kokoa 1991; Kokoa 2001)
Helicotylenchus dihystera - Soil (Bridge and Page 1982; Kokoa 1991; Kokoa 2001)
Helicotylenchus dihystera - Roots (Kokoa 1991; Kokoa 2001)
Helicotylenchus mucronatus - Root and tuber rot (Bridge and Page 1982; Kokoa 1991; Kokoa 2001)
H. mucronatus - Roots and soil (Kokoa 1991)
Heterodera spp. - (Bridge and Page 1982; Kokoa 2001)
Longidorus sp. - Vine and tuber rot (Levett 1987)
Meloidogyne hapla - Root-knot (Bridge and Page 1982; Kokoa 1991; Kokoa 2001)
Meloidogyne incognita - Root-knot (Bridge and Page 1982; Levett *et al.* 1987; Kokoa 1991; Kokoa 2001)
Meloidogyne javanica - Root-knot (Bridge and Page 1982; Levett *et al.* 1987; Kokoa 2001)
M. arenaria - (Kokoa 1991)
M. javanica - (Kokoa 1991)
Meloidigyne sp. - (D'Souza *et al.* 1986; Hartemink *et al.* 2000; Kokoa 2001)
Meloidigyne sp. - Soil (Kokoa 1991)
Meloidogyne spp. - Root-knot (Thrower 1958; Levett *et al.* 1987; Muthappa 1987; Kokoa 1991)
Nothotylenchus sp. - (Bridge and Page 1982; Kokoa 2001)
Paratrichodorus minor - (Bridge and Page 1982; Kokoa 2001)
Pratylenchus sp. - Soil (Kokoa 1991; Kokoa 2001)
Pratylenchus coffeae - (Bridge and Page 1982; Kokoa 2001)
Radopholus similis - (Bridge and Page 1982; Kokoa 2001)
Radopholus n.sp. (a) - Soil (Bridge and Page 1982; Kokoa 2001)
Radopholus n.sp. (b) - Soil (Bridge and Page 1982; Kokoa 2001)
Radopholus n.sp. (c) - Soil (Bridge and Page 1982; Kokoa 2001)
Rotylenchulus reniformis - Roots and soil (Bridge and Page 1982; Kokoa 1991; Hartemink *et al.* 2000; Kokoa 2001)
Scutellonema insulare - (Bridge and Page 1982; Kokoa 2001)
Seriespinula n.sp. - (Bridge and Page 1982)
Syro vexillatrix - Soil (Kokoa 1991; Kokoa 2001)
Trichodorus cylindricus - (Bridge and Page 1982; Kokoa 2001)
Tylenchulus sp. - Vine and tuber rot (Levett 1987)
Tylenchus sp. - (Bridge and Page 1982)
Tylenchus sp. - Soil (Kokoa 1991; Kokoa 2001)
Xiphinema brasiliense - (Bridge and Page 1982; Kokoa 2001)
Xiphinema ensiculiferum - (Bridge and Page 1982; Kokoa 2001)
Xiphinema orthotenum - (Bridge and Page 1982)
Xiphinema n.sp. - (Bridge and Page 1982; Kokoa 2001)
Xiphinema sp. - (Bridge and Page 1982; Kokoa 2001)

EVALUATION OF METHODS FOR SCREENING TARO (*COLOCASIA ESCULENTA*) GENOTYPES FOR RESISTANCE TO LEAF BLIGHT CAUSED BY *PHYTOPHTHORA COLOCASIAE*

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ABSTRACT

Three screening methods; spray-on, stick-on and leaf-disc were compared to reliably identify moderate or partial resistance against taro leaf blight caused by Phytophthora colocasiae. *Each of the method was tested on susceptible, moderately resistant and resistant cultivars at three, four and five months of plant age. No significant differences ($P \geq 0.05$) were observed among inoculation methods and plant ages for the area under disease progress curve (AUDPC) of the susceptible and resistant cultivars. Using the leaf-disc method, twenty-six elite taro genotypes from third recurrent breeding cycle were screened and six moderately resistant genotypes, which are likely to be associated with polygenic and durable resistance were advanced to the fourth breeding cycle for further evaluation.*

Key words: Taro, leaf blight, breeding cycle, polygenic, inoculation

INTRODUCTION

Taro leaf blight (TLB) caused by *Phytophthora colocasiae* Racib. is considered to have originated in Southeast Asia where it coevolved with its principal host taro (*Colocasia esculenta* L.). It is now widely distributed throughout the tropical regions of the world. The disease entered the southern Pacific countries including Papua New Guinea (PNG) and Solomon Islands during the Second World War. Since then, the disease continued to spread in PNG. In 1976 a severe epidemic occurred on the islands of Manus, and in 1988 the disease occurred for the first time in Milne Bay and devastated the entire taro crop. TLB remains a major constraint to taro production in PNG (Gunua *et al.* 1998) and significant reduction in corm yields as high as 50% has been reported (Cox and Kasimani 1988; Jackson *et al.* 1980).

Early efforts to combat TLB in PNG included the use of cultural practices and chemicals. However, these efforts were not sustained because most farmers could not afford the costs of chemicals, equipment and labour. In this realization, the National Agricultural Research Institute (NARI) of PNG initiated a breeding programme in 1993 to develop cultivars resistant to TLB. The original programme was based on the use of resistant sources that had characteristics of major gene resistance and were therefore, likely to be vulnerable to breakdown from single mutations in the pathogen. Recently, the programme shifted its focus on recurrent population breeding and is discarding the genotypes with hypersensitive reactions likely to be associated with single major gene(s), as it is very difficult to select polygenic resistance in the presence of major gene(s). From progeny to progeny, it is possible to accumulate minor genes, which are likely to be polygenic and durable. Since, there is no identifiable indicator of such, as the hypersensitive flecks in major gene resistance, there is an important need for identifying reliable screening method that will help selecting for polygenic resistance.

The components of such resistance, like lesion diameter, latent period and area under disease progress curve can be useful criteria for its identification, but demands a reliable and quantified screening technique. TLB is normally irregularly distributed within a field and within the same genotype. One part of the field may have severe disease and another part may have much lower disease. During dry daytime conditions, but with heavy night dews, it is possible for one plant to be severely diseased (due to new infections arising from old lesions on the same plant) but for adjacent plants to have little disease. This characteristic cause serious problems when selecting resistant progeny under natural conditions, as it is not possible to distinguish between resistant plants and those that have simply escaped infection. This again demands the identification of a reliable screening method for making the breeding programme more efficient and successful.

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In the past, different TLB screening methods have been used to assess the host response. Ivancic *et al.* (1996) carried out resistance tests on taro using screen-house tests, shade-house tests and tests on detached leaves without recommending any effective and reliable method for use. Recently, Fullerton *et al.* (2000) screened taro varieties using spraying, field inoculation of plants with paper tabs and *in vitro* inoculation of leaf discs to determine the variability in lesion development in each of the methods. In a separate study, Fullerton *et al.* (2001) identified some of the factors causing variability in lesion development using the leaf-disc method. Thus, the screening techniques previously developed have not been fully exploited and have never been critically compared for reliability.

The objectives of the present studies were to i) determine the reliability, efficiency and practicality of three different screening methods for resistance to TLB, and ii) use the selected method to screen 26 advanced genotypes from the third breeding cycle to determine their responses to TLB.

MATERIALS & METHODS

Controls and breeding lines

The evaluation of screening methods was carried out on three controls - Numkowec, Ph-21 and Bangkok, which are respectively, susceptible, moderately resistant and resistant to TLB isolate named Bubia-isolate. The preferred method was used to screen 26 advanced lines selected from Cycle 3 breeding progeny.

Field layout and maintenance

Each of the 29 genotypes (three controls and 26 breeding lines) were replicated three times as single plants in a randomized complete block design. The plants were spaced at 0.6 m between and within rows for inoculations and intercultural convenience. The total plot size was 2.4 x 17.4 m. Four rows of taro cultivar NT 03 were planted outside the plot as guard rows. The experiment was rain-fed without any fertilizer application and weeds were controlled manually. Taro hawk moth (*Hippotion celerio*) larvae which attack the leaves, were physically removed during weeding or whenever sighted.

Preparation of inoculum

Preparation of inoculation solution followed the method described by Fullerton et al. (2000). Triton stock solution was prepared by mixing 0.4 ml Triton X 100 with 400 ml boiled water. The stock solution was well shaken and kept in a fridge when not in use. To prepare inoculation solution, one part Triton stock solution was mixed with nine parts (v/v) of clean boiled water. This dilution was used for washing sporangia off the lesions for the preparation of sporangial suspension.

Preparation of sporangial suspension

Leaves with young lesions showing heavy sporulation were collected early in the morning. Immediately after collection, the leaves were sprinkled with water and placed in a plastic bag. The plastic bag with its top folded over without being sealed was then stored in a cool place at approximately 25°C until leaves were used later in the day. To prepare a sporangial suspension, either sporulating lesions or edges of large lesions were cut-off the leaves and sporangia were washed-off the lesions with a soft brush using the inoculation solution. A final concentration of 300 sporangia ml^{-1} was used in the suspension as suggested by Fullerton *et al.* (2000).

Inoculations

Plants were inoculated by three different methods (spray-on, stick-on and leaf-disc) on three successive occasions at plant age of three, four and five months. A total of nine plants per genotype were inoculated at each plant age (three plants per genotype for each of the three methods). After inoculating at three months, the plants were left for a period of approximately three weeks after which a similar procedure was repeated on new first leaf at four and five months.

Spray-on method

The spray-on method was carried out as commonly practiced for initial screening of large numbers of taro progeny in breeding programmes. The spore suspension was placed in a 250 ml hand-pumped sprayer and sprayed onto the second fully expanded leaf surface until wet as described by Wall and Wiecko (1998). The Triton wetting agent was added to the inoculum suspension to ensure that the droplets remained on the leaf. Inoculations of plants were done late in the afternoon after 1600 hours.

Stick-on method

The stick-on method was carried out as described by Fullerton *et al.* (2000). The name is derived from the fact that the inoculum is held on the leaves by sellotape. The sporangial suspension was poured into a beaker, and blotting paper tabs (previously cut with a standard office paper-punch) were added. Ten paper tabs successively drawn from the sporangial suspension were placed directly onto the upper surface of the taro leaf lamina of the second leaf

(counting from the top). Tabs were placed in two rows of five, one row on each side of the leaf at approximately 2.5 cm apart. Two strips of 50 mm sellotape were cut and a strip was carefully placed on each row of tabs while the sides were pressed firmly to ensure that the paper tabs were in contact with the leaf in addition to edges being properly sealed. Inoculation of plants was done in the afternoon, after 1600 hrs (Fullerton *et al.* 2000). The Sellotape strips and paper tabs were removed early next morning (Day 1). The position of each paper tab was marked by circling with a marker. The diameter of each lesion on the leaf was recorded on two, three and four days after inoculation.

Leaf-disc method

The leaf-disc assay in this experiment was carried out in the laboratory following the procedure initially described by Fullerton *et al.* (2000). Four leaf discs were collected from the fully expanded second leaf of three different plants of each genotype early in the morning while leaves were still turgid. In preparation of inoculation, a 10-cm square paper towel wetted with 10 ml of benzimidazole solution to retard senescence and Triton wetting agent was placed in a standard 127-mm^2 laboratory weighing tray. Four leaf discs were carefully laid on the paper towel in each tray and flattened with a cotton bud. Care was taken while placing leaf discs to avoid getting any of the preservation solution on top of the discs.

To inoculate leaf discs, the sporangial suspension was poured into a Petri dish and blotting paper tabs were added. Triton wetting agent was added to the inoculum suspension to ensure that tabs adhere to leaf discs. Using forceps, one tab was drawn and placed in the centre of each of the four leaf discs and each tray was wrapped in cling wrap film (Gladwrap®) and incubated at room temperature of approximately 25°C. Tabs were removed from discs 24 h after inoculation (Day 1) and trays were rewrapped. Lesion diameter was recorded on days two, three and four after inoculation. The rewrapping procedure was again repeated on days two and three following disease measurement, to preserve discs for the final reading on day four after which the discs were simply discarded.

Disease assessment and analysis

The rate of lesion development (mm) was recorded on days two, three and four after inoculation for each combination of inoculation method and plant age. When measuring and recording the lesion diameter, failed infections were recorded as 0 (missing value) and hypersensitive reactions (flecks) as 1 mm (Fullerton *et al.* 2000). Missing values or 0s, which were escapes, were eliminated from the final calculation of average lesion diameter per plant. Comparisons of inoculation method and effect of plant ages were carried out concurrently in the same field plot.

Data analysis was performed by estimating the Area Under the Disease Progress Curve (AUDPC), which represented the grid of epidemics in relation to time. The AUDPC was calculated by incorporating average lesion diameter per plant for days two, three and four (reading dates) into the following formula:

AUDPC = 0.5x((LD1+LD2)x(t2-t1)+(LD2+LD3)x(t3-t2)), where LD1, LD2 and LD3 were mean lesion diameter for days two, three and four, respectively; and t1, t2 and t3 represent first, second and third observation days after inoculations.

Intervals for separation of genotypes into resistance categories

Four intervals were used in separating the genotypes, according to the levels of disease observed. Each of the intervals represented the following resistance categories, namely highly resistant (HR), moderately resistant (MR), moderately susceptible (MS) and highly susceptible (HS), respectively. To get the range of values within each of the intervals, the minimum and maximum values were identified and the difference between the maximum and minimum value was calculated. The difference was divided by four and the value obtained would be the interval for the ranges. The calculated value is added to the maximum value of the previous range to get the maximum value for the next range.

Comparison of leaf-disc results with natural epidemics

A field assessment was conducted in a separate breeding trial at NARI, Bubia under natural infection. Assessment were based on the percent leaf area affected using the diagram developed by Gollifer and Brown (1974). Independent host responses were deduced from this trial such that leaf damage up to 10% was considered HR; 10-40% MR; 40-70% MS; and above 70% HS. The results were compared with the leaf-disc method to estimate a match frequency for two independent rankings of phenotypes.

RESULTS

Evaluation of screening methods

For all three methods, lesions ranging from 10-19 mm and 5-8 mm were observed on the susceptible cultivar

Table 1. Mean AUDPC for three check cultivars at plant ages of 3, 4 and 5 months (m)

Genotype	TLB Resistance	Mean AUDPC (Methods/ Age)								
		Stick-on			Spray-on			Leaf-disc		
		3m	4m	5m	3m	4m	5m	3m	4m	5m
Numkowec	Susceptible	27.53	18.46	10.24	18.94	13.83	11.83	22.54	26.29	16.57
Ph-21	Moderately resistant	7.99	2.96	2.27	4.10	2.43	2.10	13.93	10.29	8.58
Bangkok	Resistant	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	1.00

Numkowec and moderately resistant check Ph-21, respectively, however, hypersensitive-flecks were observed on resistant check Bangkok. Mean AUDPC of cultivar Numkowec and Ph-21 produced by spray-on method was lower relative to stick-on and leaf disc methods (Table 1). Separate analysis of variance of mean AUDPC on the three checks showed no significant difference ($P > 0.05$) between the methods of inoculation and plant ages for the susceptible and resistant checks. However, there was significant difference for methods ($P < 0.01$) and plant age ($P < 0.05$) for the moderately resistant check.

Selection of a screening method

Although, the susceptible and resistant cultivars showed no significant difference among the three screening methods, indicating that all methods are equally suitable for screening, however, there are variety of other factors, which can affect the choice and application of a particular method (Table 2). Therefore, the choice of a method for further use in screening the genotypes of cycle-3 population was largely based on the relative merits and demerits of each method (Table 2). As we intended to screen a

Table 2. Comparative advantages and disadvantages of the three different screening methods

Screening method	Advantages	Disadvantages	Remarks
Spray-on	- Easy to carry out - Less laborious - Less time consuming	- Least precise - Least technical - Symptom influenced by the environment - Inoculum amount not consistent	- Suitable for screening large populations where precision is not required and other techniques are impossible to use
Stick-on	- Inoculum amount is consistent and can be standardized	- Moderately precise - Laborious - Requires skilled persons - Time consuming - Symptom influenced by the environment - Variability in results within replicates	- Suitable only for screening small-medium size population where enough skilled persons are available
Leaf-disc	- Most precise. - Symptom not influenced by the environment - Control of incubation conditions	- Laborious - Time consuming - Highly technical	- Most precise and reliable for screening small number of genotypes

small population of 26 highly advanced and valuable breeding lines, the leaf-disc method was considered comparatively precise and reliable with little or no environmental variability and hence was used for further screening of these genotypes.

Evaluation of selected genotypes and interference of host response

A range of host response was observed in terms of lesion development when the 26 selected genotypes were inoculated with Bubia-isolate using leaf disc method. Progressive lesion diameter for days 2, 3 and 4 and AUDPC for each genotype is presented in (Table 3). All genotypes showed significantly (P<0.01) lower and higher AUDPC, when compared to susceptible (Numkowec) and resistant (Bangkok) checks, respectively. However, in comparison to the moderately resistant check (Ph-21), the genotypes C3-10, C3-17, C3-28, C3- 32 and C3-45 showed significantly (P<0.01) lower mean AUDPC and the remaining 21 showed significantly (P<0.01) higher AUDPC.

Host response was deduced for each of the genotypes (Table 4) based on the interval range of separation as outlined in Methods. Genotype C3-45 and the resistant check were grouped as HR; six genotypes and moderately resistant check as MR; 19 genotypes as MS; and only the susceptible check as HS.

Table 3. Mean lesion diameter and AUDPC calculated for 26 genotypes and three checks for days 2, 3 and 4 using leaf-disc method

Genotype	Lesion Diameter			AUDPC
	Day 2	Day 3	Day 4	
C3-3	1.47	6.57	14.53	14.57
C3-6	1.42	6.25	14.08	14.00
C3-10	1.00	4.00	8.92	8.96
C3-12	1.08	6.08	12.00	12.62
C3-14	1.25	5.25	12.50	12.13
C3-16	1.61	7.94	16.94	17.22
C3-17	1.08	3.52	8.67	8.40
C3-18	1.58	6.25	13.75	13.92
C3-19	1.64	7.21	16.14	16.10
C3-22	1.19	5.07	12.03	11.68
C3-26	1.42	6.77	15.42	15.19
C3-27	1.50	7.43	16.42	16.39
C3-28	1.00	2.64	7.50	6.89
C3-29	1.64	7.11	16.31	16.09
C3-30	1.33	6.25	13.25	13.54
C3-32	1.00	2.83	7.86	7.26
C3-33	1.50	5.17	11.77	11.81
C3-34	1.50	6.68	13.33	14.10
C3-35	1.33	5.67	12.75	12.71
C3-36	1.60	6.93	15.25	15.36
C3-40	1.25	6.08	12.33	12.87
C3-41	1.71	7.97	16.95	17.30
C3-42	1.33	6.25	12.50	13.17
C3-43	1.75	7.58	16.00	16.46
C3-45	1.00	1.92	4.17	4.51
C3-48	1.58	6.00	13.42	13.50
Numkowec	2.11	13.23	24.00	26.29
Ph-21	1.00	4.00	11.58	10.29
Bangkok	1.00	1.00	1.00	2.00
LSD (5%)				0.85
LSD (1%)				1.13

Table 4. Match coincidence of host response of 29 genotypes deduced from leaf disc method and field rating separately

Genotype	Host Response		Match coincidence
	Leaf-disc method[A]	Field rating[B]	
C3-3	MS	MS	✔
C3-6	MS	MS	✔
C3-10	MR	HR	✗
C3-12	MS	MS	✔
C3-14	MS	MR	✗
C3-16	MS	MS	✔
C3-17	MR	MR	✔
C3-18	MS	MR	✗
C3-19	MS	MS	✔
C3-22	MR	HR	✗
C3-26	MS	MS	✔
C3-27	MS	MR	✗
C3-28	MR	MS	✗
C3-29	MS	MS	✔
C3-30	MS	MR	✗
C3-32	MR	MR	✔
C3-33	MR	MR	✔
C3-34	MS	MR	✗
C3-35	MS	MS	✔
C3-36	MS	MS	✔
C3-40	MS	MS	✔
C3-41	MS	MS	✔
C3-42	MS	MR	✗
C3-43	MS	MR	✗
C3-45	HR	HR	✔
C3-48	MS	MS	✔
Numkowec	HS	HS	✔
Ph-21	MR	MR	✔
Bangkok	HR	HR	✔

[A]HR highly resistant (AUDPC 2 - 6); MR moderately resistant (> 6 -12); MS moderately susceptible (> 13 - 18); HS highly susceptible (>18).

[B] From a separate study under natural TLB epidemics at Bubia research station based on % leaf damage (< 10% HR; 10-40% MR; 40-70% MS; > 70% HS)

Comparison of Leaf-disc and field ratings

Independent host responses were also inferred for all genotypes from separate field ratings (Table 4). Field ratings were compared with the leaf-discs ratings and the comparison showed a slight difference in host response of certain genotypes. Nonetheless, there was similarity in host response in majority of the genotypes (Table 4). Percentage coincidence and difference observed on host response of genotypes under leaf-disc and field ratings showed 66% coincidence, while the remaining 34% showed no pattern.

DISCUSSION

The three methods tested in this study had been widely used in the past (Ivancic *et al.* 1996; Singh *et al.* 2000; Fullerton *et al.* 2000). However, these techniques have not been fully exploited and have never been critically compared for reliability. Our results indicated that there were no significant

differences among the three tested methods on the resistant and susceptible cultivars. This may imply that all three methods are equally suitable for screening breeding populations and advanced genotypes. However, practical merits and demerits of each of the methods would determine its suitability and should assist breeders in choosing a suitable method, taking into account the effect of the environment on disease development, precision, population size and the resources available. The present research has attempted to summarize the relative advantages and disadvantages of the three methods (Table 2), which will assist the researchers in decision making for selecting an appropriate inoculation method. It is apparent that leaf-disc method is the most precise, reliable and not influenced by environmental variability. The study also established that there are no additional advantages in performing inoculations at a specific growth stage post three months, although the results of four months apparently appeared better in terms of disease development. These findings are restricted to the 29 genotypes used in the present investigations and does not rule out that certain genotypes in taro may be associated with adult plant resistance as pointed by Singh *et al.* (2003).

The NARI breeding programme produces more than 10,000 seedlings in every recurrent cycle. Initial screening which is restricted to single plants is focused on negative selection i.e. discarding the highly susceptible and hypersensitive genotypes from the population. The second round of selection in the form of intermediate and advanced trials, identify only limited number of genotypes which are moderately resistant to TLB, and those which qualifify the selection criteria for yield and eating quality. In this context, it is recommended to the breeding programme that progenies selected from this study should be screened in the field only at four months because of limited resources. The genotypes from advanced selections need to be analyzed more critically. More importantly, they should not be influenced by environmental variability for a reliable estimate of components of polygenic resistance, like AUDPC. As such, leaf disc method should be used for elite genotypes before they are advanced to variety release trials.

The present study evaluated 26 advanced genotypes selected from third breeding cycle by the leaf disc method. The method differentiated host responses among 26 genotypes such that six genotypes were MR, 19 were MS, and one genotype was HR. The HR genotype (typifying hypersensitive reaction) was discarded from the parent population for creating Cycle 4 because of the possibility of association of this genotype with single major gene. Of particular interest are six moderately resistant genotypes (C3-10, C3-17, C3-22, C3-28, C3-32 and C3-33), which are likely to be associated with polygenic and durable resistance. These genotypes will be recommended for further varietal evaluations if they qualify other set selection criteria. If required, 19 moderately susceptible genotypes could also be included in the programme provided that they are further crossed with resistant parents to increase the number of minor resistant genes in the subsequent progeny.

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l	- litre
ml	- millilitre
ha	- hectare
mm	- millimetre
cm	- centimeter
M	- metre
a.s.l.	- above sea level
yr	- year
wk	- week
h	- hour
min	- minute
s	- second
k	- kina
n.a.	- not applicable or not available
n.r.	- not recorded

var - variance
s.d. - standard deviation
s.e.m.- standard error of difference
d.f. - degrees of freedom

Levels of significance

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* - $0.01 \leq p < 0.05$
** - $0.001 \leq p < 0.01$
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