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CONTENTS

POTENTIAL FOR EXPORTING FRUIT FROM PAPUA NEW GUINEA TO OVERSEAS MARKETS DURING THEIR OFF-SEASONS

C. Camarotto[1] and R. Michael Bourke[1]

ABSTRACT

This study is an initial identification of fruit crops that could be exported from Papua New Guinea to nearby overseas markets during their off-seasons. The period of plentiful supply of 57 fruit and five nut species in Papua New Guinea is compared with that in two other Southern Hemisphere countries (Australia and Indonesia) and two nearby Northern Hemisphere countries (the Philippines and Thailand). Four basic patterns occur for the crops examined. Firstly, there are clear consistent differences between the main production periods in the Northern and Southern Hemispheres for some species, such as durian, rambutan and mandarin. For other species, such as avocado and watermelon, the production periods overlap in the two hemispheres. A few crops, such as banana and coconut, are non-seasonal in all locations. The fourth pattern is displayed by other species including guava, pawpaw and lime, for which production is non-seasonal in certain environments and seasonal in others.The best prospects for exporting fresh fruit from Papua New Guinea are for durian, langsat, mangosteen, pulasan and rambutan to certain Asian markets during the Northern Hemisphere non-production period. There is potential for other fruit exports to both Northern Hemisphere Asian markets and Southern Hemisphere markets in Australia, but this is limited by other factors including quarantine restrictions, the highly perishable nature of some fruit, limited demand and the poor quality cultivars grown in Papua New Guinea. Fruit in this category includes avocado, grapefruit, lime, mandarin, mango, pomelo, raspberry and strawberry.

Key words: *Fruit, nuts, production season, export potential, Papua New Guinea, Australia, Indonesia, Philippines, Thailand.*

INTRODUCTION

In recent years low world prices have led to a decline in the value of traditional export crops from Papua New Guinea (PNG). To counter this, alternative export crops need to be identified to supplement and even replace these. Globally, horticultural products have been growing in importance as agricultural exports from developing countries. Fruit constitutes 70 per cent of the total horticultural exports from developing countries and its relative importance has increased between 1975 and 1985 (Islam 1990:9). A number of horticultural crops have potential as exports, particularly if they can be supplied when the commodity is not in season in the overseas market (Fleming and Hardaker 1992). Fruit and nuts have not been exported from PNG in the past.

There are four potential markets for PNG fruit and nut producers. These are:

1. **Fresh fruit sold within PNG**. There is a large unsatisfied demand for sweet fruit within PNG, particularly in the highlands and in certain lowland towns. Prospects for further domestic sales are very good for mandarin, mango, guava, pineapple, orange and rambutan.

2. **Processed indigenous nuts sold within PNG and overseas**. The potential for selling processed indigenous nuts on domestic and overseas markets is good. Galip nut (*Canarium indicum)* is the most promising and this species is being developed commercially in the Solomon Islands (Evans 1991),

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Vanuatu (Walter and Sam 1993) and Hawaii. Other indigenous nut species which have commercial potential are okari (*Terminalia kaernbachii*), aila (*Inocarpus fagifer*), pao (*Barringtonia procera*) and karuka (*Pandanus julianettii*).

3. **Highland fruit species exported to Asia.** Potential exports for specialist producers include banana passionfruit (*Passiflora mollissima*), cape gooseberry (*Physalis peruviana*), cherimoya (*Annona cherimolia*), highland yellow passionfruit (sweet granadilla) (*Passiflora ligularis*), naranjilla (*Solanum quitoense*) and tree tomato (tamarillo) (*Cyphomandra betacea*).

4. **Fruit exported to nearby countries during their off-season.**

This paper is concerned with the last named potential market. Based on experience elsewhere, it was anticipated that the production period in PNG would generally be similar to that in other Southern Hemisphere countries and different from that in Northern Hemisphere countries (Stephenson 1991). Hence, PNG producers may be able to export fruit to major urban markets in Asia, such as Singapore and Hong Kong, during the non-producing period in the Northern Hemisphere. At the same time it needs to be recognised that producers in other Southern Hemisphere countries may be potential competitors for these markets. It is also possible that market niches for PNG produce exist in nearby Southern Hemisphere countries during their off-seasons. The Southern Hemisphere market considered here is Australia, but potential also exists for export to New Zealand.

In this preliminary study, the production patterns of 62 fruit and nut crops in PNG are compared with those in two nearby Southern Hemisphere countries (Australia and Indonesia)[2] and two nearby Northern Hemisphere countries (the Philippines and Thailand). The aim of this paper is to undertake an initial identification of potential crops that could be supplied during the off-season in overseas markets. While the focus is on production periods, the actual export potential depends on many other factors including production costs, available germplasm, market prices, market demand, transport availability, marketing strategy, presentation and packaging (Cull 1984, Watson 1990). After identifying the crops with the greatest potential for off-season production, some consideration is given to these factors, but detailed analysis is required before export markets could be developed.

METHODS AND DATA SOURCES

The criterion for including a crop in this comparison was that reliable information was available on the crop's production period (seasonality) in PNG. In the initial selection of crops, agronomic suitability was not considered. In fact a number of the fruit crops examined do not produce well in PNG, such as apple, custard apple, plum and pomegranate. Reviews of fruit and nut production in PNG by Aburu (1982), Henty (1982), Tarepe and Bourke (1982) and Woodhouse (1991) indicate the suitability of different crops in different environments. A number of crops, which are important in Asian markets, are not considered because of lack of information on their production period in PNG, for example, lychee and longan.

After assembling the PNG data (Bourke *et al.* in press), information was sought from Australia (three states), Indonesia, the Philippines and Thailand. It was necessary to compile information from a number of sources for each place. We focus on the period when supply is plentiful, not the total production period. For example, some mandarin fruit may be produced in all months in PNG, but about 80 per cent of production occurs in the period May to August, and this is taken as the period of plentiful supply. This distinction is important for the study as we are interested in the period when fruit is in poor supply, but not necessarily completely absent, in the overseas market. However, the basis for defining this period is not always consistent between sources. In practice the production period may vary somewhat from year to year and between locations in the same state or country. For example, differences in the period occur between south and central Thailand and south and north Queensland. The production periods

[2] Most of Indonesia is located in the Southern Hemisphere, although some islands are just north of the equator. The data used here is from locations south of the equator.

Table 1. Period of plentiful supply of 62 fruit and nut crops in Papua New Guinea (Highlands, Lowlands), Australia (Queensland, Northern Territory, New South Wales), Indonesia, the Philippines and Thailand**

Common name	Scientific name	PNG Hlands	PNG Llands	Australia QLD/NT	Australia NSW	Indonesia	Philippines	Thailand
Abiu	*Pouteria caimito*		1-12	1-12				
Apple	*Malus sp.*	3-4		12-4	1-4			6-7
Avocado	*Persea americana*	1-4	1-4	4-12	4-8	5-6;12-2	2-7	5-7
Banana	*Musa cvs*	1-12	1-12	1-12	1-12		1-12	1-12
Brazil cherry	*Eugenia uniflora*		Irregular	3-5	3-5	5-6		
Breadfruit	*Artocarpus altilis*		Irregular	2-5		1-12	6-10	1-12
Bullock's heart	*Annona reticulata*		1-12	2-4			2-9	
Cape gooseberry	*Physalis peruviana*	1-12		1-12	1-4			
Cashew	*Anacardium occidentale*		10-1	8-1		6-9	3-5	2-4
Cherimoya	*Annona cherimolia*	6-9	7-10	3-5	4-5			6-9
Cherry guava	*Psidium cattleianum*		10-1	3-4	4-7			
Coconut	*Cocos nucifera*		1-12	1-12		1-12	1-12	1-12
Custard apple	*Annona atemoya*			2-7	5-9			
Custard apple	*Annona squamosa*		12-5			8-9	9-12*	6-9
Durian	*Durio zibethinus*		11-4	12-4		10-2	3-6*	3-6
Five corner (carambola)	*Averrhoa carambola*		1-12	1-12	3-5	1-12	4-6*	6-12*
Gallip	*Canarium indicum*		5-7					
Golden apple	*Spondias cytherea*		1-2	2-3		1-4		
Governor's plum	*Flacourtia indica*		1-12	1-12	1-12	9-11		
Granadilla	*Passiflora quadrangularis*		1-12	1-12				
Grapefruit	*Citrus paradisi*	3-8		5-9	6-11			
Guava	*Psidium guajava*	2-5	1-12	1-12	3-5	2-3	7-9	1-12
Jackfruit	*Artocarpus heterophyllus*		1-12	1-12		1-12	3-8	1-5
Kumquat	*Fortunella japonica*		12-2	4-6	6-7			
Langsat	*Lansium domesticum*		1-2	3-5		11-2	8-11*	7-10
Lemon	*Citrus limon*	5-10		1-12	7-10			
Lime	*Citrus aurantifolia*		1-12	1-12*	2-8	4-7		5-9
Loquat	*Eriobotrya japonica*	3-7		7-9	6-8			
Macadamia	*Macadamia integrifolia/ M. tetraphylla*	12-4		2-6	2-7			
Malay apple	*Syzygium malaccense*		12-1	2-4		8-9		11-3
Mandarin	*Citrus reticulata*	5-8		4-8	5-9	5-8	9-1	9-2
Mango	*Mangifera indica*		10-1	10-3	2-3	9-10	4-7	3-6
Mangosteen	*Garcinia mangostana*		11-3	11-3		11-3	5-10	5-9
Mulberry	*Morus nigra*	9-12		11-3	12-2			8-9
Orange	*Citrus sinensis*	4-8		5-8	10-2;6-8		10-12	9-11
Passionfruit, banana	*Passiflora mollissima*	Irregular		9-2				
Passionfruit, hybrids	*Passiflora spp.*			1-12	1-12			
Passionfruit, highland yellow	*Passiflora ligularis*	Irregular		1-12				8-12
Passionfruit, lowland yellow	*Passiflora edulis f. flavicarpa*		1-12	2-6		1-12	1-12	1-12*
Passionfruit, purple	*Passiflora edulis f.edulis*	1-4		12-2	1-4	11-1		6-8
Pawpaw	*Carica papaya*	8-10	1-12	1-12	10-12	1-12	1-12	1-12
Pilinut	*Canarium ovatum*						6-8	
Pineapple	*Ananas comosus*	9-3	10-3	1-12	12-2	1-12	4-6	1-12
Plum	*Prunus sp.*	Irregular		10-3	11-3			4-6
Pomegranate	*Punica granatum*		12-5	1-6	2-3	11-12	9-12	10-12
Pomelo	*Citrus maxima*		1-12	2-9		4-7	9-1	8-11*
Pulasan	*Nephelium mutabile*		11-3	12-6		10-12		5-9
Rambutan	*Nephelium lappaceum*		2-5	12-6		11-2	5-8*	5-9
Raspberry, black	*Rubus leucodermis*	1-12		10-5	12			
Raspberry, red	*Rubus sp.*			10-5	11-3			
Rockmelon (canteloupe)	*Cucumis melo*		8-11	1-12	12-3	1-12	12-3	1-3
Rollinia	*Rollinia deliciosa*		1-12	2-5				
Santol	*Sandoricum koetjape*		12-3	1-3		11-12	6-10	5-7
Sapodilla	*Manilkara zapota*			6-12	3-5		10-6	9-12
Soursop	*Annona muricata*		1-12	1-12		1-12	8-11	5-8*
Star apple (caimito)	*Chrysophyllum cainito*		12-1	7-11	7-11	5-7	12-4	
Strawberry	*Fragaria sp.*	6-9		6-10	9-5	7-9	12-4	12-3
Tamarind	*Tamarindus indica*		4-6	8-11		6-9	2-5*	12-2
Tree cucumber	*Averrhoa bilimbi*		1-12	1-12		1-12	1-12*	1-12
Tree tomato (tamarillo)	*Cyphomandra betacea*	3-4		2-12	3-8			
Watermelon	*Citrullus lanatus*		11-3	9-4	12-2		11-3	10-3
Watery rose apple	*Syzygium aqueum*		Irregular	2-4		Irregular		1-3*

* Conflicting data from different sources

** *Periods are months of supply with the numbers 1, 2 etc. referring to January, February etc.

were often longer or commenced earlier for locations nearer the equator. Detailed information on this variation for PNG is given in Bourke *et al.* (in press).

When discrepancies occurred in the data obtained, further clarification was sought, either from the literature or through communication with relevant experts. Where conflicting information from different sources could not be resolved, this is indicated in the main data set (Table 1). In Australia, information was obtained on the production period in New South Wales, Queensland and the Northern Territory. The Australian market is highly integrated and produce can be readily transported to distant markets within Australia. Hence we have generally considered the Australian material together.

Data Sources

The following sources are used:

The data for PNG is derived from Bourke *et al.* (in press), in which the following unpublished sources were used:

Surveys of five highland food markets by R. M. Bourke, E. J. D'Souza, K. Nema and T. N. Tarepe for the period June 1979 to September 1982.

Experimental observations recorded by S. Woodhouse at the Lowlands Agricultural Experiment Station, Keravat for the period January 1989 to March 1993.

PNG Food Marketing Corporation purchase figures for the period April 1976 to August 1981 for six purchasing centres in the highlands and lowlands.

Prices for 14 food crops and betel nut for the period January 1971 to December 1992 recorded in five urban centres. Together with other price data, these are used by the National Statistics Office to calculate the Consumer Price Index.

Observations by a network of observers for mango (5 years) and karuka nut pandanus (10 years) at a number of locations.

Collation of available literature and inter views with villagers by one of us (RMB).

K. Chapman was the primary source for Queensland and he also provided information for all other locations except PNG. Other information for Queensland and the Northern Territory was obtained from R. Broadley and V. Kulkarni and papers by Alexander (no date), Hanlon, Chacko and Baker (1989), O'Hare and Vock (1990), Wait and Jamieson (1983) and Watson (1990). Information for New South Wales came from publications by the NSW Department of Agriculture (no date a and b), Beattie (1982) and from M. R. Loebel.

The Indonesian information was largely extracted from IBPGR (1980) and from J. Kartasubrata. This was supplemented by material in Verheij and Coronel (1991). The core data for the Philippines were obtained through correspondence with C. Escano and E. Lopez, supplemented by information in Coronel (1991). The primary source for Thailand was the publication Fruits in Thailand by the Department of Agricultural Extension (1987). Other sources included P. Boonklinkajorn and S. Vasuvat. Supplementary information was extracted from Verheij and Coronel (1991).

RESULTS AND DISCUSSION

Information on the period of plentiful supply of 57 fruit and five nut crops is summarised in Table 1. Periods for the PNG lowlands (sea level to 1200 m altitude) and the highlands (1200 to 2800 m) are presented separately. Similarly, the Australian data are given for northern Australia (Northern Territory and Queensland) and southern Australia (New South Wales). Information on 15 of the most promising potential exports from PNG is presented in Figures 1, 2 and 3.

Production periods in the five countries

Distinct differences in the production period occur between locations in the Northern and Southern Hemispheres. For a number of fruit crops, the contrast between locations in the two hemispheres is particularly marked. The fruiting pattern of mangosteen illustrates this contrast. In the Southern Hemisphere countries (PNG,

Figure 1. **Period of plentiful supply of durian, langsat, mangosteen, pulasan and rambutan in Papua New Guinea, Australia, Indonesia, the Philippines and Thailand.**

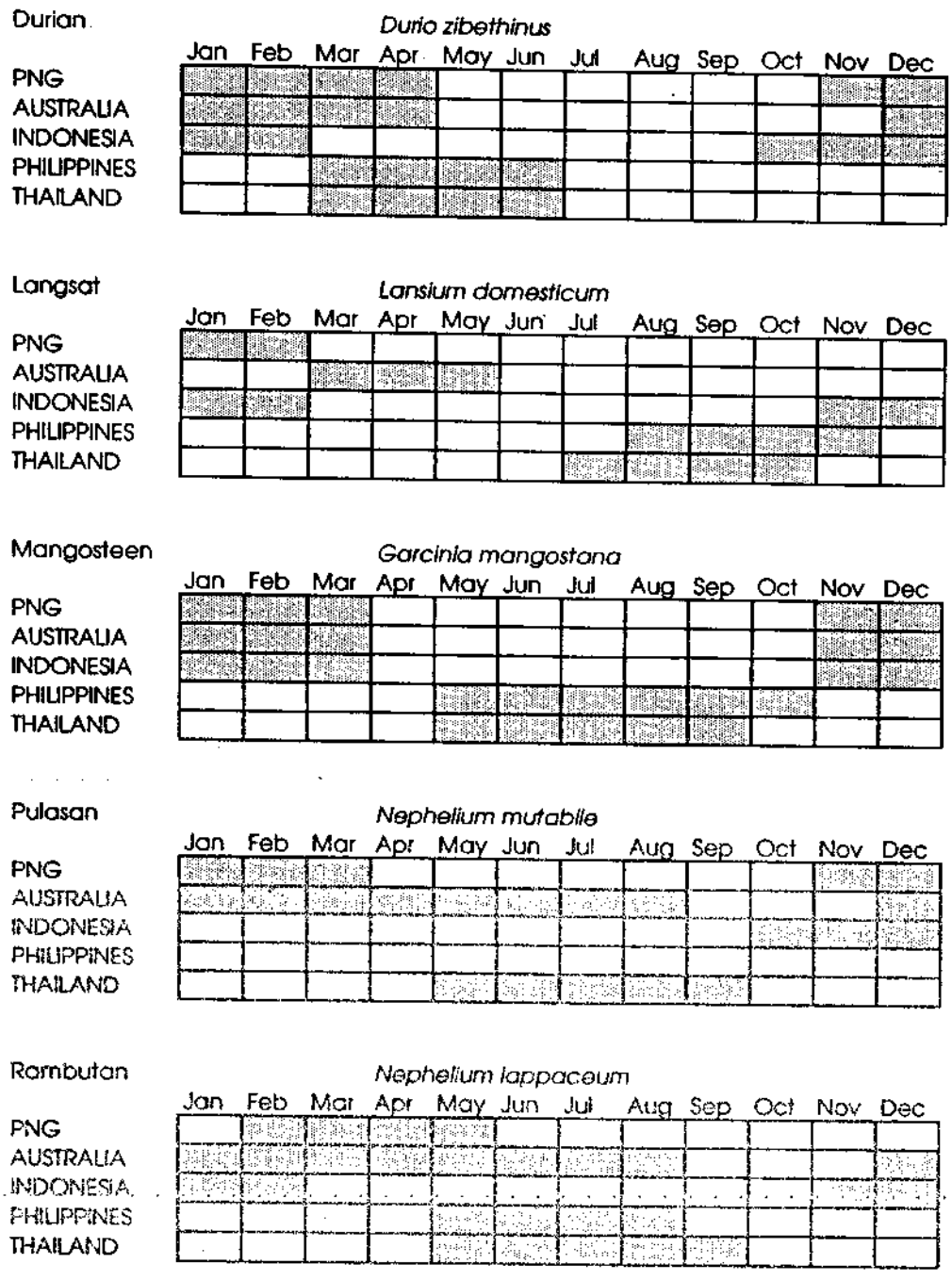


Figure 2. **Period of plentiful supply of avocado, mango, purple passionfruit, santol and strawberry in Papua New Guinea, Australia, Indonesia, the Philippines and Thailand.**

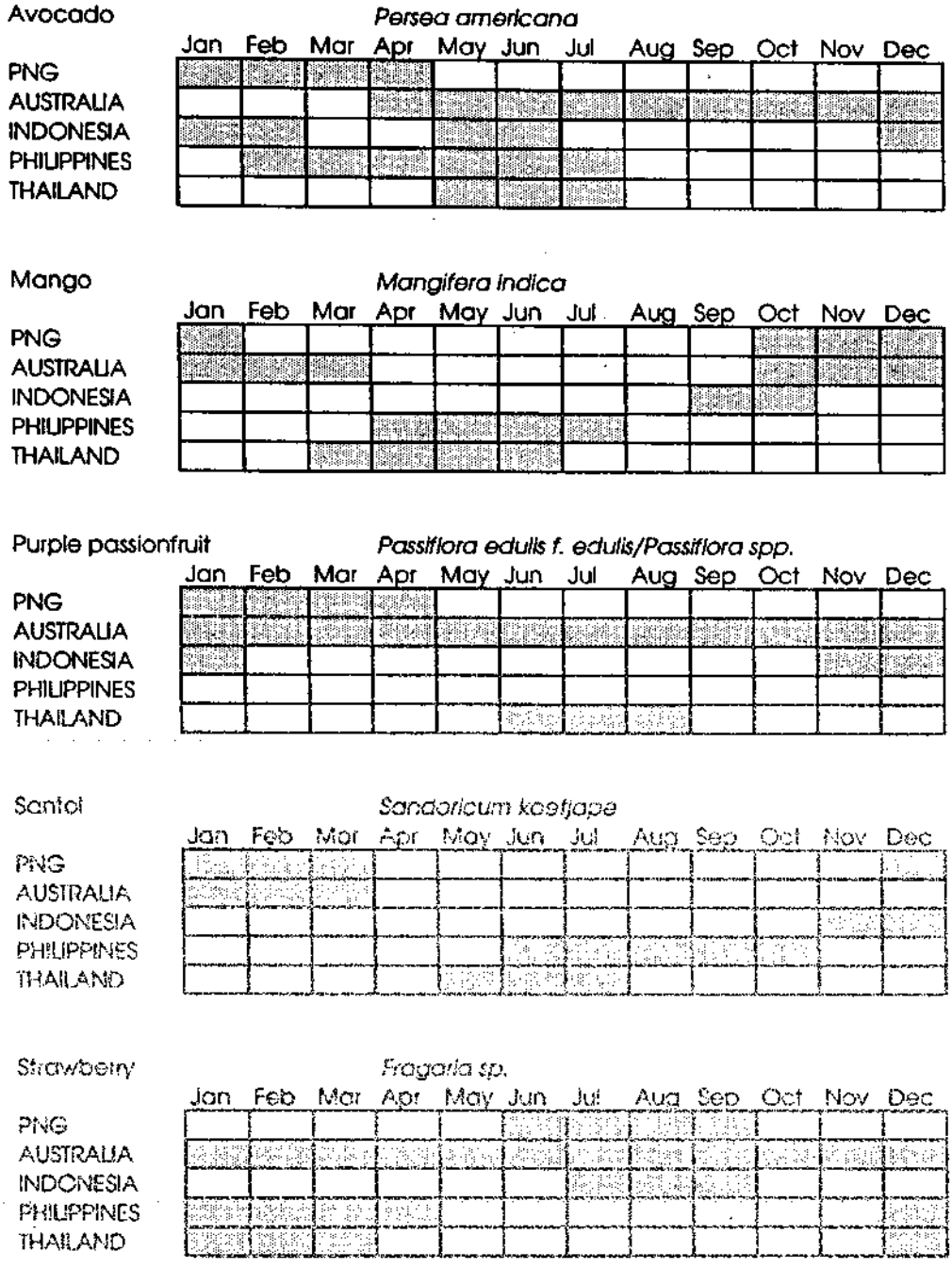
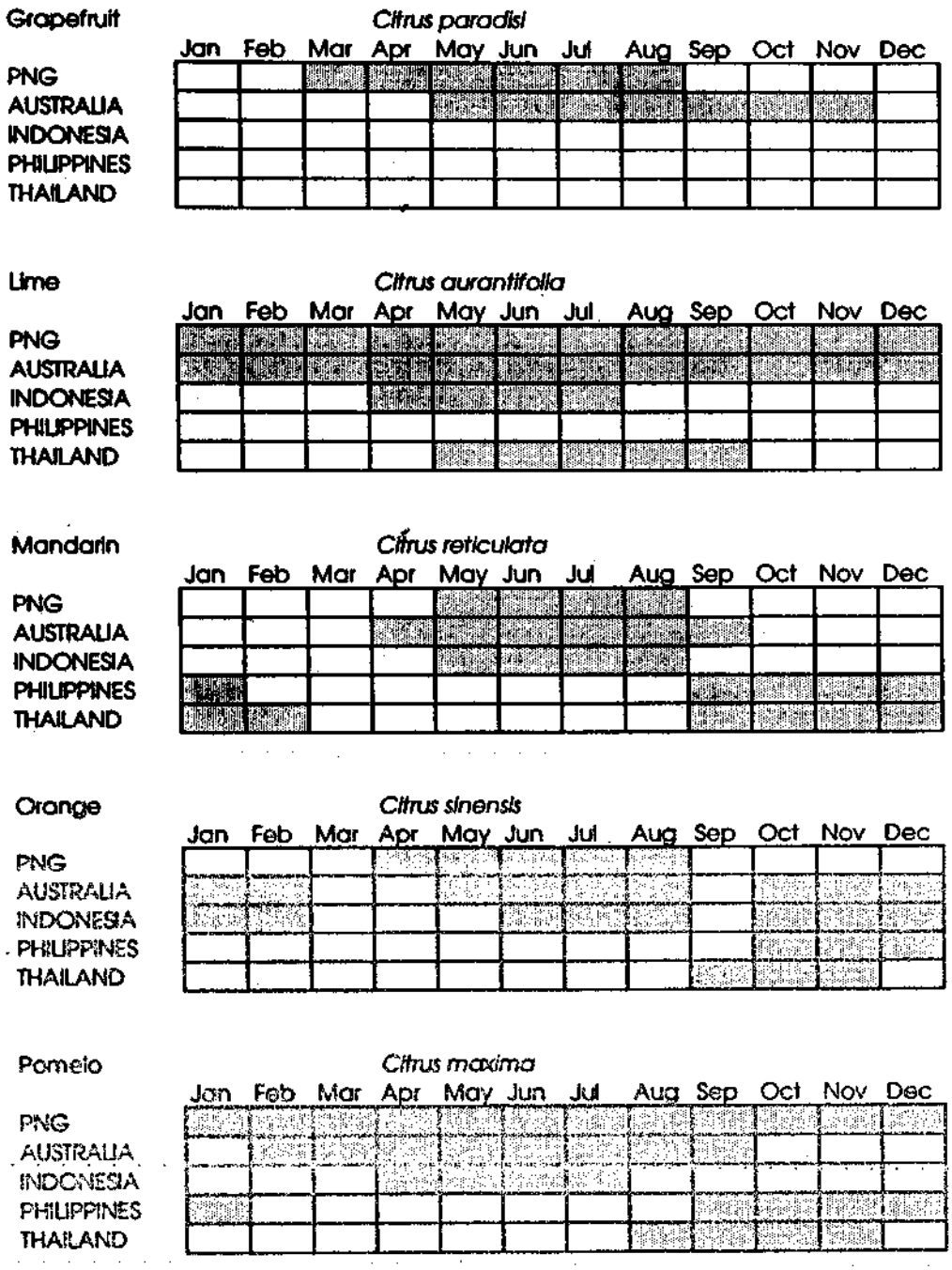


Figure 3. **Period of plentiful supply of grapefruit, lime, mandarin, orange and pomelo in Papua New Guinea, Australia, Indonesia, the Philippines and Thailand.**



Australia and Indonesia), the main production period extends from November to March. In contrast, the period in the two Northern Hemisphere countries (the Philippines and Thailand) extends from May to September/October (Figure 1). Other examples include durian, mango, santol and mandarin (Figures 1, 2 & 3). Clearly, those crops with marked complementarity in production seasons have the greatest potential for export from PNG to the Singapore and Hong Kong markets.

For other crops, the contrast between locations in the Northern and Southern Hemispheres exists, but is less striking. This is the situation for langsat, pulasan, rambutan (Figure 1), cashew nut and pomegranate (Table 1). In the case of rambutan, the Southern Hemisphere production period is generally different from that in the Northern Hemisphere, but the Australian season overlaps with the season in the Northern Hemisphere countries. For a number of fruits, the season in Australia is extended because they are grown over a wide range of latitudes and different varieties are used that have different production patterns. This is the case for avocado, passionfruit, strawberry and orange (Figures 2 and 3). The season for purple passionfruit in Queensland (December to February) and New South Wales (January to April) is similar to that in PNG (January to April) and Indonesia (November to January) (Table 1). However, the use of hybrid passionfruit species in Australia has now resulted in a continuous production period throughout the year (Beal and Farlow 1984).

Production periods in the Northern and Southern Hemispheres overlap for a number of crops including avocado, breadfruit, custard apple, cherimoya, jackfruit, star apple (caimito) and watermelon (Table 1). For example, the main production period of watermelon is similar in PNG, southern Australia, the Philippines and Thailand with a somewhat longer but similar period in northern Australia (Table 1). In the case of avocado, no simple pattern is apparent (Figure 2).The production periods of galip nut (*Canarium indicum*) in PNG and the pilinut (*C ovatum*) in the Philippines are similar, that is, May/June to July/August (Table 1). However, the two nuts are products of closely related but different species, so this is not unexpected.

A number of fruit and nut crops are non-seasonal and produce is available year round in all five countries considered. These include banana, coconut and tree cucumber (Table 1). Pawpaw is non-seasonal in all lowland tropical locations, but seasonal in the PNG highlands and sub-tropical New South Wales (Table 1). Similarly, guava production is non-seasonal in the PNG lowlands, northern Australia and Thailand, but seasonal in the PNG highlands, southern Australia, Indonesia and the Philippines. Pineapple production is seasonal in PNG and the Philippines, but non-seasonal in northern Australia, Indonesia and Thailand. This reflects the use of flowering hormones and other chemicals to induce flowering and fruiting in the latter locations.

Some fruit species produce year round in PNG, but are reported as seasonal in some other locations. These include lime and pomelo (Figure 3), bullock's heart, cape gooseberry, five corner (carambola), black raspberry, and soursop (Table 1).

Potential for export to nearby Northern Hemisphere markets

Discussion on the potential for exporting fruit from PNG to overseas markets during their off-season is restricted to species that grow reasonably well in the PNG environment. After processing, nuts can be stored in both an exporting and importing country. Hence, it is not possible to exploit seasonal differences between PNG and potential importing countries for nuts. However, differences in the production period may be important if the nuts were to be processed overseas, for example, cashew.

There are 10 fruit crops which have very different production periods in PNG from those in nearby Northern Hemisphere producing countries. These are durian, langsat, mangosteen, pulasan, rambutan (Figure 1), mango, purple passionfruit, santol, strawberry (Figure 2) and mandarin (Figure 3). Lime and pomelo are non-seasonal in PNG and thus they are available during the out-of-season period in South East Asia (Figure 3).

The best export prospects to Asian markets that exploit seasonal differences are five fruit of

South East Asian origin, that is, durian, langsat, mangosteen, pulasan and rambutan (Figure 1). All of these species grow well in the humid PNG lowlands (Woodhouse 1991); there is a good demand for the fruit in South East Asia; and seasonal differences are marked. Prospects for durian are particularly good as very high prices can be obtained in Asian markets for out-of-season fruit, although airtight containers would be required for air freight because of its strong odour (Watson 1984 a). In contrast, the season in northern Australia and Indonesia is similar to that in PNG for these five species, and hence exports would face potential competition from these two countries. At present there are experimental plantings of all five species on research stations, plantations and in some villages. However, rambutan is the only species that is currently grown for both subsistence use and for sale in PNG, but it is not common outside of the Gazelle Peninsula of New Britain. Substantial development is needed before exports could occur.

Mango is in season in PNG during the off-season in Northern Hemisphere Asian countries making it a potential export crop (Figure 2). It grows well in parts of the lowlands, including coastal Central and Western Provinces, the Markham Valley, the north coast of the Huon Peninsula, Siassi Island and parts of the Gazelle Peninsula. However, the quality of most existing trees is poor as they have been grown from seedlings, although cultivars that produce good quality fruit are available at research stations. Any exports from PNG have to compete with those from the well established Australian industry in which the production period is extended because of the wide latitudinal range over which mango is grown (Alexander, no date).

The season for purple passionfruit in the PNG highlands is different from that in Thailand (Figure 2). However, the non-seasonal lowland yellow passionfruit (*Passiflora edulis f. flavicarpa*) is grown in South East Asian countries and the non-seasonal hybrid species are likely to be grown there in the future. Hence, prospects for exploiting seasonal differences in passionfruit for exporting are poor.

Santol is another crop that has a different producing season in PNG from that in Northern Hemisphere Asian countries (Figure 2). It is not grown by villagers in PNG. It is a minor crop with limited demand in Asia and it is unlikely that sufficient demand exists to justify development as an export crop (Watson 1984 b, Woodhouse 1991).

The season for strawberry in the PNG highlands occurs during the off-season in the nearby Northern Hemisphere countries (Figure 2). Hence, there may be possibilities for a specialist producer to export strawberries to Singapore or Hong Kong. However, severe packaging, handling and transport constraints would have to be overcome if this delicate fruit was to be exported successfully.

A number of citrus fruit may have potential as exports to out-of-season Asian markets, but other considerations suggest that the potential is not great. Mandarin production is markedly seasonal in PNG and elsewhere (Figure 3). Mandarin is well suited to intermediate altitude locations (800-1400 m) in PNG (Bourke and Tarepe 1982) and there is a large unsatisfied demand for mandarin within PNG. If the existing small industry expands so that domestic demand is satisfied, PNG fruit could be exported to Asian markets during their off-seasons. However, fruit would be in competition with that from the established Australian industry.

Oranges produce reasonably well in the intermediate altitude zone and lower highlands in PNG (Bourke and Tarepe 1982) but fruit colour is poor and there are a number of major pest problems. Given that fruit from Australia and elsewhere is available virtually year round, that oranges are oversupplied on world markets and that the quality of fruit from sub-tropical and temperate environments is superior to that from PNG, there are no realistic prospects of exporting oranges.

Both lime and pomelo are non-seasonal in the PNG lowlands, but production is seasonal in South East Asian countries (Figure 3). Both have potential as export crops during the off-season in the nearby Northern Hemisphere. However, the constraints of high production and transport costs in PNG may negate any seasonal advantages that PNG producers have.

Potential for export to nearby Southern Hemisphere markets

Prospects for exporting fresh fruit from PNG to Australia during the off-season are poor for a number of reasons:

1. The production season in PNG for many fruit is similar to that in Australia. Within Australia, the overall production season is long, because production occurs over a wide range of latitudes and a mix of cultivars is used with different seasonal patterns.

2. The Australian market is well supplied with high quality fruit for much of the year. The February to April period is glutted with a good range of temperate and sub-tropical fruit, but fruit is in poorer supply between August and October (Cull 1984:11). This pattern is similar to that in PNG.

3. Quarantine restrictions in Australia are strict and high standards are set for pest and disease levels in imported fresh food. For example, entry is prohibited for all 15 fruit species for which we present data in Figures 1, 2 and 3, although no risk assessment has been conducted on many of these fruits and the restrictions could be reviewed (Louise Vanmeurs, Department of Primary Industries and Energy, Canberra, pers. comm.).

A comparison of production periods between PNG and Australia indicates that the following fruit exhibit different patterns: langsat, avocado, mango, raspberry, grapefruit and pomelo. Their potential as exports is now considered.

Langsat production appears to commence a little earlier in PNG than in northern Australia (Figure 1). Langsat is not produced commercially in PNG and is a very minor fruit in Australia. If plantings in Australia expanded beyond Queensland to other locations such as the Northern Territory or the north west of Western Australia, the Australian producing period would possibly be extended. The prospect exists that fruit could be exported to Australia before the Australian season commences but this is remote.

Avocado has potential for export to Australia, if only the production season is considered. Harvesting in Australia extends throughout most of the year, but supply is light in January, February and March, which is potentially the period of peak demand (Whiley 1984:73). The period of poor supply in Australia coincides with the period of peak production in the PNG lowlands and highlands (Figure 2). However, quarantine restrictions prevent the entry of fresh avocado into Australia because of the presence of sun blotch virus in PNG which is absent in Australia. In addition, the Australian market requires fruit with a high oil content, but PNG fruit generally have a lower oil content (M. Levett, UPNG, pers. comm., 1993). Overall, there is little prospect of exporting avocado from PNG to Australia.

The mango production season in PNG is similar to that in northern Australia (Figure 2). The season in Central Province usually commences before that in the Markham Valley and the Gazelle Peninsula, although there is considerable year-to-year variation in the start and duration of the season (Bourke *et al.* in press). If trees in Central Province were treated chemically to induce consistently earlier flowering so that fruit matured in September and October, then the prospect exists for fruit to be exported to Australia before the main Australian harvest starts in October and November.

In the PNG highlands, black raspberry is produced year round, but only minor quantities are marketed. Commercial types of red raspberry are not grown in PNG, although fruit of two indigenous self-sown red raspberry (*Rubus moluccanus* and *R. rosifolius*) are occasionally eaten (Tarepe and Bourke 1982:98). In Australia the production period for red and black raspberries extends from October to June (Table 1) with peak production in late December and January (Menzies 1986). There may be potential for exporting red or black raspberry from PNG to Australia between July and November but severe packaging, handling and transport constraints for this highly perishable fruit would have to be overcome. Freezing the fruit may overcome these constraints.

The grapefruit season in PNG commences earlier than in Australia (Figure 3). Latitude apparently influences the start of the season, as it does for mango in Australia (Alexander, no date). The grapefruit season commences in February in PNG, May in Queensland and June in

New South Wales (Table 1). There may be prospects for specialist growers in the PNG highlands or the intermediate altitude zone to export grapefruit to Australia before the Australian season commences.

Pomelo is non-seasonal in the PNG lowlands and weakly seasonal in northern Australia. As with grapefruit, specialist growers could export pomelo to the Australian market during the off-season. However, the off-season is only four months long and pomelo is a very minor fruit. Hence, prospects for exporting pomelo are not good.

Both lime and strawberry are available in PNG when they are unavailable from New South Wales producers (Table 1). However, Queensland producers supply the southern markets when local fruit is not in season. Thus, there is no potential for exporting these fruits from PNG to Australia during the off-season.

CONCLUSIONS

This preliminary study has indicated that a number of fruit species have potential to be exported from PNG to fill market niches during the non-production period in certain overseas markets. The most promising are durian, langsat, mangosteen, pulasan and rambutan for export to Northern Hemisphere Asian urban markets. Demand for durian in particular is good and further investigation is warranted. The PNG production period of langsat is a little different from that in northern Australia and it may be possible to export langsat to Australia. However, it is a poorly developed and minor crop in both countries and export potential is probably limited.

A number of other fruit have some potential to fill market niches but other constraints reduce the possibility that export markets could be developed. Mango could be supplied during the off-season to Northern Hemisphere Asian markets. If PNG production could be made to start earlier, mango could be exported to the Australian markets before the northern Australian season commences. Lack of suitable germplasm in PNG and handling problems reduce the potential. Strawberry and raspberry from PNG could fill market gaps in Asia and Australia respectively, but handling constraints are so severe that this is probably unrealistic. Avocado from PNG could fill a gap in the Australian market, but quarantine restrictions, handling problems and fruit quality make this possibility highly improbable.

A number of citrus species may have potential for export. These are mandarin, lime and pomelo to Northern Hemisphere Asian markets and grapefruit and pomelo to Australia. As with all other fruit species, considerable development of the PNG industry is required before this could eventuate.

The next stage in an investigation of the potential for exporting fruit from PNG to overseas markets is research in the target markets regarding demand, price and quarantine restrictions for each species. Numerous other factors need to be considered before investment in an industry could be recommended, including production costs, packaging, handling constraints and transport availability.

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REVIEW OF ALOMAE DISEASE OF TARO

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ABSTRACT

*The virus disease complex of taro (*Colocasia esculenta *(L.) Schott.) known as "alomae" is thought to be caused by a dual infection of taro large bacilliform virus (TLBV) and taro small bacilliform virus (TSBV). Alomae and a similar but less severe disease called "bobone" are restricted to Papua New Guinea and the Solomon Islands. Symptoms of alomae disease include a feathery mosaic on the leaves, young leaves are often crinkled and fail to open normally, and the plants become stunted and eventually die. Alomae disease can result in total yield loss and bobone can cause 25% yield loss. Control of alomae and bobone is by roguing, by control of insect vectors, breeding for disease tolerant cultivars and virus elimination through plant tissue culture and dissemination of virus tested planting stock.*

Key words: *Alomae, taro large bacilliform virus, taro small bacilliform virus, tissue culture, virus detection*

INTRODUCTION

Taro (*Colocasia esculenta* (L.) Schott.) is a member of the monocot family Araceae, which has around 100 genera and approximately 1500 species (Purseglove 1988). There are two distinct types of taro: *Colocasia esculenta* (L.) Schott. var. *esculentum* which produces one central corm and is referred to in Papua New Guinea (PNG) as "Taro tru", and *Colocasia esculenta* (L.) Schott. var. *antiquorum* (Schott.), Hubbard and Rehder, which produces several cormels surrounding the one central corm and is sometimes referred to as the "eddoe" type.

Taro is an important staple food crop in PNG and other countries in the South Pacific. It is grown primarily for its edible corms and to a lesser extent for its foliage (Rangii 1977). The major growing areas in PNG include the Telefomin area of West Sepik Province, Manus, Gazelle Peninsula of East New Britain and parts of the Huon Peninsula and the North Solomons (Gumah 1989).Over the last twenty years there has been a gradual decline in the growth of taro mainly due to inherent pest and disease problems. The virus disease complex of taro known as "alomae" is one of the most important factors contributing to the decline of taro in Papua New Guinea (Pearson 1981) and the Solomon Islands (Gollifer and Brown 1972). Despite its agronomic significance, the disease has not been thoroughly investigated. This paper collates the available information an alomae disease including its etiology, epidemiology and control.

GENERAL CHARACTERISTICS AND SYMPTOMS

Alomae is a lethal disease which is thought to be caused by dual infection with taro large bacilliform virus (TLBV) and taro small bacilliform virus (TSBV). A similar but milder disease, "bobone", is thought to be caused by infection with TLBV only. However, there is a considerable amount of confusion in the literature regarding the etiology and symptomatology of the two diseases.

Taro cultivars differ in their susceptibility to alomae and bobone diseases. In the Solomon Islands, growers group taro on size in to large ("male taro") and small ("female taro") cultivars (Jackson 1978), which have chromosome numbers of 2n = 42 and 2n = 28, respectively (Gollifer *et al.* 1977). Jackson and Gollifer (1975) reported that male taro cultivars are susceptible

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to alomae disease whereas female taro have some resistance to alomae but are susceptible to bobone.

In male taro, one of the early symptoms of alomae disease is the development of a feathery mosaic on the leaves. Young leaves are often crinkled and fail to open normally, and the lamina and veins become thickened. Other symptoms include shortening of the petioles and the presence of irregularly shaped outgrowths on the petiole surface (Jackson 1978). As the disease progresses, the leaves fail to open and the plants become stunted. Finally, the tips of the unopened leaves die and a systematic necrosis progresses down the petioles resulting in the death of the plant (Gollifer and Brown 1972).

The early symptoms of bobone disease are generally similar to those of alomae, except that the leaves are more stunted and the lamina are more curled and twisted (Gollifer and Brown 1972). In contrast to alomae disease, however, necrosis of the leaves is rare and the plants usually recover.

Jackson (1978) reported that taro plants infected with TSBV alone become slightly stunted, show chlorosis of the marginal leaf veins and the leaf blades curl slightly downwards. The disappearance of symptoms from infected plants has also been observed (Golifer *et al.* 1977).

Taro Large Bacilliform virus

Taro large bacilliform virus (TLBV) is a possible member of the "Rhabdoviridae" as it has morphologically characteristic bullet-shaped or bacilliform particles measuring 300 - 335 nm x 50 - 55 nm (Brunt *et al.* 1990).

The virus is persistently transmitted in nature by the plant hopper *Tarophagus proserpina* (Dabek and Plumb 1975). Attempts to transmit the virus using the aphid *Aphis gossypi* and by mechanical inoculation, seed or pollen, were unsuccessful (Brunt *et al.* 1990, Kenton and Woods 1973). The natural host range of TLBV is restricted to *C. esculenta* although the virus can be experimentally transmitted to *Philodendron selloum* (Brunt *et al.* 1990). Gollifer *et al.* (1977) reported the distribution of TLBV to be restricted to PNG and the Solomon Islands.

Particles of TLBV are found in both mesophyll and phloem cells, causing an increase in the number of polyribosomes and a build-up of starch in the chloroplasts (Strauss 1983). Infected cells are found to contain inclusion bodies (viroplasms) which may be of some diagnostic value.

Taro Small Bacilliform virus (TSBV)

Taro small bacilliform virus (TSBV) has been classified as a possible member of the Badnavirus group based on the presence of 125 nm x 28 nm virions and the transmission of the virus is by the mealybug, *Planococcus citri* (Brunt *et al.* 1990).

The virus is not transmitted by mechanical inoculation, grafting or by the aphid, *Aphis gossypii*, and has a natural host range restricted to *C. esculenta*. Under glasshouse conditions, TSBV has been transmitted to several members of the Araceae, including *Alocasia macroryhiza* and *Xanthosoma spp.* (Brunt *et al.* 1990). The virus appears to be distributed throughout many taro growing areas in the South Pacific, including PNG, Solomon Islands, Fiji, Vanuatu, Western Somoa and the Cook Islands (Gollifer *et al.* 1977).

YIELD LOSSES

Little information is available on the yield losses of taro due to infection with TLBV and/or TSBV. The lethal alomae disease (TLBV and TSBV), however, is clearly the most devastating virus disease of taro. Gollifer *et al.* (1978) reported that (i) the percentage of plants showing symptoms in any given taro field is directly proportional to yield loss, and (ii) if alomae disease does not kill the plant then the corms harvested from infected plants are not of a useful size.

Yield losses as a result of bobone disease average approximately 25% (Gollifer *et al.* 1978).

CONTROL

1. Cultural Methods

There have been few attempts to control alomae and bobone disease of taro under experimental conditions (Gollifer *et al.* 1978). In the field the traditional practice for controlling these diseases is roguing, and this has resulted in a reduction of the incidence of bobone disease from 30% to 1% in the Solomon Islands (Jackson and Gollifer 1975). This method of control is not entirely successful, however, since only plants showing severe symptoms are removed, leaving the symptomless plants or those showing mild symptoms to act as virus reservoirs.

The establishment of gardens in new areas reduces the build-up of vectors within a garden and probably reduces the incidence of the disease (Shaw *et al.* 1979). For a successful control, however, all vectors must be eradicated from new planting material and the distance between new and existing plots should be as great as possible. Unfortunately, the land available for growing taro is limited and as a result, the distance between new and existing plots is decreasing, thus increasing the chances of viliferous vectors moving into new plots.

2. Vector

A possible method to control these diseases may be through the biological control of the vectors (Shaw *et al.* 1979). Species of ladybird beetle (*Cryptolaemus* spp.) have been found in Hawaii, for example, which are predacious on mealybugs. Further, large populations of *T. proserpina* have been controlled in Hawaii by the introduction of the egg suckling bug of *Cytrohinus fulvis* from the Philippines. Related species of *Cytrohinus* have been reported in PNG.

There has been no comprehensive study on the control of the vectors of TLBV and TSBV in PNG and the Solomon Islands using insecticides. However, Shaw *et al.* (1979) proposed that the best way to control alomae and bobone disease was through an integrated approach consisting of (i) regular inspections for symptoms and subsequent roguing of diseased plants, (ii) chemical control of insect vectors and (iii) selection of apparently healthy plants for propagation stock.

3. Tissue Culture

Taro is a vegetatively propagated crop, with the petiole base attached to 1-2 cm of apical corm tissue from the previous seasons harvest being used as new planting stock. A key factor to controlling alomae and bobone disease, therefore, is the propagation and dissemination of virus tested planting stock. The most successful method for eradicating viruses from plants is through heat treatment (thermotherapy), meristem tip culture or a combination of both (Walkey 1985).

Heat therapy involves growing infected plants or plant parts in a controlled environment cabinet at 30 to 40°C for a periods of six to twelve weeks. Although this procedure does not usually eradicate the virus from the whole plant, the meristems usually become virus free. These virus free shoots are removed and regenerated into healthy plants using either meristem tips or bud grafts.

Healthy plants from a wide range of crops have been regenerated from meristem tips, including taro (Walkey 1985). The two main advantages of this technique are (i) there is minimal variability produced in the regenerated plants and (ii) mature plants are generally produced much quicker from meristem tips than from other plant tissue. The combined use of meristem tip culture and thermotherapy has also been widely used in the eradication of viruses from plants.

All three viruses that infect taro, namely TLBV, TSBV and dasheen mosaic potyvirus (DMV), have been eliminated from taro plants using tissue culture (Hartman 1974, Zettler *et al.* 1989), without additional heat treatment. Taro plants can be readily freed from TLBV and TSBV by meristem tip culture when small (0.5 mm or less) meristem tips are used (Zettler *et al.* 1989). Hartman (1974) successfully eradicated DMV from taro and *Xanthosoma spp.* by excising shoot tips trimmed down to the apical dome (with one or two leaf primordia), and culturing these tips on a slightly revised Murashige and Skoog medium (M&S). Tissue cultured plantlets were screened for DMV by electron microscopy and mechanical inoculation to *Philodendron selloum* seedlings and were found to be free of DMV at the levels of sensitivity for these two techniques.

A variety of media have been used to culture and regenerate taro plants from excised meristem tips. Jackson *et al.* (1977) used the medium of Linsmaier and Skoog supplemented with varying concentrations of indolea-3-cetic acid and kinetin but reported that growth of taro plantlets was best on unsupplemented media. Kesevan *et al.* (1991) used a basal Murashige and Skoog medium supplemented with varying levels of indole-3-acetic acid and kinetin, whereas Ghani (pers comm. 1989) supplemented their basal medium of Murashige and Skoog with indole -3-butyric acid and N-Benzyl-9-(2tetra hydropyranyl)-adenine.The IRETA Tissue Culture Unit in Western Somoa maintains its taro collection on Murashige and Skoog minimal organic medium supplemented with 0.3 mg/l Naphthalene acetic acid and 1.0 mg/l of 6-Benzylaminopurine (Dr.M.B.Taylor, pers. comm.). Yam *et al.* (1990) used half-strength Murashige and Skoog medium containing 25ml/l of "Taro extract" to regenerate plantlets of *Colocasia esculenta* var. *esculenta*. The addition of the taro extract, obtained from boiled and filtered taro corm tissue, was necessary for regeneration of plantlets. Regardless of the medium used, considerable variation in growth rate and amount of suckering has been observed between cultivars. Our experience here at Unitech is that some cultivars of variety *'esculenta'* grow very easily in tissue culture, sucker readily while other varieties are extremely slow.

4. Breeding

Failure to discover alomae disease resistant cultivars which are also high yielding from within the South Pacific region prompted attempts to breed for resistance (Jackson and Pelomo 1980). Shaw *et al.* (1979) suggested that if cultivars showing resistance to the bacilliform virus diseases were crossed with cultivars showing favourable agronomic qualities then it may be possible to develop disease resistant progeny with acceptable taste and yield. Thirteen varieties of female taro have been found which show resistance to alomae disease (Gollifer *et al* .1978). Jackson and Pelomo (1980) successfully crossed these taro cultivars (female) that showed resistance to alomae with taro cultivars that are high yielding but susceptible (male) and reported that the progeny showed considerable differences in plant height, leaf size and petiole colour.

CONCLUSIONS

Alomae is one of the most important diseases affecting taro in Papua New Guinea and Solomon Islands. Despite its agronomic significance, however, a great deal of confusion still exists in the literature regarding the exact nature of the disease. Apart from the initial reports of the association of two bacilliform viruses with the disease, little has been done to further confirm this association or to characterise the viruses involved. Further, there are conflicting reports in the literature regarding the disease symptoms. These problems cannot be fully resolved until techniques to detect the viruses are found.

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COMPARATIVE STUDY ON RATOONING POTENTIAL OF STANDARD RICE VARIETIES OF PNG

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ABSTRACT

The comparative ratooning potential of 4 standard varieties of PNG was studied under lowland field conditions. The crop performance was measured for yield and yield components, of both the main and ratoon crop. Senis was the highest yielding and the yield of rest of the varieties was statistically at par with each other, in the main crop. On contrary to this Wantok and Tambu were the highest yielding varieties under ratoon crop, while Niupela and Senis yielded significantly lower. The yield and its components of the varieties behaved similarly. Wantok and Tambu seem to be good for ratooning.

Key words: *Ratooning potential, rice varieties, yield components.*

INTRODUCTION

Rice ratooning means to have another rice crop without transplanting a second crop. The crux of the technique is to induce growth of stubbles of the main crop. It is a low cost technology to get extra yield, without spending any money on land preparation, nursery raising and doing the back breaking job of transplanting. For mechanised rice cultivation it also saves on machinery use. The practice of ratooning saves at least 20% in water requirements for ratoon crop (Grist 1959). In addition to this, ratoon crop has a shorter growing duration and is relatively free from weeds and costs less than a second transplanted crop.

It has been practised in many parts of the world and has been found to be very advantageous. In China, the rational practice of ratooning was advocated as far back as 1954 (Iso 1954), and more recently, it has been reported to be economical in Sichuan province of China (Jinguo 1991), and India (Singh *et al.* 1987), where a second crop is impossible to grow. To find out the most suitable genotypes, variants, segregating material and hybrids (Sutaryo and Suprihatno 1993, Singh *et al.* 1984, 1987) have been screened elsewhere in the world. In PNG Sajjad (1993) has also recommended the practice to save money and time to raise another rice crop. Lin (1994) has written a supplementary note, commenting on the article of Sajjad (*op. cit.*). Lin not only supported the guidelines of the author but also suggested some modifications. In fact he has described some specific practices most commonly used in Taiwan, for over twenty years of rice ratooning.

We also envisaged selecting the best variety (ies) with a better ratooning potential, for PNG, where the cost of rice cultivation is already relatively high, compared to rest of the rice producing countries of the world. This prompted the present study and the results are presented in this paper.

MATERIALS AND METHODS

Four standard rice varieties of PNG namely Wantok, Tambu, Niupela and Senis were selected for the study. The field grown 20 days-old seedlings of the varieties were transplanted on 29.5.1991, at a square planting of 20 cm x 20 cm., by using two seedlings per hill. The experiment was conducted in Randomised Complete Blocks and had three replications. Each variety was planted on a gross area of 15 m^2 per replication. The compound fertiliser was used at N.P.K. rate of 100,50,50 kg/ha respectively. All

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P,K, and 40% N were applied at the transplanting time. The two top dressings (30% N for each) were done 20 and 40 days after the transplanting date.The other normal cultural practices were followed during the growing period of the crop. The crop was harvested on 2.10.1991. The datum on yield was recorded by harvesting 25 plants per genotype per replication. The data on yield components were recorded on 10 guarded plants per genotype per replication. The main crop was harvested by leaving 25 cm high stubbles from ground level, to facilitate vigorous sprouting. Immediately after harvesting the main crop, the field was irrigated and urea fertiliser was broadcast at the rate of 60 kg N/ha. The ratoon crop was harvested on 29.1.1992, using the same procedure as for the main crop.

EXPERIMENTAL RESULTS

Yield

It is evident from the results (see Table 1) that yield of Senis, in the main crop was significantly higher than the others, while the yield of the rest of the varieties was at par with each other. On the contrary, in the ratoon crop, Wantok, Tambu were the highest yielders, and Senis and Niupela, the lowest yielders.

Plant height

For the main crop, plant height of Niupela was the maximum, followed by Wantok, Tambu and Senis. Plant height of later three varieties were statistically non significant with each other. Under ratoon crop, the four varieties behaved similar to the main crop. Plant height of Niupela was again the highest, and plant height of rest of the varieties was statistically at par with each other.

Number of productive tillers per hill

Under main crop, number of productive tillers per hill was the lowest in Niupela. Under ratoon crop, Senis produced the highest productive tillers per hill and Niupela the lowest. The tillering capacity of Wantok and Tambu was statistically at par with each other and was significantly less than Senis.

Table 1. Comparative yield and yield components of four standard rice varieties of the main (first row) and ratoon (parentheses), under lowland field conditions at Bubia, during 1991-1992.

Varieties	Yield t/ha	Plant ht (cm)	Productive tillers/hill	Panicle length (cm)	Grains/ panicle	Spikelet fertility (%)
Wantok	7.1B (3.3a)	79.0B (75.9b)	14.2A (10.2b)	26.6B (20.6b)	94.0C (44.8b)	80.8A (75.6a)
Tambu	6.9B (3.9a)	83.6B (70.7b)	11.3AB (10.8b)	26.1A (19.6b)	102.0C (46.8b)	81.3A (79.4a)
Niupela	7.3B (2.0b)	110.7A (99.9a)	9.0C (8.4C)	25.3A (23.5a)	155.0A (77.3a)	84.9A (68.3b)
Senis	8.5A (1.7b)	94.0B (68.9b)	12.8A (12.3a)	26.6A (20.2b)	124.4B (46.5b)	84.9A (69.5b)

Figures followed by different letters are significant at 5% level, according to DMRT.

Panicle length

Under main crop, panicle length of Tambu, Senis and Niupela were longer than that of Wantok. Under ratoon crop, maximum panicle length was recorded for Niupela, while the trait was statistically at par with each other for rest of the varieties.

Number of grains per panicle

Under main crop, Niupela produced the highest number of grains (155/panicle), followed by Senis (124.4), Tambu (102.0), Wantok (94.0). For the ratoon crop, maximum number of grains were also produced by Niupela, compared to rest of the varieties. The rest of the varieties were statistically at par with each other for the trait.

Spikelet fertility (%)

Under the main crop, spikelet fertility of all the varieties was statistically at par with each other. But in the ratoon crop, maximum spikelet fertility was observed for Wantok and Tambu, while spikelet fertility for rest of the varieties was statistically at par with each other.

DISCUSSION

It is evident from the results of the study that under the ratoon crop, Wantok and Tambu produced statistically higher yield than rest of the varieties under study, while the yield potential of Niupela and Senis was statistically at par with each other. For yield components, the results of the study was very interesting. For instance, Senis has produced the maximum number of productive tillers per hill, while maximum value of panicle length has been recorded for Niupela. Again Niupela has produced the highest number of grains per panicle.

Maximum spikelet fertility has been recorded for Wantok and Tambu, while Niupela has shown significantly lower spikelet fertility. It is clear that the top yielders have also had significantly the highest spikelet fertility.

CONCLUSION

It may be concluded from the results of the study that Wantok and Tambu are good for ratooning. Yield and spikelet fertility may be used as selection criteria for ratooning ability.

RECOMMENDATIONS

To make rice ratooning more productive & economical, a package for the management of both the main and ratoon crops is recommended as under:

Main crop

Transplant 20 days-old seedlings in well puddled field. The dykes (bunds) should be up to 45 cm to retain the water all the time. Transplantation should be accomplished by using two to three seedlings per hill at a square planting of 20 cm x 20 cm. Use compound fertiliser at N.P.K. rate of 100, 50, 50 kg/ha respectively. Apply all P, K and 40% N at the time of transplanting. Top dress the crop two times (30% N each), 20 and 40 days after the transplanting date. Light top dressing has also been recommended at the grain filling stage (Lin 1994). Harvest the main crop, by leaving the stubbles 20-25 cm high from ground level.

Ratoon crop

Immediately after harvesting the main crop, irrigate the field and apply N at the rate of 60 kg/ha, in the standing water. The sprouts will start growing very vigorously only if the fertiliser is applied. If fertiliser is not added, the sprouts growth will not be that robust; and colour of the crop will be pale, the very undesirable feature of ratoon crop. The two subsequent irrigations should be thorough and water must stand up to 7.5 cm in the field. A greater care is required to monitor the insect pests build up in the ratoon crop, another undesirable feature of ratoon crop. If insect pest build up beyond the threshold level, use insecticides to control the population build up. More recently Lin (1994) has recommended that after one week when the new shoots sprout from the stubbles to a height of about 15 cm, the stubbles should be cut again 3 to 5 cm above ground level. This practice he has considered

very critical because the cutting of the regrowth and stubbles at a lower level will induce development of more new shoots. He has further argued that more shoots will develop more roots at the lower nodes which in turn sustain a strong and healthy ratoon crop.

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NUTRITIONAL ASSESSMENT OF STEEPLY SLOPING SOILS FROM AIYURA IN THE EASTERN HIGHLANDS OF PAPUA NEW GUINEA

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ABSTRACT

Prior to commencing long-term soil loss studies at the Highlands Agricultural Experiment Station at Aiyura in the Eastern Highlands of Papua New Guinea, the nutritional status of soils from the experimental site was assessed by soil analysis and nutrient omission pot trial. Two soils were assessed; the first, an Orthoxic Tropudult, was located on long convex slopes with northerly aspect and the second, an Umbric Tropaquult, occupied a hummocky microtopography with short slopes and a southerly aspect. Soil tests suggested both surface (0 to 0.15 m depth) soils were strongly acid (pH 5.0 to 5.4 in 1:5 soil/water suspension), contained allophane and active Al (pH 7.9 to 8.2 in 1:50 soil/NaF solution), and were strongly P fixing (P retention >70%) with low P availability (< 4 mg kg^{-1} Olsen-P). With maize (Zea mays L.) as the test plant, short duration (35 day) omission pot trials confirmed (P < 0.05) these soils were P and S deficient. Plants suffering P and S deficiency were 8 to 24% shorter, and amounts of both fresh and dry matter produced were 15 to 43% lower, and S deficient plants were distinctly yellower in colour. No deficiency was apparent with omission of B, Ca, Cu, Fe, K, Mg, Mn, Mo, N, Ni or Zn. Also, addition of lime had little effect.

Key Words: *Soil test, Nutrient omission pot trial, Maize, Phosphorus deficiency, Sulfur deficiency*

INTRODUCTION

Within the International Board for Soil Research and Management (IBSRAM) Project "*PACIFIC LAND* Management of Sloping Lands in the Pacific", a series of research plots have been established on the Highlands Agricultural Experiment Station (HAES) at Aiyura in the Eastern Highlands of Papua New Guinea (Wayi and Konabe 1993). The primary objective of the IBSRAM sloping lands project in PNG is twofold: (1) to quantify soil loss and monitor fertility decline under traditional compared with improved farming practices, and (2) to develop an improved farming practice that will reduce soil loss, improve soil fertility and extend the productive use of these sloping lands (Wayi and Konabe 1993). Sweet potato (*Ipomoea batatas*) is the traditional crop. Fundamental to these objectives is the need to identify soil nutritional deficiencies as these may initially limit this crop's growth and subsequently, either singly or in combination with soil loss, determine changes in its productivity over time. The project is expected to continue for a period of 5 to 10 years.

In order to develop a sustainable and economic crop and soil management program, the nutritional status of the soil must firstly be diagnosed. Analysis of soil provides information in advance of crop establishment as to whether or not a nutrient is likely to be limiting for a particular crop, but these data are only as good as the soil test's calibration against a measured yield response. In fertility studies, it is often advisable to also look at the soil from the plant's point of view, especially if analytical and financial resources are restricted. Nutrient omission pot trials provide a cost-effective method of diagnosing nutritional limitations in soils from the plant's perspective (C.J. Asher and N.J. Grundon, pers. commun.), especially in the tropics (Sanchez 1976). For convenience, a standard test plant (e.g. maize, *Zea mays* L.) with well characterised deficiency symptoms (e.g. Grundon 1987) is often used. Fertiliser trials using the desired

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combination of crop and soil can follow to further quantify nutritional limitations.

The objectives of this assessment were to: (1) diagnose nutritional limitations of surface (0 to 0.15 m depth) soils from the IBSRAM project site by omission pot trial; and (2) suggest directions for future nutritional studies by considering how existing disorders may interact with soil loss to determine the sustainable cropping potential of these soils.

METHODS

Experimental Site

The IBSRAM project site is located at HAES (6° 19' S, 145° 55' E) at an altitude of 1700 m in the Aiyura Valley near Kainantu, Eastern Highlands Province, PNG. The Aiyura Valley is characterised by broad valleys and strongly rolling (10 to 20° slopes) topography, interrupted by occasional steeply dissected conical hills. Regional geological maps (1:250 000) indicate HAES is underlain by the Akuna intrusive complex of Lower Miocene age, and field examination of boulders embedded in the soil matrix suggests a dominant lithology of porphyritic dolerite. Although a draft mantle of volcanic ash overlies the Kainantu District, volcanic ash was not observed or mapped on the site.

From aerial photographs (flown in 1986 at 1:25,000), a 2 ha area of uniform and stable slope (both north- and south-facing aspects) was selected, and a systematic grid (12.5 m by 10 m) established for soil and contour survey. Soil morphology data to 1.2 m were described from auger cores. Additional surface soil morphology data were obtained from a series of mini-pits (0.3 m by 0.3 m by 0.3 m). Soils were classified according to Soil Taxonomy (Soil Survey Staff 1990). A contour map with a 1 m contour interval was also compiled. From these surveys, separate experimental areas on north- and south-facing slopes were identified. Experimental plots were selected; eight within the north-facing site and twelve within the south-facing site (Wayi and Konabe 1993). Construction of plots to measure run off and soil loss commenced in October 1991 (Wayi and Konabe 1993). Separate surface (0 to 0.15 m) samples representing north- and south-facing soils were collected from within the experimental area. Each sample, a composite of six 80 kg subsamples, was air dried, sieved < 5 mm and stored in a sealed plastic container prior to assessment by nutrient omission pot trial. A 2 kg subsample of each soil was retained for analytical characterisation.

Soil analysis

Soils were dried at 4°C and ground < 2 mm before analysis. Soil analytical procedures followed those outlined in Rayment and Higginson (1992). Soil pH and electrical conductivity (EC) were determined on a 1:5 soil to water suspension at 25°C. Soil pH was also determined on a 1:50 soil to saturated (approximately 1M) NaF solution. Organic C was determined by Walkley and Black wet oxidation with titrimetric finish. Total N was determined following Kjeldahl digestion. Native P availability was determined following extraction in 0.5M $NaHCO_3$ at pH 8.5 for 30 min. (Olsen-P), and P in solution was determined colorimetrically by the molybdenum blue procedure. Phosphorus retention was also estimated colorimetrically following a standard addition of KH_2PO_4. Exchangeable Ca, Mg, Na and K were leached from the soil with 1 M NH_4OAc at pH 7 without pretreatment for soluble salts. After removal of excess NH_4OAc, the soil was releached with 1 M NaCl and the leachate retained for determination of CEC. Exchangeable cations were determined by atomic adsorption spectrometry, and CEC by the Kjeldahl method. Exchangeable acidity (hydrogen and aluminium) was estimated following equilibration with 1M KCl by titration with standard NaOH. Effective CEC (ECEC) was estimated as the sum of total exchange cations. Acid saturation was then estimated as [exchangeable acidity x 100 / (total exch. cations)]. Particle size analysis was determined after Bruce and Rayment (1982). Air dry and field capacity gravimetric water contents were also determined; air dry water content after drying prepared soil at 105°C for 48 h, and field capacity water content after allowing saturated soil to drain freely for 24 h and then drying at 105°C for 48 h.

Nutrient Omission Pot Trial

Diagnosis of nutritional limitations to plant growth by omission pot trial followed the procedure of

Asher and Grundon (unpublished report[4]) a procedure similar to that of Middleton and Toxopeus (1973). Pot trials utilised shadehouse and laboratory facilities of the Department of Agriculture, PNG University of Technology, Lae. North- and south-facing soils were assessed separately.

In these omission trials, the control treatment was the complete nutrient or ALL treatment. Omission treatments were then arranged to omit or lack only one element (e.g. ALL-N, ALL-P, ALL-K). In each trial, the ALL treatment was replicated 12 times and omission treatments were replicated four times with treatments completely randomised with no blocking. Experimental units were 166 mm PVC pots containing 2.4 kg air dry soil. For the ALL treatment, nutrients were applied separately to the soil in solution form at the following rates (kg ha^{-1}): 100 N as NH_4NO_3; 80 P as $NaH_2PO_4.2H_2O$; 80 K as KCl; 35 Ca as $CaCl_2$; 30 Mg as $MgCl_2.2H_2O$; 25 S as Na_2SO_4; 5 Fe as sulfate-free Fe EDTA; 2 B as H_3BO_3; 4 Zn as $ZnCl_2$; 5 Mn as $MnCl_2.4H_2O$; 3 Cu as $CuCl_2.2H_2O$; 0.4 Mo as $(NH_4)_6Mo_7O_{24}.4H_2O$; and 0.1 Ni as $NiCl_2.6H_2O$. Omission treatments were arranged identically, except to omit or lack only one element. An additional ALL + Lime treatment was included with 5 t ha^{-1} lime (as $CaCO_3$).

Soils were then wet to field capacity and sealed. After a 7 d equilibration period, six germinated maize (cv. Pioneer 6875) seeds with radical length 5 to 15 mm were planted in each pot. These were thinned to four uniform plants per pot after emergence. Pots were watered daily to field capacity with distilled water. Plants were grown until well-defined growth responses (see e.g. Grundon 1987) were produced. Individual plant heights were recorded prior to harvest 35 d after sowing (DAS), and plants tops harvested at ground level. Fresh weights were immediately recorded. Plant tops were then dried (70°C for 48h) and reweighed.

Plant height, top fresh weight and top dry weight data were expressed relative to the mean of the ALL (=100%) treatment. Since the experimental design was unbalanced, omitted nutrient effects were determined by two-sample t-test with each omission treatment compared in turn with the ALL; in total, 14 individual sets of data were analysed. Significant departures from the ALL treatment were determined at $P < 0.05$.

RESULTS

Soil morphology

Soils were deep (> 1.4 m) with rooting depths > 1.0 m, and were imperfectly to moderately well drained (Wayi and Konabe 1993). Earthworm activity was common in the A and upper B horizons. Surface soils, typically black (10YR 2/1) to very dark greyish-brown (10YR 3/2) loams to clay loams, were 0.1 to 0.4 m thick and weak to moderate, fine to medium crumbs to subangular blocky structure. There was a smooth clear boundary into gravelly loam to clay loam B horizons that were either strongly gleyed or contained a high percentage of coarse fragments dominated by irregularly shaped iron and manganese concretions up to 20 mm in diameter. Subsoil structure was weak to moderate, medium to coarse subangular blocky. Gleyed horizons became greyer (5Y 6/1 to 7/2) and concretionary horizons yellower (10YR 5/6 to 5/8) with depth. The B horizons, usually 0.9 to 1.2 m thick, overlay a mottled yellowish brown, silty clay loam B-C horizon with moderate coarse columnar structure.

Morphological data suggested local microrelief has influenced soil formation to a great extent. Generally, soils with long, north-facing convex slopes are moderately well drained, have a concretionary B horizon and have been classified as fine clayey mixed isothermic Orthoxic Tropudults. Their counterparts on south-facing slopes, however, occupy a hummocky microtopography with short slopes. Typically, these soils are imperfectly drained, have a strongly gleyed (reduced) B horizon in their depressions, and have been classified as fine clayey mixed isothermic Umbric Tropaquults (Wayi and Konabe 1993).

[4] ASHER, C.J. and GRUNDON, N.J. Diagnosis of nutritional limitations to plant growth by nutrient omission pot trial. Department of Agriculture, The University of Queensland, Brisbane Qld 4072, Australia.

Table 1. **Surface (0 to 0.15 m) soil properties (with standard error) of Orthoxic Tropudult (north-facing) and Umbric Tropaquult (south-facing) soils used in nutrient omission pot trials from Highlands Agricultural Experiment Station, Aiyura.**

Property	Orthoxic Tropudult	Umbric Tropaquult
pH (1:5 soil/water)	5.4 (0.2)	5.0 (0.2)
pH (1:50 soil/NaF) [1]	7.9	8.2
EC (1.5; dS m^{-1})	0.06 (0.01)	0.06 (0.01)
Organic C (%)	4.7 (0.01)	5.2 (0.6)
Total N (%)	0.41 (0.05)	0.40 (0.04)
Extratable P (mg kg^{-1})	3.8 (0.4)	3.4 (0.3)
P retention (%)	73 (3)	71 (6)
CEC (cmol (+) kg^{-1})	22 (3)	19 (2)
Exch. Ca (cmol (+) kg^{-1})	5.3 (1.0)	2.8 (0.5)
Exch. Mg (cmol (+) kg^{-1})	2.2 (0.3)	1.5 (0.3)
Exch. K (cmol (+) kg^{-1})	0.65 (0.11)	0.34 (0.03)
Exch. Na (cmol (+) kg^{-1})	0.02 (0.01)	0.02 (0.01)
Exch. Acidity (cmol (+) kg^{-1}) [2]	1.2	0.9
Gravimetric soil water: [2]		
Air dry (40°C, %)	16	16
Field capacity (%)	42	44
Particle size analysis: [2]		
Sand (0.2-2 mm, %)	39 (8)	31 (5)
Silt (0.002-0.02 mm, %)	27 (2)	32 (2)
Clay (< 0.002 mm, %)	34 (9)	38 (6)

[1] analysis of soil survey and site characterisation samples only
[2] analysis of soil collected for pot experiment only

Soil analysis

Orthoxic Tropudult and Umbric Tropaquult surface soils had similar properties (Table 1). Interpretive indices follow Bruce and Rayment (1982) and Landon (1991). Both soils were strongly acid (pH 5.0 to 5.4, 1:5 soil/water) with low levels of soluble salts. With pH (1:50 soil/NaF) levels of 7.9 to 8.2, both soils were also likely to be derived from volcanic ash suggesting the presence of allophane and active Al. Organic C and total N levels were medium to high. Extractable P levels were low (< 4 mg kg^{-1} Olsen-P) and soils appeared strongly P fixing with P retention values >70%. Levels of CEC and exchangeable Ca, Mg and K were medium to high whereas levels of exchangeable Na were low. Effective CEC levels were low (<10 cmol (+) kg^{-1}). Base saturation levels were medium at 25 to 37%. Exchangeable acidity levels were <1.2 cmol (+) kg^{-1}, with low acid saturation levels of 13 to 16%, suggesting that only Al-sensitive crops are likely to affected.

In these very strongly acid soils, problems due to low P availability are likely and crop responses to fertiliser P are probable. Lime may need to be

Table 2. **Plant height, top fresh weight and top dry weight (expressed relative to the ALL treatment = 100%) data for a nutrient omission pot trial conducted on an Orthoxic Tropudult (north-facing) soil from Highlands Agricultural Experiment Station. Aiyura.**

TREATMENT	Plant data (with standard error) expressed relative to ALL treatment (=100%)		
	PLANT HEIGHT	FRESH WEIGHT	DRY WEIGHT
ALL	100 (0.8)	100 (3.9)	100 (4.2)
ALL + Lime	105 (1.6)	106 (4.3)	110 (5.0)
ALL-B	100 (2.5)	93 (7.2)	95 (4.8)
ALL-Ca	100 (1.8)	101 (8.2)	99 (7.6)
ALL-Cu	95 (2.3)	88 (7.0)	88 (7.1)
ALL-Fe	95 (3.4)	97 (8.8)	96 97.0)
ALL-K	103 (2.9)	100 (6.8)	102 (7.6)
ALL-Mg	100 (1.7)	94 (6.3)	95 (6.6)
ALL-Mn	100 (2.1)	102 (8.0)	101 (8.2)
ALL-Mo	98 (1.6)	94 (9.0)	98 (8.6)
ALL-N	97 (1.4)	99 (3.2)	101 (2.2)
ALL-Ni	100 (0.9)	105 (6.7)	109 (6.0)
ALL-P	89 (0.3)*	72 (3.2)*	81 (2.0)*
ALL-S	92 (2.0)*	82 (3.9)*	85 (3.3)*
ALL-Zn	96 (2.5)	102 (8.6)	107 (7.5)

* values in the same column are different ($P < 0.05$) from the ALL treatment.

applied to raise pH levels above 5.5, and a lime requirement of some 5 t ha^{-1} to a depth of 0.15 m was suggested. However, liming these ash-derived soils may induce micro-nutrient (e.g. Fe, Mn, Cu or Zn) deficiency or cation imbalance (e.g. Ca:K ratio) due to low ECEC levels. Omission pot trials should resolve this issue.

Nutrient omission pot trials

Similar maize growth responses to omission treatments were observed in Orthoxic Tropudult and Umbric Tropaquult soils. From ca. 17 DAS, plants in ALL-P pots were visibly smaller than those of the ALL. There were no distinct symptoms other than a mild purple discolouration of the leaf sheaths similar to that suggested by Grundon (1987). From the same time, ALL-S plants were visibly smaller and distinctly chlorotic (Grundon 1987). This chlorosis uniformly affected the whole plant (i.e. young and old leaves and stems were yellow) with some reddening of stems and the tips of older leaves being necrotic. Other treatments including ALL+ Lime appeared similar to the ALL suggesting that lime (at 5 t ha^{-1}) did not induce any potential micro nutrient deficiency, or cation imbalance.

Orthoxic Tropudult. At harvest, plant heights ranged from 53 to 96 cm, top fresh weights from 29 to 55 g pot^{-1} and top dry weights from 2.32 to 4.26 g pot^{-1}, and variations in these parameters were highly inter-correlated (r values > 0.75, $n = 66$, $P < 0.01$). Mean values for the ALL treatment were: plant height 81 cm; fresh weight of tops 45 g pot^{-1} ; and dry weight of tops 3.33 g pot . Mean values for the omission treatments expressed relative to the ALL treatment (= 100 %) are given in Table 2. Reductions ($P < 0.05$) in plant height and fresh and dry weights of plant tops were observed for ALL-P and ALL-S. With omission of P, plants were 11%

Table 3. **Plant height, top fresh weight and top dry weight (expressed relative to the ALL treatment = 100%) data for a nutrient omission trial conducted on an Umbric Tropaquult (south-facing) soil from Highlands Agricultural Experiment Station, Aiyura.**

TREATMENT	Plant data (with standard error) expressed relative to ALL treatment (=100 %)		
	PLANT HEIGHT	FRESH WEIGHT	DRY WEIGHT
ALL	100 (0.7)	100 (2.5)	100 (2.6)
ALL + Lime	95 (1.9)	99 (8.1)	100 (7.4)
ALL-B	104 (3.4)	113 (3.6)	107 (3.2)
ALL-Ca	104 (4.0)	107 (4.7)	106 (5.6)
ALL-Cu	104 (2.4)	105 (6.1)	101 (5.8)
ALL-Fe	100 (4.5)	104 (9.7)	105 (10.5)
ALL-K	97 (3.2)	83 (8.6)	83 (9.0)
ALL-Mg	105 (3.4)	106 (3.1)	103 (3.5)
ALL-Mn	106 (1.9)	120 (7.9)	115 (8.8)
ALL-Mo	100 (3.2)	103 (8.7)	94 (5.7)
ALL-N	101 (4.6)	103 (10.5)	94 (9.8)
ALL-Ni	99 (3.3)	101 (9.1)	96 (8.0)
ALL-P	91 (1.6)*	65 (3.6)*	74 (4.4)*
ALL-S	76 (8.6)	57 (10.9)*	57 (10.0)*
ALL-Zn	101 (4.5)	96 (10.0)	93 (9.3)

* values in the same column are different ($P < 0.05$) from the ALL treatment.

shorter, top fresh weights 28% lower and top dry weights 19% lower than the ALL. With omission of S, plants were 8% shorter, top fresh weights 18% lower and top dry weights 15% lower than the ALL.

Umbric Tropudult. At harvest, plant heights ranged from 10 to 110 cm, top fresh weights from 12 to 59 g pot^{-1} and top dry weights from 1.33 to 5.42 g pot^{-1} and variations in these parameters were highly inter-correlated (r values > 0.87, n = 66, P < 0.01). Mean values for the ALL treatment were: plant height 83 cm; fresh weight of tops 45 g pot^{-1} ; and dry weight of tops 4.14 g pot^{-1}. Mean values for omission treatments expressed relative to the ALL treatment (= 100%) are given in Table 3. Reductions ($P < 0.05$) in plant height and fresh and dry weights of plant tops were observed for ALL-P and ALL-S, whereas an increase ($P < 0.05$) in plant fresh weight only was recorded for ALL-B. With omission of P, plants were 9% shorter, top fresh weights 35% lower and top dry weights 26% lower than the ALL. With omission of S, plants were 24% shorter, top fresh weights 43% lower and top dry weights 43% lower than the ALL. With omission of B, plant fresh weight was 13% greater than the ALL suggesting a possible oversupply of B (2 kg ha^{-1}) in the ALL treatment. However, there was no significant difference in dry weight of plants in the ALL and ALL-B treatments.

DISCUSSION

For Orthoxic Tropudult and Umbric Tropaquult soils, omission of P and S caused a decrease ($P < 0.05$) in plant height and amounts of fresh and dry matter produced relative to the control treatment. These results suggest the supply of P and S from the soil was limiting for plant growth, and deficiencies of these elements are likely (but not certain) to occur in the field. With inherent P and S deficiency in these soils prior to commencement of the IBSRAM PACIFICLAND Project, it is

likely that nutrition and soil loss will act in combination to determine changes in crop productivity over time, and effects due to soil loss alone will be difficult to quantify. Nutrient omission experiments may be repeated in time to determine if the severity of P and S deficiency has increased or if other nutrients have become limiting.

The ultimate test of a nutrient disorder is to demonstrate responses in yield, growth rate and/or quality as a consequence of corrective measures. Fertiliser P and S rate experiments using sweet potato as a test plant are planned to quantify growth responses to both applied and solution P and S. The recognition of foliar symptoms of nutrient disorders in sweet potato during the course of the IBSRAM project will be facilitated by: (1) visual comparison with photographs (e.g. O'Sullivan *et al.* 1993) and (2) analytical comparison of measured and "critical" nutrient concentrations in plant tissue (e.g. O'Sullivan *et al.* 1993). Regular collection and analysis of leaf samples will allow nutrient stresses to be monitored over time, and provide a basis for describing the nutritional degradation of these soils.

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NOTES ON TWO MINOR INSECT PESTS IN THE HIGHLANDS REGION

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ABSTRACT

Notes on two minor pests in the Highlands Region of Papua New Guinea are presented. The distribution, life history and plant damage caused by Ragwelellus festivus *(Miller) (Heteroptera: Miridae), a potential pest of several plant species and of* Omiodes indicata *(F.) (Lepidoptera: Pyralidae) a defoliator of field crop, garden and pasture legumes is briefly described.*

Key words: *Papua New Guinea, Entomology,* Ragwelellus, Omiodes, *legumes.*

RAGWELELLUS FESTIVUS

INTRODUCTION

Ragwelellus festivus (Miller) (Heteroptera: Miridae) was first described (Miller 1954) from specimens collected in 1953 on experimental plots of cinchona (*Cinchona calisava* var. *ledgeriana*). At that time, cinchona was being considered as a tree crop for the production of the anti-malarial drug quinine but after synthetic anti-malarial derivatives were developed, the pest status of *R. festivus* diminished. During 1976, breeding populations of this mirid were noted on guava (*Psidium guajava*) and non-plucking tea (*Camellia sinensis*) at the Highlands Agricultural Experiment Station (HAES), Aiyura and were also present on the old cinchona trees there.

TAXONOMY AND DISTRIBUTION

Ragwelellus festivus (Miller, 1954)
Eucerocoris festivus Miller, 1954:703
Eucerocoris (*Eucerocoris*) *festivus* Odhiambo, 1962:314.
Ragwelellus (*Narinellus*) *festivus* Odhiambo, 1965:21.

The species was first described and the genitalia illustrated by Miller (1954) but further descriptions were given by Odhiambo (1962) when the latter proposed two subgenera for *Eucerocoris*. Later, *Ragwelellus* was raised to full generic rank (Odhiambo 1965) and Carvalho (1981) further described and provided illustrations of genitalia for the eight species of this genus in Papua New Guinea.

R. festivus is widely distributed within the mainland of Papua New Guinea (PNG) and has been collected from the four Highland Provinces in addition to the Morobe and Oro Provinces (Carvalho 1981) at elevations of below 150 m to 2250 m. It is probable that its range extends to other Provinces and into Irian Jaya.

DESCRIPTION AND LIFE HISTORY

R. festivus is an elongate, fragile mirid, reddish-brown in colour. Adults are 7-8 mm long, 1.4-1.7 mm wide and have 4 segmented antennae longer than 11 mm. They are quite mobile but were easily collected on host trees while the nymphs attempted to escape by movement around or under a leaf. All stages were collected from guava, tea and cinchona. The eggs which were embedded in the mid-ribs of recently expanded leaves, had an incubation period of 24-25 days. Immature stages, all of which feed on soft flush tissue, passed through five nymphal stages over a five week period and the males developed slightly faster than females. Pre-oviposition pe-

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riod was 6-8 days and the total generation time about 10 weeks under ambient conditions at Aiyura (6°19'S; 145°55'E; 1550 m elevation) (Table I). In cage studies, adults survived at least four weeks and females laid up to 15 eggs although natural fecundity was probably higher.

PLANT DAMAGE AND ECONOMIC SIGNIFICANCE

On cinchona the damage to soft flush tissue appeared slight but damage to guava was occasionally severe and caused the death of tissue, leaf wrinkling and distorted growth. When feeding occurred on developing guava fruits, extensive scabbing, enough to make the fruit unmarketable, resulted. Attack to the soft flush leaves and young shoots of tea bushes frequently killed them or deformed subsequent growth. Caged adults readily fed on the mid-ribs and laminae of young leaves of avocado (*Persea americana*) but no natural infestation was observed.

The species was originally described as a pest of cinchona but has now emerged as a moderate-severe pest on guava and has been found to attack tea bushes. However, it is unlikely that *R. festivus* will develop into a significant pest of tea in the Highlands of PNG since the eggs and immature insects along with the flush tissue would be removed during the regular plucking rounds. The species undoubtedly feeds on the soft flush tissue of native host trees in the forest in the absence of cultivated hosts. One such unidentified shrub was located in the primary forest above Aiyura.

OMIODES INDICATA

INTRODUCTION

The cosmotropical pest, Omiodes indicata (F.) (=*Hedyleptaindicata*) (F.) (Lepidoptera: Pyralidae) is a minor pest of field crop, garden and pasture legumes in the highlands, Markham Valley and Wau areas of PNG. In lowland areas, the pest is usually adequately controlled by parasites (Young 1984) but the insect has recently increased both in importance and range within the country. After moderate damage to soybean, a crop which has been promoted as a high protein food for institutions (Bourke 1978), observations on the life history, damage and control of this pest were conducted at HAES, Aiyura during 1976-77.

TAXONOMY AND DISTRIBUTION

Omiodes indicata (Fabricius, 1775)
Phalaena indicata Fabricius, 1775:640.
Hedylepta vulgalis Guenee,1854:202, pl.6, fig.8.

Omiodes indicata is a widely distributed species of the large pyralid subfamily Pyraustinae and is currently placed in the Spilomelini. The species has been named independently by several authors but the species-group names *indicata Fabricius* and *vulgalis* Guenee are the most widely used names. The species has until recently been placed in the genus *Hedylepta* Lederer, 1863, by almost all authors but Munroe (1983: 74) has placed *Hedylepta* in synonymy with *Omiode* Guenee, 1954. Munroe (1983) provides a detailed list of both genus-group synonyms of *Omiodes indicata*. No modern taxonomic account is available for this group.

DESCRIPTION AND LIFE HISTORY

Adults are medium sized moths, yellow-orange in colour with three black bands on the forewings and two on the hindwing. Females may lay over 300 eggs on the lower leaf surfaces and these hatch in 3-5 days (Kapoor *et al.* 1972, Bortoli *et al.* 1982 a). The larvae, which are green with blackish head capsules, passed through four instars over an 18-24 day period under ambient conditions at HAES, Aiyura. Pupation took 7-14 days (mean 10.21 ± 1.12 for females, 10.34 ± 1.18 for males) and the pre-oviposition period 4-5 days. The generation time occupied 5-6 weeks at Aiyura and the sex ratio was very close to 1:1. The adults survived for 7-10 days when offered 5% sucrose solution.

HOST AND PLANT DAMAGE

The moth was reared from nine pasture species, five garden legumes and four grain legume species grown as field crops (Table 2).The feeding sites were readily noticeable as silvery

Table 1. **Duration of life history stages of *R. festivus* on tea bushes at Highlands Agricultural Experiment Station, Aiyura.**

STAGE	NUMBER OF SPECIMENS RECORDED	RANGE (days)	MEAN (days)	STANDARD DEVIATION
Egg	38	17-31	24.55	3.93
1st instar	19	3-9	5.95	1.50
2nd instar	30	4-9	6.40	1.65
3rd instar	12	5-8	6.75	0.97
4th instar	9	5-7	5.67	0.85
5th instar	5	9-12	10.40	1.14

areas on host plants. Larvae webbed the leaves of host plants together with silk threads and within the shelters so constructed, fed on the parenchyma layers of the leaves leaving only the epidermal membranes. In heavily infested soybean crops, every plant had at least one *O. indicata* larvae and some had 20 or more feeding sites, but the loss of photosynthetic area was rarely significant.

CONTROL

Parasites. Larvae and pupae of *O. indicata* were collected from soybeans between October and December 1976. These were held in a laboratory at 15-28°C for pupation, parasite or moth emergence. The results, tabulated in Table 3, show that 69.1% of the 529 *O. indicata* collected emerged as moths, 18.7% were parasitised and 12.1% failed to produce adult organisms.

Apanteles iulis Nixon (Hymenoptera: Braconidae) was by far the most numerous parasite. It attacked *O. indicata* larvae and as the host pupated, the parasite emerged to spin white silken cocoons beside the remains of the host pupa. On each host 2-11 *A. iulis* pupae were produced (mean 6.90 ± 1.90) and the adults emerged after a pupal period of 6-12 days (mean 8.70 ± 2.11 for females; but significantly longer ($p < 0.001$) at 8.87 ± 1.10 for males). Similarly, *Bracon* sp. (Hymenoptera: Braconidae) parasitised the larval hosts and emerged as adults from the host pupae. These parasites emerged 10-12 days (mean 11.6; N=5) after the *O. indicata* larvae pupated.

One specimen of *Compsilura concinnata* Meigen. (Diptera: Tachinidae) was also reared from a moth pupa collected as a larva.

In addition, a single specimen of the hyperparasite *Stictopisthus* sp. (Hymenoptera: Ichneumonidae) emerged from an *O. indicata* pupa but it is not known which of the above parasites it attacked.

During February 1977, three larvae of *O. indicata* were collected from wing bean plants at Aiyura. All were parasitised by *A. iulis*.

Chemical. Although *O. indicata* must be regarded as only a minor pest of legumes in the highlands region, a small unreplicated spray trial was conducted. Results showed that a 0.15% trichlorfon spray at 7-10 day intervals, beginning a week before flowering, would give satisfactory control and that yields of soybeans were not reduced by the feeding damage. It was also shown that 0.10% carbaryl sprays had a phytotoxic effect on soybeans of the NG 4661 variety.

Table 2. **Recorded host plants of *O. indicata* at Aiyura.**

SPECIES	COMMON NAME
*Arachis hypogaea**	Peanut
Cajanus cajan	Pigeon pea
Centrosoma pubescens	butterfly pea
Desmodium intortum	Green leaf desmodium
Desmodium uncinatum	Silver leaf desmodium
Galactia tenuiflora	-
Glycine max *	Soy bean
Glycine wightii	Vars. Copper, Tinaroo
Macrotyloma axillare	Archer Dolichos
*Mucuna pruriens**	Velvet bean
Phaseolus lanatus	Lima bean
Phaseolus vulgaris	String bean
*Pisum sativum**	Pea
*Psophocarpus tetragonolobus**	Winged bean
Rhynchosia minima	–
Vigna parkeri	Vigna
*Vigna radiata**	Mung bean
Vigna unguiculata	Cowpea

* The species (as *Diaphania indica* (F.)) has also been reported from these host plants at low or mid-altitude regions by Young (1984).

Table 3. **Fate of 529 *O. indicata* collected as larvae or pupae at Highlands Agricultural Experiment Station, Aiyura.**

	NUMBER COLL.	% OF TOTAL	TOTAL NO. PARASITES	% FEMALE MOTHS
Emerged as adult *O. indicata*	366	69.1		49.4
Failed to develop	64	12.1		
Parasitised by *A. iulis*	96	19.1	662	41.2
Parasitised by *Bracon* sp.	2	0.4	5	_
Parasited by *C. concinnata*	1	0.2	1	_

DISCUSSION

The *O. indicata* life cycle recorded was similar, although slightly longer, to that found elsewhere (e.g. Bortoli *et al.* 1982 a) probably due to the cooler temperatures experienced at the (0.3 m altitude of Aiyura. In India, Rawat and Singh (1980) reported that although the pest was active throughout the year, soybeans were more heavily infested during the cooler season.

It is certain that many other legumes, of which about 500 species are known from PNG (Verdcourt 1979), are utilised as hosts (for example, (Young 1984) recorded *Medicago sativa* from the lowlands).

In subsistence farming systems, the rates of parasitism may be higher than those recorded here because the plant hosts and pests may be more widely distributed in space and time. It is also possible that the sampling conducted may have underestimated parasitism because some larvae, collected unparasitised, may have been stung if they had remained in the field. Similarly, rates may have been higher at times other than this due to seasonal conditions.

In addition to the natural enemies of *O. indicata* listed in Table 3, *Aphanogmus* sp. nr. *fijiensis* Ferriere (Hymenoptera: Ceraphronidae) has been reared from a pupa collected in the lowlands of Papua New Guinea. It is possible that this species is a hyperparasite of *C. concinnata* or of *Peribaea* spp. (Diptera: Tachinidae) since many of this family are thought to be parasitic on Diptera (CSIRO 1970) and *P. aegyptia* has been reared from *O. indicata* and is found, along with *P. alternata* in the highlands region (Shima 1981). Worldwide, the level of parasitism varies widely, with rates ranging from 1.7-11.9% in the Philippines (Litsinger *et al.* 1978), 8.7% in Brazil (Bortoli *et al.* 1982 b) and over 85% by a single species in Colombia (Garcia 1975). If parasitism rates are high, chemical control is seldom justified (Schoonhoven 1978), but since several workers have conducted spray trials (e.g. Garcia 1971, Rawat and Singh 1980), it is obvious that (as at Aiyura), effective biological control does not occur in all crop growing areas.

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INSECTS OF THE GIANT SENSITIVE PLANT (*MIMOSA INVISA*) AT RAMU, PAPUA NEW GUINEA

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ABSTRACT

Fourteen species of insects in 3 orders and 9 families mainly lepidopterans were collected on Mimosa invisa *at Ramu. The pierid,* Eurema hecabe *L. was the most abundant followed by the lymantriid,* Euproctis *sp. nr.* trispila *Turner. However, damage to* M. invisa *was minor; and there appeared to be no competitor with the introduced biological control agent,* Heteropsylla spinulosa *Muddiman, Hodkinson & Hollis (Psyllidae), for feeding sites.*

Key words: Mimosa invisa, Eurema hecabe, Heteropsylla spinulosa, *Papua New Guinea.*

INTRODUCTION

Mimosa invisa Martins ex Colla (Mimosoidea) commonly known as giant sensitive plant (GSP) is a native of central America. GSP can be biennial or perennial (depending on duration of growing season) and is distributed widely in the tropics. Norris (1987) pointed out that the weed is well established in most Pacific countries including Australia. In Papua New Guinea (PNG) GSP is well established and is creating serious problems in pastures, plantations, subsistence cropping situations, and non-productive areas. It is found up to 2000 m.a.s.l and on most off-shore islands. Heavy infestations of GSP can seriously change the ecology.

Control of such a prolific weed with chemical herbicides has usually proved too expensive, and there was a high risk of contaminating the environment and people handling the chemicals. Ramu Sugar Ltd (RSL) already spends up to K200,000 annually on costs of herbicides and regular slashing of GSP on its sugarcane estate and ranches in the Markham Valley (Ramu Sugar Ltd, unpublished reports).

A biological control programme for GSP was initiated by RSL in December, 1992. The psyllid, *Heteropsylla spinulosa* Muddiman, Hodkinson & Hollis has proved to be successful in controlling *M. invisa* in Queensland (M. Vitelli, pers. comm.), and therefore this bug was introduced into PNG in an attempt to control GSP. The psyllid is highly specific to GSP (Muddiman *et al.*1992) and early indications were that the bug has established in the Markham-Ramu valleys (Kuniata and Dori 1993).

The present survey attempts to document important phytophagous insects on the foliage of GSP at RSL and possibly identify those which might compete with *H. spinulosa* for feeding sites on the plant.

MATERIALS AND METHODS

Insect collections were made during the growing stage of the plant from December to May on fortnightly intervals. This period coincided with the wet season at RSL. Immature and adult stages of insects found on GSP at RSL were collected using standard techniques, and the immature stages were reared to adults before these were sent to various specialists at International Institute of Entomology, London (UK) for identification. Most specimens are held in the collection at RSL.

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RESULTS

Fourteen species of phytophagous insects were recorded on GSP at Ramu (Table 1). Most of these are polyphagous lepidopterans.

Eurema hecabe L.

This is a common yellow butterfly widely distributed in PNG and Asia. Adults are often seen congregating in marshy areas to drink. The green larva feeds voraciously on foliage and tender shoots of *M. invisa*.

Females oviposit single elliptical eggs in an upright position on leaves. The larva (green) first feeds on foliage and then on tender portions of shoots and pupates inside fine silken strands on the leaves or stems. Larval stage is 14-15 days while the pupal stage is 5-6 days.

Some eggs were parasitized by *Trichogramma chilonis* Ishii (Hym. Trichogrammatidae).

Euproctis sp. nr. *trispila* Turner

Adult is cream to light orange. Females lay round, glossy eggs in masses on leaves and cover these with brown scales. Caterpillars are brown and hairy. On hatching larvae disperse and feed on leaves and tender shoots. Before pupation the larva spins a loose brown cocoon and pupates on the leaves or axils. Duration of larval and pupal stages were 20-23 and 9-10 days, respectively.

Euproctis sp. are commonly known as tussock moths and are general defoliators of forest trees. However, in PNG *Euproctis* sp. nr. *varians* (Walker) was reported feeding on cocoa foliage (Bourke *et al.* 1973).

Adoxophyes sp. nr. *trirhabda* Diakonoff

The larva is active and feeds inside a loose case made up of leaves. Pupation also takes place inside this case. The pupal stage is about 4-6 days.

An unidentified species of *Adoxophyes* was reported damaging tea leaves in a glass house at Konedobu (Anon. 1971).

Metallochlora neomela Meyrick

The moth is green. Larva is light green and feeds on foliage. Pupation takes place in a loose leaf case. Duration of the larval and pupal stage were 7-9 days and 5-6 days, respectively. This moth is quite rare on GSP at Ramu.

Homona sp. prob. *trachyptera* Diakonoff

The habits were similar to *Adoxophyes* sp. nr. *trirhabda*. The larva feeds on foliage from inside a loose leaf case and also pupates in the same. Pupal stage takes about 6 days.

An unidentified species of *Homona* was reported as a pest of tea in PNG (Bourke *et al.* 1973).

Gymnoscelis ? imparatalis Walker

The moth is green, larva light brown and feeds on leaves of GSP. Pupation lasts for about 13 days and takes place in a loose leaf case. Larvae are often parasitised by a solitary *Apanteles* sp. (Hym. Braconidae).

Disease

A disease probably viral was observed on several clumps of *M. invisa*. The symptoms were little leaf and stunted growth, yellowish appearance and infected stems become brittle and break-off easily. Seed production is also reduced.

DISCUSSION

The present survey indicated the insect fauna encountered on GSP at Ramu were general feeders and do not appear to pose any competitive threats to the establishment of *H. spinulosa*. Most insects encountered were also collected on certain cultivated crops, for example, *Euproctis* sp. nr. *varians* on cocoa (Bourke *et al.* 1973); *Homona* sp. nr. *trachyptera* on tea (Bourke *et al.* 1973); *Helicoverpa armigera* on a wide range of crops, *Nodaria cornicalis* on soya bean (Brier & Rogers 1991) and *Balclutha* sp. on a number of graminaceous crops (Hill 1987). It is possible that GSP might be an alternate host

Table 1. **Phytophagous insects collected from *Mimosa invisa* at Ramu Sugar estate.**

SPECIES	ORGAN OF PLANT ATTACKED	RELATIVE ABUNDANCE
LEPIDOPTERA		
Geometridae		
Gymnoscelis ? imperatalis Walker	leaves	+
Metallochlora neomela Meyrick	leaves	+
Unidentifed species	leaves	-
Lymantriidae		
Euproctis sp. nr. *trispila* Turner	tender shoots	++
Noctuidae		
Helicoverpa armigera (Hubner)	tender shoots	-
Mythimna sp.	tender shoots	-
Nodaria cornicalis Fabricius	tender shoots	-
Pieridae		
Eurema hecabe Linnaeus	tender shoots	+++
Tortricidae		
Adoxophyes sp. nr. *trirhabda* Diakonoff	leaves	+
Homona sp. nr. *trachyptera* Diakonoff	leaves	+
COLEOPTERA		
Coccinellidae		
Epilachna signatipennis (Boisduval)	leaves	-
HOMOPTERA		
Cicadellidae		
Balclutha sp.	tender shoots	+
Pseudococcidae		
Unidentified mealybug	stalk, axils	-
Psyllidae		
Heteropsylla cubana Crawford	leaves	-

- rare, + few, ++ abundant, +++ very abundant

for over-wintering stages of these insects and it may be necessary to control GSP in near proximity to cropping situations.

The feeding behaviour of *H. spinulosa* could assist in the transmission of the viral disease encountered in GSP. Nymphs and adults of this psyllid suck sap from the plants and therefore might be able to transmit this virus. However, no detailed work has been done in this area.

Four species of spiders belonging to Araneidae and Oxyopidae were encountered in large numbers and could be important predators of phytophagous insects on GSP. Populations of *H. spinulosa* were usually high and mostly adults get caught in the spider webbings. Therefore, it is unlikely that predation from these spiders will have any significant effect on the introduced biological control agent of *M. invisa* (M. Vitelli, pers. comm.).

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EFFECTS OF GOAT MANURE, NPK-FERTILIZER, INSECTICIDES AND FUNGICIDES, AND COMPOST ON POTATO YIELD AT THE YASUBI RURAL EXTENSION CENTRE

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ABSTRACT

Two preliminary field trials were conducted at the Yasubi Rural Extension Centre in the South Fore Census Division of the Okapa District in the Eastern Highlands Province as a part of the ongoing research to develop a low input potato production system(s) for the Okapa SMAFSP area. In Trial 1, conducted during the dry period of March - July, application of goat manure increased marketable tuber yield and numbers significantly (P<0.01). Tuber yield increase was almost 200%. There was no response to either mixed NPK-fertilizer or routine spraying of insecticides and fungicides. In Trial 2, conducted during the wet period of November-March, application of 500 kg/ha of mixed NPK-fertilizer increased total tuber yield significantly (P<0.01). Increasing the fertilizer rate from 500 to 750 kg/ha did not increase the total tuber yield significantly (P<0.05). Application of additional P as triple superphosphate (TSP) and N as urea failed to influence total tuber yield significantly (P<0.05). There was no response to application of compost and the possible reason for this is discussed.

Key words: *South Fore, Okapa, potato, goat manure, NPK, insecticide, fungicide, compost.*

INTRODUCTION

The South Fore Census Division (CD) in the Okapa District of the Eastern Highlands Province is under the Smallholder Market Access and Food Supply Project (SMAFSP) area. SMAFSP is directed at less developed areas where economic and social development is generally lacking. Therefore, one of its main objectives is to increase and diversify opportunities for earning cash income. Improving the production and marketing of potato has been identified as one of the methods to achieve this objective in the Okapa SMAFSP area.

At present, Okapa district produces about 20% of the total potato produced in the country (Department of Agriculture and Livestock 1989) but most of it is cultivated in the North Fore which is outside the project area. Entire production is by small farmers. Although production data are unavailable at present, it is believed that yields are generally low due to low soil fertility, use of either no or little inorganic fertilizers, poor management, and perhaps lack of quality seed.

Potato usually responds to inorganic fertilizer application. In Papua New Guinea the general recommended rate of inorganic fertilizer is 750 kg of 12-12-17-2 NPK fertilizer mixture plus 250 kg of triple superphosphate (TSP) per hectare (SAPPRD 1986). However, farmers in Okapa generally do not use any inorganic fertilizers, insecticides and fungicides because of high cost of transport and lack of capital.

Using locally available organic fertilizers is an option to substitute expensive inorganic fertilizers. Quality seed potato is expensive and not freely available.Therefore, yields have to be increased to maximize returns for farmers' investments on seed. Using either optimum level of inorganic fertilizer or organic manure are two options available to the farmer to maximize re-

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turns. Hence, there is a need for low input technology for potato production to match the local physical and socio-economic environment.

This paper reports the results of two preliminary field trials conducted, as a part of the ongoing research, to develop a low input potato production system(s) for this area.

MATERIALS AND METHODS

Two trials were conducted at the Yasubi Rural Extension Centre in the South Fore CD of the Okapa District in the Eastern Highlands Province (1600 m a.s.l.). The first trial (Trial 1) was started in March and concluded in July, 1991 while the second trial (Trial 2) commenced in November, 1991 and terminated in March, 1992. The soil is a brown clay soil which is the dominant soil type in the area. The soil analysis data are presented in Table 1.0. The treatments in both trials included:

Trial 1

1. Control
2. 250 kg NPK/ha
3. 500 kg NPK/ha
4. 250 kg NPK/ha + Spraying
5. 500 kg NPK/ha + Spraying
6. 25 t manure/ha
7. 25 t manure/ha + Spraying

Trial 2

1. Control
2. 750 kg NPK/ha + 250 kg TSP/ha
3. 500 kg NPK/ha + 250 kg TSP/ha + 50 kg N/ha
4. 500 kg NPK/ha + 250 kg TSP/ha + 100 kg N/ha
5. 500 kg NPK/ha + 250 kg TSP/ha + 50 kg N/ha
6. 500 kg NPK/ha
7. Compost
8. Compost + 50 kg N/ha

In Trial 2, nitrogen application in treatments 3 and 4 were applied four weeks after planting whereas in treatments 5 and 8, nitrogen was applied at planting.

Trial 1 was laid out using a randomized complete block design (RCBD) with three replicates. The plots were raised beds and 8.0 m² in size. The manure treatment was applied in bands five weeks before planting and mixed thoroughly with the soil.The goat manure used was collected from the cement floor underneath the goat night house at Bena Bena Goat Breeding Station which is situated about 20 km south of Goroka along the highlands highway in the Eastern Highlands Province. It contained 1.98% nitrogen, 0.5% phosphorus and 3.47% potassium on a dry matter basis.

Five weeks after the application of manure, potato (*Solanum tuberosum* Linn.) cultivar Sequoia was planted in furrows. The spacing was 70 cm between and 30 cm within rows. The NPK-fertilizer was applied in furrows and mixed thoroughly with the soil. Immediately after the application of the NPK-fertilizer, potato seeds were planted in the same farrows. Insecticide (Orthene) and fungicide (Topsin-M DO) were applied to treatments 4, 5 and 7 at the recommended rates from the third week at ten days interval. The last spraying was done 88 days after planting.

In the second trial, the compost was applied two weeks before planting.The size of the plots, spacing, potato cultivar and the method used for fertilizer applications were the same as in Trial 1. However, the trial was laid out in a completely radomized design (RCD). Samples of the third compound leaf from the top of the plant from all plots were collected 60 days after planting for N, P and K determination. Normal cultural practices were employed during the duration of the respective trials. At maturity, 12 plants from the centre of the plots were harvested. In the first trial, tubers less than 30 g were considered as unmarketable. The data collected on the number and yield of tubers were subjected to the respective analysis of variances for RCBD (Trial 1) and RCD (Trial 2) and the means were tested using the least significance difference (LSD) test (Little and Hills 1978).

RESULTS

In Trial 1, application of goat manure at 25 t/ha significantly ($P<0.01$) increased the marketable tuber yield and numbers.The total number of tubers per plant was also increased significantly ($P<0.01$) (Tables 2 and 3). Application of mixed NPK-fertilizer at either 250 or 500 kg/ha failed to

Table 1. **Chemical Analysis of Soil Samples (0-15cm) from Yasubi Rural Extension Centre.**

ELEMENT		VALUE	INTERPRETATION
pH (1:2.5; soil:distilled water)		5.60	moderately acidic
Olsen Available P (mg/kg)		5.26	very low
Extractable Cations:			
Potassium (K) (me/100 g)		0.54	medium
Calcium (Ca) (me/100 g)		6.10	medium
Magnesium (Mg) (me/100 g)		2.16	medium
Sodium (Na) (me/100 g)		0.08	very low
Sulphate sulphur (mg/g)		18.00	medium
Boron (mg/g)		0.70	low
Cation Exchange Capacity (CEC)		21.00	medium
Percentage Saturation	K	2.50	desirable
	Ca	29.00	< desirable
	Mg	10.20	desirable
	Na	0.40	< desirable
Organic Matter (%)		8.80	medium
Total Nitrogen (%)		0.42	medium
Phosphate Retention (%)		56.00	medium

influence either tuber yield or numbers significantly ($P<0.05$). Spraying with insecticide and fungicide had no effect on tuber yield or numbers (Tables 2 and 3).

In Trial 2, application of 500 kg NPK/ha of mixed NPK-fertilizer increased total tuber yield significantly ($P<0.01$) (Table 4.0). Increasing the fertilizer rate from 500 to 750 kg/ha did not increase the total tuber yield significantly ($P<0.05$). Addition of additional P as TSP and N as urea and the time of N application failed to influence total tuber yield significantly ($P<0.05$). There was no response to application of compost (Table 4).

The nitrogen and phosphorus concentrations of leaf were not significantly ($P<0.05$) affected by the treatments applied (data not presented). However, the potassium concentration of the leaf showed significantly ($P<0.05$) higher levels in treatments 1, 7 and 8 (Table 5).

DISCUSSION

Generally, most nitrogen recommendations for potato in tropical areas are in the range of 80-150 kg/ha. For phosphorus and potassium, most recommendations are in the range of 100- 200 kg/ha and 60-180 kg/ha as P_2O_5 and K_2O, respectively (FAO 1984). The soil from the experimental site at Yasubi appears to be fertile. However, the phosphorus level is very low as indicated by the soil analysis data (Table 1).

Potato needs a good supply of readily available phosphorus and because its root system is not extensive, it does not readily utilize the less available forms of phosphorus. In most cases, therefore, phosphorus fertilizer applications are considerably higher than the 30-50 kg/ha of P_2O_5 taken up by the crop (FAO 1984).

The lack of response to NPK fertilizer in Trial 1 may be largely attributed to the dry conditions prevailed during the experimental period. Observations during this period indicated that plant canopy development was poor in the treatments

Table 2. **Effect of NPK-fertilizer, goat manure and spraying on the yield of potato tubers.**

TREATMENT	TUBER YIELD (t/ha)	
	MarketableTubers	Unmarketable Tubers
1. Control	9.33	0.59
2. 250 kg NPK/ha	8.04	0.82
3. 500 kg NPK/ha	7.09	0.95
4. 250 kgNPK/ha + Spraying	9.95	0.72
5. 500 kg NPK/ha + Spraying	11.63	0.92
6. 25 t Manure/ha	26.75	1.29
7. 25 t Manure/ha + Spraying	29.67	1.59
LSD (P < 0.05)	3.42	0.57
LSD (P < 0.01)	4.79	0.80
CV (%)	13.10	33.20

except those that received goat manure.The canopy duration too was relatively short as compared to that of the manurial treatments. For maximum light interception, better canopy development and longer duration are necessary (Mengel and Kirkby 1987).This in turn would enhance photosynthesis, and consequent translocation of photosynthates to tubers, resulting in increased tuber yield. Furthermore, it is generally accepted that there must be enough moisture available in the soil for a fertilizer to be efficiently utilized by a crop. Because of the prevailing dry conditions during that period, soil moisture may have been limiting, thereby contributing to the poor response of potato to the applied NPK fertilizer.

The highly significant response to manure may be attributed to the fact that since it was applied five weeks before planting, there was probably a high degree of breakdown by the micro-organisms which may have resulted in the mineralization of nutrients. This is highly possible because even though there were dry conditions, the residual moisture in the manure could have contributed to the favourable conditions for microbial activity to proceed, thus, rendering the nutrients available for plant uptake.

The significant response to NPK in Trial 2 which was conducted during the wet season demonstrates the importance of the time of planting of potato in this area. Also, the recommended rate of 750 kg NPK/ha + 250 kg TSP/ha (SAPPRD 1986), although gave higher tuber yield, it was not significantly (P<0.05) higher than those of treatments 3, 4, 5 and 6 (Table 4). Furthermore, because of the high cost of fertilizers, transport and lack of capital, it would be prohibitive for farmers in the South Fore area to use higher amounts of inorganic fertilizers.There appears to be little or no benefit in using NPK fertilizer rates of more than 500 kg/ha and using of additional TSP and urea.

In the current study, compost application failed to influence tuber yield. The nutrient content of the compost and the nutrients availability depend on the nature of the vegetation used and the stage of decomposition. The compost material used was obtained from fallen dry leaves which appear to be of low quality. The material was only partially decomposed when applied two weeks before planting. Due to the poor quality of the compost used the results from the compost treatments should be treated with caution, and the use of compost as an organic fertilizer requires further investigation.

Potassium concentration of the leaf showed no correlation with the total tuber yield (Tables 4 and 5). Tuber yields in the NPK-fertilizer treatments were significantly (P<0.01) higher than those of the compost and control treatments.

Table 3. **Effect of NPK-fertilizer, goat manure and spraying on the number of fresh potato tubers.**

TREATMENT	NUMBER OF TUBERS/PLANT		
	Total tubers per plant	Marketable tubers	Unmarketable tubers
1. Control	3.64	2.22	1.42
2. 250 kg NPKha	3.22	1.89	1.33
3. 500 kg NPK/ha	3.75	2.03	1.72
4. 250 kg NPK/ha + Spraying	3.52	2.19	1.33
5. 500 kg NPK/ha + Spraying	4.33	2.47	1.86
6. 25 t Manure/ha	8.55	5.61	2.94
7. 25 t Manure/ha + Spraying	8.41	5.83	2.58
LSD (P < 0.05)	1.84	1.17	1.13
LSD (P < 0.01)	2.59	1.65	1.59
CV (%)	20.50	20.80	33.80

Table 4. **Effect of NPK-fertilizer, TSP, N and Compost on the yield of potato tuber.**

TREATMENT	TOTAL TUBER YIELD (t/ha)
1. Control	12.43
2. 750 kg NPK/ha + 250 kg TSP/ha	37.03
3. 750 kg NPK/ha + 250 kg TSP/ha + 50 kg N/ha*	26.72
4. 500 kg NPK/ha + 250 kg TSP/ha + 100 kg N/ha	34.13
5. 500 kg NPK/ha + 250 kg TSP/ha + 50 kg N/ha	25.27
6. 500 kg NPK/ha	29.36
7. Compost	10.71
8. Compost + 50 kg N/ha	14.94
LSD (P < 0.05)	13.32
LSD (P < 0.01)	18.35
CV (%)	32.30

* N application in treatments 3 and 4 were applied four weeks after planting whereas in treatment 5 and 8, N was applied at planting time.

Table 5. **Potassium content (dry matter basis) of the third compound leaf at 60 days after planting.**

TREATMENT	POTASSIUM CONTENT (%)
1. Control	5.25
2. 750 kg NPK/ha + 250 kg TSP/ha	3.43
3. 500 kg NPK/ha + 250 kg TSP/ha + 50 kg N/ha*	3.07
4. 500 kg NPK/ha + 250 kg TSP/ha + 100kg N/ha	3.11
5. 500 kg NPK/ha + 250 kg TSP/ha + 50 kg N/ha	3.28
6. 500 kg NPK/ha	4.08
7. Compost	4.93
8. Compost + 50 kg N/ha	4.63
LSD ($P < 0.05$)	0.81
LSD ($P < 0.01$)	1.12
CV (%)	11.80

* N application in treatment 3 and 4 were applied four weeks after planting whereas in treatment 5 and 8, N was applied at planting.

This is in contrast to the findings of Sivasupiramaniam *et al.* (unpublished) who found significant correlations between potassium contents of leaf and potato tuber yield. The critical concentration to define the deficiency limit of potassium in leaf 50 days after planting was found to be 3.8% (Singh 1987). In the present study, the relative sufficiency level of potassium was observed in treatments 1, 6, 7 and 8. However, apart from treatment 6, treatments 1, 7 and 8 had significantly ($P < 0.01$) lower tuber yields. Therefore, it may be assumed that potassium was not the limiting nutrient. This is consistent with the soil analysis (Table 1).

CONCLUSION

The potential use of goat manure as a organic fertilizer for crops such as potato can not be overemphasized. However, at present goat (as well as sheep) population in the South Fore CD is very small. Therefore, the availability of manure and its potential use as a fertilizer source may not be fully realized in the immediate future.

Potato responded poorly to NPK-fertilizer during the dry season; but, in the wet season higher tuber yields were obtained. This indicates the proper time of planting potato in the South Fore area (October-March) for maximum tuber yields.

Application of additional P and/or N is not necessary. The present study indicates that application of insecticide and fungicide in a smallholder situation may not be necessary provided healthy seeds and normal cultural practices are employed. Further study is required on the use of compost on potato production in the South Fore area. Some aspects which need to be considered are the type of compost material used and the labour requirement for material collection.

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CORDYCEPS SP. AN IMPORTANT ENTOMOPATHOGENIC FUNGUS OF CICADA NYMPHS AT RAMU, PAPUA NEW GUINEA.

L. S. Kuniata [1]

ABSTRACT:

Nymphs of the cicadid Baeturia papuensis *and* B. valida *have become pests of commercial sugarcane at Ramu Sugar estate, Papua New Guinea. Field observations made in 1989-92 showed that the first monsoon rains in October/November significantly ($p < 0.001$) enhanced mortality by a pathogenic fungus,* Cordyceps *sp. Mortalities of 5th instar nymphs in the field ranged from 2-67%, 0-80% and 0-50% in 1990, 1991 and 1992, respectively. Attempts to artificially innoculate planting furrows with ground cadavers infected with* Cordyceps *sp. are also discussed.*

Keywords: *Cicadas*, Baeturia papuensis, B. valida, Cordyceps *sp., sugarcane.*

INTRODUCTION

The cicadids, *Baeturia papuensis* de Boer and *B. valida* Blote (Homoptera: Tibicinidae) (identified by A.J. deBoer) have become serious pests of commercial sugarcane (hybrids of *Saccharum* spp.) at Ramu Sugar estate, Papua New Guinea (PNG) (Kuniata & Nagaraja 1992; Kuniata & Sweet 1991). The first outbreak was observed in late 1988 where cicadid damage has since been a severe problem (Ramu Sugar Ltd., unpublished reports). At Ramu, as elsewhere, cicadid damage to sugarcane as a result of nymphs feeding on the roots caused either the failure of the infested plants to ratoon (regrowth after harvest) or the subsequent ratoon shoots to die when about 30 cm high (Wilson 1960, Chandler 1981). Yield losses have not yet been accurately quantified but it is known that this pest has caused annual reduction in cane stool population of 4-10 percent (Kuniata & Nagaraja 1992).

Control of cicada nymphs with insecticides has been shown to be ineffective (Wilson 1969, Chandler 1981, L.S. Kuniata, unpublished data). Indeed such treatments often caused much worse infestations than in their absence (Chandler 1981).

More than 28 species of *Cordyceps* have been recorded from Papua New Guinea in a very wide range of hosts (Kobayasi & Schimizu 1976, Shaw 1984) with *C. ctenocephala* H. Sydow, *C. prolifera* Y. Kobayasi and *C. sinclairii* Y. Kobayasi found attacking cicada nymphs (Kobayasi and Schimizu 1976). The entomopathogenic fungus found in the nymphs *B. papuensis* and *B. valida* at Ramu Sugar estate was identified by Dr H.C. Evans (IIBC, UK) as *Cordyceps* sp. suggesting that this might be a new species. Seasonal occurences of this pathogen has not been studied and therefore these studies were initiated. Artificial innoculation of planting furrows with ground *Cordyceps* sp. cadavers were also attempted.

MATERIALS AND METHODS

Cicada nymphs infected with *Cordyceps* sp. can be identified in the field by the external outgrowth of the synnemata. Dead nymphs without these were taken to the laboratory and placed in containers of heat-treated soil and observed for synnemata production. The various instar nymphs collected were separated by the size of the front femur (Kuniata & Nagaraja 1992).

Field Survey

Field observations were made between October

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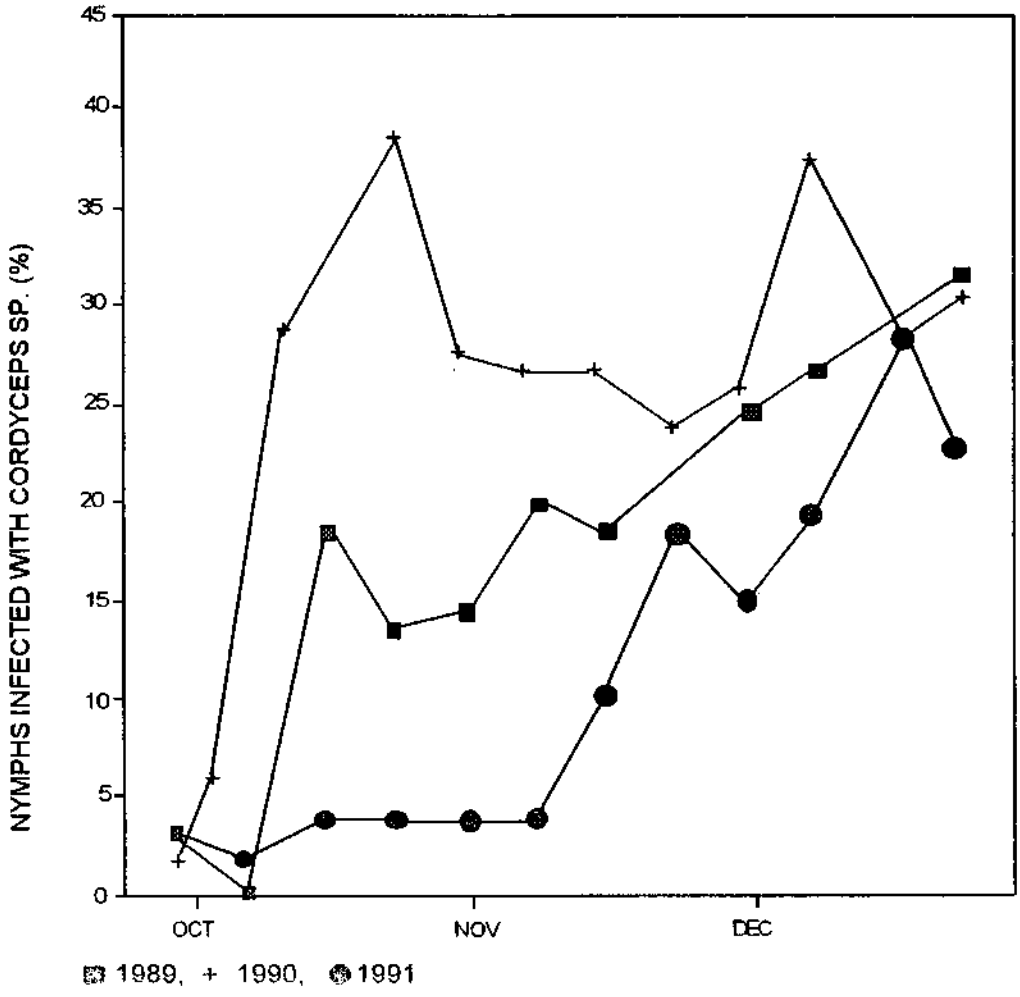
Figure 1. **Summary of *Cordyceps* sp. in cicada nymphs observed in rainfed sugarcane at Ramu. At other times of the year these infections were usually low (< 5%).**



and December, each year with 3, 7 and 11 fields sampled in 1989, 1990 and 1991, respectively. Each of these fields were between 10-25 ha and were sampled at various intervals for the presence of nymphs infected with *Cordyceps* sp. Each sample consisted of a 50 x 50 cm area dug up around a sugarcane plant to a depth of 40 cm. This volume of plant and soil was examined visually in the field and all the cicada nymphs present were recorded. A total of 30 samples were randomly taken from each field at each sampling date. Exuviae found above ground within the area of the sampled plant were also counted in order to estimate total nymph population.

Another 111 fields of 1st, 2nd and 3rd ratoon cane from the estate (8,000 ha) were sampled in November,1991 for the presence of *Cordyceps* sp and cicada nymphs infestations. A further 74 fields were sampled in 1992.

Field Trials

A field trial was planted in mid-November 1990 at RSL in field #DS107. The treatments were ground cadvers infected with *Cordyceps sp* applied in the planting furrow at 30 kg/ha and untreated control. The ground cadavers were first mixed with sandy loam soil (heat treated) before being applied in the furrows. Equal amount of sandy loam soil (without *Cordyceps* sp) was applied in the untreated control plots. The treatments were systematically allocated in the field. Plot sizes were approximately 0.27 ha and treatments replicated 3 times. A similar trial was also planted in

Table 1. **Distribution of cicada nymph densities and *Cordyceps* sp. infection levels in differemt varieties and cane classes. (Number in paranthesis were total number of nymphs collected).**

CLASS/VARIETY	FIELDS SAMPLED	MEAN NYMPHS PER STOOL	*CORDYCEPS* SP. %
1st Ratoon			
Cadmus	22	0.7	8.50 (308)
Q117	7	0.4	13.89 (56)
Others	15	1.5	10.83 (450)
TOTAL/MEAN	44	0.9	11.07
2nd Ratoon			
Cadmus	21	3.1	8.66 (1922)
Q117	2	0.2	0.00 (8)
Others	5	1.9	14.81 (190)
TOTAL/MEAN	28	1.7	7.82
3rd Ratoon			
Cadmus	17	3.2	19.79 (1088)
Q177	7	4.4	1.47 (616)
Others	15	1.3	9.34 (390)
TOTAL/MEAN	39	2.96	10.20

early December 1990 in field #CS109.

Cicada nymph densities and *Cordyceps* sp. infection levels were estimated towards the end of November in 1991 (1R) and 1992 (2R). Thirty sugarcane stools (30 cm x 30 cm x 40 cm) were randomly dug out within a plot and searched for cicada nymphs with *Cordyceps* sp. infections. Egg-mass leaves were sampled in early February of 1991 (Plant), 1992 (1R) and 1993 (2R). Two hundred stalks from each plot were randomly sampled and individual leaves with cicada egg-puntures were counted.

RESULTS

Field Survey

The two species of cicadas found attacking sugarcane at Ramu Sugar Estate were *Baeturia papuensis* and *B. valida*. Prior to 1989, the proportion of nymphs infected with *Cordyceps* sp. were less than 1%.The range of *Cordyceps* sp. infections observed in individual fields from October to December were 2-67% (1990), 0 - 30% (1991) and 0-50% (1992) (Figure 1). During other times of the year infections were usually less than 5%. In general only the 5th instar nymphs were affected by *Cordyceps* sp.

A highly significant correlation was observed between total weekly rainfall (mm) and percentage of nymphs infected with *Cordyceps* sp.

Table 2. **Distribution of *Cordyceps* sp. infection on the estate by different geographical regions. Total number of cicada nymphs is given in parenthesis.**

GEOGRAPHIICAL REGION	NUMBER OF FIELDS	*CORDYCEPS* SP. %
AN + BN	7	0.81 (123)
AS 010-068	9	23.08 (26)
AS100's-600's	11	12.70 (126)
BS	15	2.17 (460)
CN & DN	12	19.58 (189)
CS	11	2.01 (1393)
DS	15	12.99 (462)
EN + FN100's	8	29.23 (804)
ES	7	8.24 (170)
FN 300 -1000's	9	12.49 (961)
FS	4	2.35 (85)
GN	3	5.63 (231)

($r = 0.892^{***}$, df = 17, $p < 0.001$). Levels of infections appeared to peak 6-9 weeks after the onset of the monsoon rains. In 1990 the monsoon rains began in early September but in 1991 and 1992 this was delayed until mid-October.

Mean *Cordyceps* sp. infection levels between ratoon classes and 1st ratoon cane fields were not significantly different ($X^2 = 1.63$, df = 2; $X^2 = 1.32$, df = 2, respectively) (Table 1). But those infection levels observed in 2nd and 3rd ratoon cane fields were highly significant ($X^2 = 14.16$, df = 2, $p < 0.001$; $X^2 = 16.56$, df = 2, $p < 0.001$, respectively). Cadmus fields appeared to show higher *Cordyceps* levels than Q117 and the other varieties.

Table 2 shows the distribution of cicada nymphs and *Cordyceps* sp. by different geographical regions on the estate. Highly significant differences were observed in nymph numbers and *Cordyceps* sp. levels to particular geographical regions sampled ($X^2 = 4732.6$, $p<0.001$, df = 11; $X^2 = 77.68$, $p<0.001$, df = 11, respectively).

Baeturia valida has been recorded only in a few localities on the estate. In 1991 about 38 percent of *B. valida* nymphs were affected by *Cordyceps* sp. (N = 803). Regression analysis showed a negative and highly significant correlation between cicada nymphs infected with *Cordyceps* sp. and subsequent nymph populations ($r^2 = -0.971$, $p < 0.001$, df = 4). The relationship was more quardratic than a linear one. Using this relationship, an infection of more than 24% should be sufficient to maintain nymph populations below the critical level of 4 nymphs/ stool.

Field Trials

The results from field trials with ground *Cordyceps* sp. in field #DS107 indicated significantly higher levels of cicada nymphs were infected with *Cordyceps* sp. in the innoculated plots than the untreated controls during three seasons (Table 3). In general nymph populations were higher in the untreated ratoon cane than the treated plots, however there were no significant differences observed in average egg-mass leaves.

In field CS109 no significant differences were observed in cicada nymph numbers, egg-mass leaves and *Cordyceps* sp. levels, however the untreated plots had significantly higher *Cordyceps* sp. and egg-mass leaves in the 2 ratoon crop (Table 3). *Cordyceps* sp. infection levels observed in CS109 trial were generally higher than in DS107.

Table 3. **Average number of cicada nymphs, egg-mass leaves and nymphs infected with *Cordyceps* sp. in fields #DS107 and #CS109 following application of ground *Cordyceps cadavers*. Numbers in parenthesis are total nymphs collected.**

	DS107			CS109		
	Innoculated	Untreated control	t-test	Innoculated	Untreated control	t-test
Plant						
Av. nymphs/stool	0.4	0.2	0.648 n.s	0.02	0.01	-
% nymphs with *Cordyceps* sp.	18.80 (36)	0.0 (18)	6.372**	100 (2)	100 (1)	-
Av. egg-mass leaves/100 stalk	-	-	-	-	-	-
1st Ratoon						
Av. nymphs/stool	2.4	4.1	3.406*	1.5	1.6	0.264 n.s
% nymphs with *Cordyceps* sp.	45.77 (216)	0.40 (369)	8.995***	77.0 (135)	81.4 (135)	1.712 n.s
Av. egg-mass leaves/ 100 stalk	124.0	113.0	2.765 n.s	61.7	61.7	-
2nd Ratoon						
Av. nymphs/stool	1.3	1.9	1.858 n.s	0.7	0.7	0.258 n.s
% nymphs with *Cordyceps* sp.	14.20 (117)	4.3 (171)	4.651**	15.0 (51)	27.5 (60)	4.651**
Av. egg-mass leaves/ 100 stalk	230.0	249.3	3.326*	91.0	100.7	3.326*

n.s, not significant; * P < 0.05; ** P < 0.01; *** P < 0.001; (-) not determined.

DISCUSSION

Three species of *Cordyceps* have been recorded attacking cicadids in Papua New Guinea (Kobayasi & Schimizu 1976, Shaw 1984).The species found attacking nymphs of *B. papuensis* and *B. valida* is probably recorded for the first time (H.C. Evans, pers. comm.).

The abundance of *Cordyceps* sp. on cicada nymphs at Ramu Sugar estate increased with the onset of the monsoon rains in October/ November. It is possible that these rains are critical in the movement of the innoculum in the soil. Costilla and Pastor (1986) have shown that irrigating sugarcane fields after ploughing appeared to enhance the pathogenic action of *Cordyceps* causing up to 99.4 percent mortality among cicada nymphs. Under natural and undisturbed soil conditions at Ramu Sugar estate the mean infection levels were about 39% (range = 2-67%) in 1990, 20% (range = 0-80%) in 1991 and 6% (0-50%) in 1992. The lower mean infection levels observed in 1991 and 1992 were probably due to the delay in the monsoon rains.

Older ratoon cane fields appeared to show higher *Cordyceps* sp. levels which were probably due to accumulation of innoculum in the soil from previous seasons. The abundance of cicada nymphs and *Cordyceps* sp. in certain parts of the estate might suggest preference to certain soil types or breeding sites. Kuniata and Nagaraja (1992) showed strong varietal preference for oviposition and therefore certain cane fields might sustain higher levels of cicada infestations. The results from the trials where the planting furrows were innoculated with ground *Cordyceps* (DS107) indicated possibilities of using this technique in the distribution of this pathogen to other parts of the estate having low innoculum in the soil. Pre-treatment levels of *Cordyceps* sp. observed in field DS107 were less than 1% while this was about 28% in CS109. *Cordyceps* sp. levels observed in CS109 were not significantly different probably due to a high initial innoculum already present in the soil at the time of planting. The low *Cordyceps* sp. levels observed in 2nd ratoon cane (1993) was due to estimations made during the dry season in September.

Both cicadid species have a univoltine life cycle with more than 80% of the nymphs in the 5th instar stage by October/November and by end of November about 60% of these would have emerged as adults (Kuniata & Nagaraja 1992). It was observed that this species of *Cordyceps* mainly attacks this nymph stage and therefore it is critical for the pathogenic action of this fungus to be initiated well before nymph emergence. This can be achieved with early monsoon rains or through irrigation.

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AN OVERVIEW OF THE PATHOLOGY OF GENUS COLOCASIA

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ABSTRACT

This paper reviews information available from various sources which relates to diseases of taro in Papua New Guinea. Taros are subject to infection by both aerial and soil-borne pathogens. The pathogens which exploit taro production include fungi, bacteria, nematodes, viruses and virus-like organisms and mycoplasmas, some of which are able to reduce yields quite substantially. Because of the nature of this crop, its traditional system of cultivation and the strong influence of ecosystem on both the host and the pathogens, it appears that taro pathogens do interact with their host and that the mechanism of resistance is relatively narrow. Thus, the integrated pest management (IPM) approach appears to be appropriate for taro disease control.

Key words: *Taro, diseases, fungi, bacteria, nematode, viruses, mycoplasmas.*

INTRODUCTION

Taro (*Colocasia esculenta* L.) is ranked second by McArthur (1972), after sweet potato followed by yam and bananas, in terms of annual production in PNG. This vegetatively propagated crop has been grown mainly under primitive mixed cropping system over a wide geographical area, from Highlands to dry and wet coastal lowlands and to coral atoll islands with varying climatic characteristics.

This crop is probably a host to many of the diseases infecting the Araceae family than its relatives including species of *Alocasia*, *Xanthosoma*, *Cyrtosperma* and *Amorphophallus* taros. Diseases described so far appear to indicate conspicuously that most or possibly all are diseases of taro, *C. esculenta*.

In Papua New Guinea (PNG) the most common recorded disease is the taro leaf blight (*Phytophthora colocasiae* Racib.) (Shaw 1963, Clarkson 1981, Bourke 1982 b, Bayliss-Smith 1982, Shaw 1984, Muthappa 1987, Tomlinson 1987). Surveys for pests and diseases of plants in provinces from 1989 to 1992 has revealed the same trend. Philemon and Hyde (1990, unpublished report) have noticed this similarity in the Western Province and the prevalence of favourable climatic conditions at that time was100% leaf defoliation (per. obs.). Other common diseases with varying significance are leaf spots caused by *Cladosporium colocasiae* Saw., *Phyllosticta* spp. and *Xanthomonas campestris* (Pammel) Dowson, infecting leaves and species of *Pythium*, *Rhizoctonia*, *Phytophthora*, *Fusarium*, *Sclerotium*, *Erwinia carotovora* (Jones) Bergy, Harrison, Breed, Hammer & Huntoon (Shaw 1963 & 1984, Muthappa 1987, Tomlinson 1987) and *Hirschmanniella miticausa* Bridge, Mortimer and Jackson causing rots of stem, root and corm (Mortimer *et al. 1981*, Bridge and Page 1982, Bridge *et al.1983).The* nematode *H. miticausa* has been recorded once at a site in the Southern Highlands Province (Bridge and Page 1982) and a more recent finding was at Karaisa, Tufi in the Northern Province. In both cases taro corms were rotten, pink to reddish in colour.This nematode has been found to be responsible for the severe losses of taro in the Solomon Islands (Mortimer *et al.*1981, Bridge *et al.* 1983) and its presence in PNG poses a serious threat to taro production.

The cultivation and yield of taro vary greatly and this variation is correlated to: (a) land selection and preparation; (b) nutrient levels in the soil; (c) varieties of taro available; (d) choice of planting material; (e) planting time; (f) planting techniques and (g) crop density (Bourke and Perry 1976, Bourke 1982 a & b, Anonymous 1982, Hombunaka 1985).The yield losses induced by diseases alone are variable and under

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conducive environment significant losses may occur. Jackson (1980) and Gollifer *et al.* (1978) have found that yield losses of between 30-50% and 25% were induced by *Phytophthora* leaf blight and Dasheen bobone rhabdovirus (DBRV), respectively.

People whose dietary demand includes taro and have moved and settled down either in urban cities and towns of the same country or foreign countries has raised high prospects for additional taro cultivation. The demand for taro in the latter for the Pacific Island communities in New Zealand alone in 1976 was estimated to be around 1,500 metric tonnes and this has gone up over the years (Anonymous 1982). Export of taro to New Zealand came mainly from Fiji, Tonga and Western Samoa. To meet such demands either for local consumption or export meant an increase in taro production through expansion in area and the adoption of monocropping farming system for taro cultivation. The cultivation of this crop under monocropping system is being expanded continuously, albeit such an increase in area planted to taro and the adoption of monocropping farming have led to increased pathological problems.

DISEASES

About forty taro diseases induced by fungi, bacteria, nematodes, viruses, virus-like causal agents and mycoplasmas have been recorded in PNG (Shaw 1963, 1984; Muthappa 1987). Diseases induced by virus like agents and mycoplasmas are, so far, absent. The information available on the etiology of all agents, as well as the epidemiology of diseases recorded in PNG is relatively limited and in many cases lacking. The only diseases that are being well researched and documented in the South Pacific region include the taro leaf blight (*Phytophthora colocasiae*) and the Dasheen viruses: Dasheen mosaic potyvirus (DMPVY), Dasheen bobone rhabdovirus (DBRV) and Dasheen badnavirus (DBV). The following is a brief account of diseases recorded on taro in PNG.

Fungal diseases

Approximately twenty species of fungal pathogen have been recorded in association with the taro crop, inducing either foliar, stem, root or corm rot diseases in PNG.

Foliar diseases

The most important diseases in this group are the taro leaf blight (*P. colocasiae*), (*Cladosporium* leaf spot) (*C. colocasia* Saw.) and *Phyllosticta* leaf spot (*Phyllosticta* spp.), each inducing varying effects (Clarkson 1981, Ooka and Trujillo 1982, Shaw 1984, Muthappa 1987, Tomlinson 1993). The *Phytophthora* leaf blight alone has induced losses that range from 30-50% (Jackson 1980). Others in this group are common but rarely of economic importance.

Other diseases whose incidence and severity are sporodically endemic and mild and thus considered of minor importance are blossom blight (*Choanephora cucurbitarum* Berk. and Rav.) Thaxter, leaf blight (*Thanatephorus cucumeris* (Frank) Donk and other leaf spot fungi including *Johnstonia colocasiae* M.B. Ellis, *Phoma* spp., *Leptosphaerulina triflii* (Rostrup) Petrak, *Cercospora* spp. and *Colletotrichum* spp. (Shaw 1963 & 1984, Muthappa 1987). No research has been done on these pathogens, as well as on the epidemiology of diseases induced by them and thus the extent of damage and yield reduction are still unknown in PNG.

Root and Corm rot diseases

The pathogens that are responsible for inducing diseases of roots and corms are basically soil-borne fungi. These fungi infect roots and corms either before or after harvesting and generally may cause soft or dry rot. Their presence is related to the conducive environment under which taro is grown and is attributed to either (a) poor drainage conditions in heavy clay soils (*Phytophthora* spp., *Pythium* spp. and *Rhizoctonia* spp.) and (b) the history of the land including the vegetation grown before taro is planted as plant debris harbour fungi likely to infect taro (*Botryodiplodia theobromae* Pat., *Sclerotium rolfsii* Sacc., *Chaetophoma* spp., *Rhizoctonia* spp., *Periconia* spp., *Fusarium* spp. and *Epicoccum* spp.) (Shaw 1963, Ooka and Trujillo 1982, Shaw 1984, Muthappa 1987).

The intensity of damage induced by the rot-causing organisms on stored corms, cuttings and suckers is dependent on (a) the magnitude

and severity of the mechanical damage or injury caused during harvesting and transportation and (b) the fungal flora able to metabolise the damaged tissues. The latter includes most of the major rot-causing organisms including *Pythium* spp., *P. colocasiae*, *B. theobromae*, *Fusarium* spp. and *S. rolfsii* (Shaw 1963, Jackson 1980, Ooka and Trujillo 1982, Shaw 1984, Muthappa 1987).

Bacterial diseases

Two bacterial diseases have been reported on taro (Shaw 1984: Muthappa 1987; Tomlinson 1987), and these include *Erwinia carotovora* (Jones) Bergy, Harrison, Breed, Hammar and Huntoon sub. sp. *carotvora* causing stem and corm rot and *Xanthomonas campestris* (Pammel) Dowson pv. *aracearum* (Berniac) Dye inducing leaf blight. Tomlinson (1987) has established that *X. campestris* pv. *aracearum* as being pathogenic to taro. Besides these two species, no other bacterial pathogens have yet been reported in association with taro diseases in PNG. Jackson (1980) has reported *E. chrysanthemi* as being one of the rot-causing organisms of the stored taro corms in the Solomon Islands and it is possible that this species may also be found in the stored taro corms elsewhere where taro is grown including PNG.

The bacterial pathogens of taro can be differentiated on the basis of symptomatology in addition to their cultural characteristics (Table 1). The stem and corm rot caused by *E. carotovora*

Table 1. **Different characteristics of presently identified bacterial diseases of taro.**

CHARACTERISTICS	TBR	TBLB
Symptoms	Small water-soaked lesions on tissues which enlarge rapidly becoming smelly, creamy-white, watery, decayed mass (Agrios 1978, Jackson 1980).	Leaf spotting and blight (Muthappa 1987, Tomlinson 1987).
Species	*Erwinia carotovora* sub. sp. *carotovra* (Dye 1969, Skerman *et al.* 1980, Ooka and Trujillo 1982).	*Xanthomonas campestris* pv. aracearum (Tomlinson 1987).
Cultural features	Fast growth, mucoid and hydrolyses Casein and cotton oil (Krieg 1984).	Fast growth, highly mucoid, yellow and round colonies (Tomlinson 1987)
Dissemination	Infected organs and plants, in soil and in pupae of maggots eg. seed corm maggot *Hylemyia cilicrura* (Agrios 1978).	Rain splash onto wounded leaf surface (Tomlinson 1987).
Control	Resistant varieties, avoid corm injury, do not scrape roots and small suckers from corms to be stored, dip corms in suspension of 1% sodium hypochlorite and leaflined pits for corm storage (Jackson 1980, Ooka and Trujillo 1982, Anonymous 1993).	Avoid leaf injury and allow thorough decomposition of plant debris before taro is planted (Anonymous 1978, Tomlinson 1987).

TBR = Taro bacterial rot; TBLB = Taro bacterial leaf blight.

sub sp. *carotovora* is probably the most important bacterial disease and the disease that has been most commonly recorded in PNG (Shaw 1963 & 1984, Muthappa, 1987).

Nematode Diseases

Among the known plant parasitic nematodes, Bridge and Page (1982) have found about fifteen different genera of plant parasitic nematodes associated with taro plants in PNG. (Table 2). Some of these are known pathogens of other crops in different parts of the world (Bridge 1978, Orton Williams 1980). Four are listed in Table 3 as the most common nematodes of taro (Jackson 1980, Bridge and Page 1982) though Mortimer *et al.* (1981) and Bridge and Page (1982) considered *Hirschmanniella miticausa* as the most potent and important nematode pathogen infecting taro crop.

Table 2. **Plant nematodes genera and species found in association with taro in PNG. (Adapted from Bridge and Page 1982).**

COMMON NAME	SCIENTIFIC NAME	SPECIES
Foliar nematode	*Aphelenchoides*	*besseyi*
Foliar nematode	*Aphelenchoides*	spp.
–	*Aphelenchus*	*avenae*
Ring nematode	*Criconemella*	spp.
–	*Gracilacus*	*aonli.*
Spiral nematode	*Helicotylenchus*	*dihystera*
Spiral nematode	*Helicotylenchus*	*mucronatus*
–	*Hirschamnniella*	*miticausa.*
Lance nematode	*Hoplolaimus*	*indicus.*
Lance nematode	*Hoplolaimus*	*seinhorsti*
Cyst nematode	*Heterodera*	spp.
Root knot nematode	*Meloidogyne*	*arenaria*
Root knot nematode	*Meloidogyne*	*incognita*
Root knot nematode	*Meloidogyne*	spp.
Root lesion nematode	*Pratylenchus*	*coffeae.*
Root lesion nematode	*Pratylenchus*	spp.
Burrowing nematode	*Radopholus*	spp.
Reniform nematode	*Rotylenchulus*	reniformis
–	*Scutellonema*	spp.
–	*Tylenchus*	spp.
Dagger nematode	*Xiphinema*	*elongatum*
Dagger nematode	*Xiphinema*	spp.

Table 3. **Economically important plant nematodes of taro in PNG. (Adapted from Bridge and Page 1982).**

NEMATODE	ASSOCIATED SYMPTOMS OF DAMAGE	DISTRIBUTION
H. miticausa	Red necrosis of corm corm rot (= mitimiti disease)	Tagura (SHP)* Tufi (NP)*
Meloidogyne spp.	Root swellings (= root knots or galls)	SHP* , Markham valley, MP*
Pratylenchus coffeae	Necrosis of corm	SHP* , ENBP*
Radopholus spp.	Red necrosis of corm tissue and rot	ESP*

* SHP = Southern Highlands Province; NP = Northen Province; MP = Morobe Province; ENBP = East New Britain Province; ESP = East Sepik Province.

The disease induced by *H. miticausa* is known in the Solomon Islands as "mitimiti" disease (Jackson 1980, Motimer *et al.* 1981, Bridge *et al.* 1983) and has been recorded in PNG (Bridge and Page 1982). In PNG, *H. miticausa* has been found infecting taro corms at a single site in Tagura, Pangia in the Southern Highlands Province (Bridge and Page 1982). A more recent finding of this nematode was in 1990 at Karaisa, Tufi in the Northern Province.

Viruses, virus-like organisms and mycoplasmas

Three viruses with different particle morphology have been recorded infecting taro by Gollifer *et al.* (1977), Shaw *et al.* (1979), Zettler and Jackson (1979), Jackson (1980) and Brunt *et al.* (1990), all three are reported to be present in PNG (Jackson 1978, Jackson 1980, Perason 1981, Shaw 1984, Muthappa 1987). The two viruses: Dasheen bobone rhabdovirus (DBRV) (taro large) and Dasheen badnavirus (DBV) (taro small) are both bacilliform in shapes albeit, differ in particle size of about 330 nm x 50 nm and 125 nm x 30 nm, respectively (James *et al.* 1973, Kenten and Woods 1973, Jackson 1980, Brunt *et al.* 1990). Both are found mainly within the South Pacific region (James *et al.* 1973, Jackson 1980). The third: Dasheen mosaic potyvirus (DMPVY) however, appears to be cosmopolitan in distribution and has been reported worldwide both in the tropic and subtropic regions (Brunt *et al.* 1990). In the Australasian and the Pacific regions, DMPVY has been recorded by Brunt *et al.* (1990) from PNG, French Polynesia, Gilbert Islands, Fiji, Vanuatu, Solomon Islands, Guam and Australia and it is possible that this virus may be present in other Pacific countries where taro is cultivated.

In addition to their sharp geographical distribution there are several differential characteristics for each virus (Table 4). Considering distribution, incidence and host range, DMPVY is by far the most common viral disease of taro because it has both more motile vectors, mainly aphid species including *Myzus persicae* (Sulzer) (Hem: Aphididae), *Aphis craccivora* Koch. (Hem: Aphididae), *A. gossypii* Glover (Hem: Aphididae) and *Pentalonia nigronervosa* van-der Goot (Hem: Aphididae) (Jackson 1980, Pearson 1981, Ooka and Trujillo 1982, Rodoni 1986) and wide host range (Gollifer *et al. 1981*, Shaw *et al.* 1979, Shanmuganathan 1980, Chase and Zettler 1982, Zettler and Hartman 1986). Pearson (1981) listed two species of Aphids responsible for the transmission of this virus in PNG and they are *A. gossypii* and *P. nigronervosa*. The host range is wide and Brunt *et al.* (1990) listed a total of 59 species of plants which 40 are dicotyledons and 19 monocotyledons known to have been in-

Table 4. **Charaterisation of taro virus.**

Charateristics	Dasheen mosaic potyvirus (DMPVY)	Dasheen bobobe rhabdovirus (DBRV) (Taro large)	Dasheen badnavirus (DBV) (Taro small)
Symptoms	Mosaic, leaf distortion and chlorotic feathering (Pearson 1981)	Stunting, thichering, pickering and distortion of leaves (Gollifer & Brown 1972, James *et al.* 1973, Pearson 1981).	Vein clearing and slight leaf distortion (Jackson 1980, Pearson 1981).
Distribution	UK, Italy, Denmark, Belgium, Netherlands, S. Africa, Nigeria, Cameroon, Taiwan, China, Japan, India, Florida, Brazil, California, Costa Rica, USSR, Dominica, Puerto Rico, PNG, Venezuela, French Polynesia, Egypt, Glibert Islands, Guam, Fiji, Vanuatu, Solomon Is. and Australia (Brunt *et al.* 1990).	Solomon Islands, PNG (Shaw *et al.* 1979, Jackson 1980, Pearson 1981).	Solomon Islands, Fiji, Vanuatu, W. Samoa, PNG, Cook Islands (James *et al.* 1973, Jackson 1980, Pearson 1981).
Particle morphology	Filament flexous rods 750 nm long (Kenten and Woods 1973 , Chase & Zettler 1982, Brunt *et al.* 1990).	Rhabdo or bullet-shaped; 335 nm long and 55 nm wide (Gollifer & Brown 1972, Brunt *et al.* 1990).	Bacilliform; 125 nm long and 28 nm wide (Gollifer & Brown 1972, Brunt *et al.* 1990).
Transmission	Aphids, mechanical (Morales & Zettler 1977, Gollifer *et al.* 1977 Hartman 1972, Zettler & Abo El-Nil 1978, Pearson 1981).	Leafhopper *Tarophagus proserpina* (Gollifer *et al.* 1977, Jackson 1980).	Mealy bug *Planococcus citri* (Kenten & Woods 1973, Jackson 1980).
Hosts	*Agloanema, Alocasia, Amorphophallus, Arisaema, Caladium, Crytosperma, Cryptocoryne, Dieffenbachia, Philodendron, Richardia, Zantedeschia, Colocasia and Xanthosoma* (Chase & Zettler 1982, Rana *et al.* 1983, Zettler & Hartman 1986).	*Tetragonia expansa, Colocasia esculenta* (Gollifer *et al.* 1977, Shaw *et al* 1979).	*Colocasia esculenta, Alocasia macrorrhiza, Xanthosoma spp.* (James *et al.* 1973, Gollifer *et al* 1977).
Control	Use resistant cultivars, strict quarantine to prevent its introduction, apply insecticide, (Jackson 1980, Pearson 1981, Ooka & Trujillo 1982).	Use resistant cultivars, destroy diseased plants, apply insecticide (Jackson 1980, Pearson 1981, Ooka & Trujillo 1982).	Use resistant cultivars, destroy diseased plants, apply insecticide (Jackson 1980, Pearson 1981, Ooka & Trujillo 1982).

fected by this virus. The virus is common albeit, its effect on yield is still undetermined.

The former two viruses are also transmitted by motile insect vectors by leafhopper *Tarophagus proserpina* Kirkaldy (Hem: Delphacidae) and the mealy bug *Planococcus citri*, respectively though, host range is narrow mainly species of *Colocasia*, *Alocasia* and *Xanthosoma* (Gollifer *et al.* 1977: Shaw *et al.* 1979). Infection of taro by DBRV has been shown to have reduced yield by 25% (Jackson 1980).

Unfortunately virus-like and mycoplasma induced diseases of taro have not yet been reported infecting taros in PNG. It is most probable that diseases induced by these two groups of pathogens is absent worldwide.

RECOMMENDED MEASURES FOR CONTROL OF DISEASE

It is not essentially necessary to adopt a single control measure or method such as chemicals for the control of diseases, as one may prove ineffective, costly and unsafe. Several control methods should be considered and options drawn to determine which control measure or combinations of control measures can be applied with great benefit. But preferably, integrated control measures of exclusion, eradication, protection and host resistance be applied and Agrios' (1978) system should be considered and used as a guide for disease control in taro cultivation and production.

Regulatory methods

In order to prevent the introduction of alien and exotic strains and even the spread of taro diseases to other disease-free areas, countries must have strict quarantine regulations. These regulations must govern both the importation from abroad and movement internally of planting materials. The plant quarantine officers (incl. quarantine officers and plant inspectors) must be consulted prior to importing or moving plant and plant parts to new sites. Where such officers are not available, liaison with the nearest agriculture office for further information should be established. The movement of planting materials from areas known to have diseases of significance should be discouraged to ensure that diseases are restricted locally (Bridge and Page 1982).

Cultural methods

The cultural method of control is geared towards diseases already established and is aimed at reducing the level of infection and eradicating the diseases.The following cultural methods should be considered and applied to control some diseases infecting taro.

Host eradication

Taro relatives and other plant species that are known hosts to some of the taro diseases must be removed and burned or buried deeply in the soil. Removing affected parts (Jackson 1980) and whole diseased plants (Jackson 1978 & 1980, Pearson 1981) give good control of *Phytophthora colocasiae*, the causal agent of taro leaf blight and DBRV (Taro large) and DBV (Taro small), respectively.

Crop rotation

Soil-borne pathogens including fungi and nematodes can be sometimes reduced or eliminated through the absence of host plants (Agrios 1978) thus, replanting taro and its relatives on the same site should be discouraged and avoided (Jackson 1980, Bridge and Page 1982) to ensure that inocula levels left from the previous cropping are reduced.To further enhance the reduction of the inocula levels plant debris including small corms should be removed after harvest as these could harbour the pathogens.

Sanitary measures

There are several simple sanitary measures that have proved effective in disease control. Roguing infected plants (Gollifer and Brown, 1972, Jackson 1978, Pearson 1981) and removing affected parts (Jackson 1980, Ocka and Trujillo 1982) has given effective control of leaf diseases. Paring away diseased tissue (Bridge and Page 1982: Bridge *et al.*1983) and using disease-free planting materials are effective means of reducing the spread of diseases.

Improving growing conditions

To attain the expected potential of taro, in terms of production or yield even in the absence of diseases depends on several factors. For a start, select big (about 5.0 cm) healthy, high quality propagating material (Bourke and Perry 1976, Bourke 1982 a) and if small sucker setts are used (less than 2.5 cm) close spacing gives best result (de la Pena 1977, Anonymous 1982). Where diseases are present the same practices must be applied. Other practices that can sustain taro production include proper drainage of field (Anonymous 1982, Bourke 1982 a & b), mulching, timing of planting and proper spacing will significantly improve plant growth. Such improved practices and others can directly or indirectly control soil-borne diseases.

Tissue culture

Propagating materials derived from tissue culture method has proved a break through and a great success in that it (a) allows for rapid propagation of taro as planting material (Jackson *et al.* 1977) and (b) propagating materials derived from tissue culture techniques are often disease-free (Anonymous 1984, George and Sherington 1984).

Biological methods

Where possible biological agents can be used to control taro diseases.The eggs and the first instar nymphs of the planthopper *Tarophagus proserpina* was found being attacked by a mirid predator *Cyrtorhinus fuvlus* Knight (Hem: Miridae) (Jackson 1980).The presence of the predator has proved effective in controlling the planthopper population, albeit the level of control of virus spread is still not known.

Physical methods

Heat treatments have been used quite widely in eradicating soil-borne pathogens.The nematode *H. miticausa* can be eradicated from taro corms by immersion in hot water at a temperature of 50 degrees Celsius for 15 minutes (Bridge and Page 1982).

Chemical methods

It is not possible to recommend chemical control of diseases in the rural or small farm situation due largely to the costs of the chemicals and equipment and the risks chemicals pose to both humans and the environment. Where both costs and know how are not problem areas, chemicals can be applied but with great care. Several chemicals mainly copper and dithiocarbamate fungicides have been proved effective in fungal disease control including Tribasic copper sulphate, Mancozeb, Metiram, Captafol, Bordeaux, Copper oxychloride, Ridomil, Aliette and Captan (Jackson 1980). Nematicides (Bridge and Page, 1982) have been recommended for the control of nematodes. It is worth mentioning that the rate of chemicals recommended and methods of application depends on the environment (rainfall and temperature) under which taro is grown.

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FIJI DISEASE VIRUS OF SUGARCANE: A REVIEW OF TECHNIQUES FOR ITS DIAGNOSIS AND ELIMINATION FROM TISSUE CULTURE AND PLANTING MATERIALS

M.E. Wagih [1]

ABSTRACT

A practical scheme for developing sugarcane plants free of Fiji Disease Virus (FDV) and a reliable diagnostic method to test for the virus in tissue culture and planting materials are of key importance to sugarcane improvement as well as quarantine. Establishment of tissue culture techniques and development of diagnostic techniques are reviewed. The practical implications of such techniques are discussed.

Key words: *Fiji disease virus, sugarcane, tissue culture techniques, diagnostic techniques.*

INTRODUCTION

Several serious fungal, bacterial and viral pathogens of sugarcane not only reduce crop vigor, yield and quality but also constitue a barrier to the exchange of sugarcane germplasm. Fiji disease virus (FDV) is one of the most serious systemic viruses of sugarcane. It belongs to the family *Reoviridae* and disseminates by vegetative propagation of infected planting material. The disease occurs in Australia and in a number of Pacific Islands including Papua New Guinea.

Currently the transfer of planting material from areas of infection to disease-free areas, for cultivation, agronomic evaluation or use in breeding programs, is severely restricted. The financial losses caused by the virus arise from crop failure and also result from the inability of farmers to grow superior cultivars, such as NCo310, in contaminated areas. The need for the introduction of pathogen-tested seed schemes and the implementation of other disease control measures result in further financial losses due to Fiji disease. The estimated loss due to the virus has been shown to be enormously high, amounting in Australia alone to about 4.5 million dollars for the year 1980 (CSIRO 1985).

Despite the fact that Fiji disease is such a substantial problem, no commercial treatment has been developed to free sugarcane from the causal virus. Several attempts to eliminate the virus from setts by heat treatment were unsuccessful. The failure of heat therapy in this situation was probably due to the fact that the use of large setts allowed deep-seated virus particles to escape the effect of heat. It was therefore considered that heating smaller plant pieces (e.g. excised axillary buds) may result in the elimination of FDV. However, such an approach was contingent upon the availability of a successful technique for establishing sugarcane axillary buds, which proved to be a difficult task (Maretzki and Hiraki 1980). The use of embryogenic callus cultures has been suggested as an alternative means of obtaining FDV-free plants.

Due to the lack of both true bud or callus-culture techniques for regenerating sugarcane and a convenient and reliable diagnostic method for detecting FDV, sugarcane plants are presently quarantined for up to two years before they can be released. This is causing unnecessary delay and cost. Thus a practical scheme for developing FDV-free sugarcane plants and a reliable diagnostic method to test for the presence of the virus in transported planting material is of key importance to quarantine and the sugar industry in the Pacific region.

Recently, a practical scheme for developing sugarcane plants (cultivar NCo310) free of bac-

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teria, fungi and FDV has been developed (Wagih 1990). New methods were described for routine establishment of true axillary bud cultures and embryogenic callus cultures from young rolled leaves. In addition, sensitive, specific and reliable FDV diagnostic techniques were developed. These included an Enzyme-Linked Immunosorbent Assay (ELISA) and a Nucleic Acid Hubridization Assay (NAHA) using ^{32}P-labelled probe mix of five FDV clones. A review of the research work on FDV elimination and diagnosis is presented here.

1. TISSUE CULTURE TECHNIQUES

1.1 **Axillary Bud Culture**: Procedures for establishing axillary bud-cultures of field-grown FDV-infected sugarcane plants of cultivar NCo310 were described by Wagih (1990). For optimum culture conditions donor plants were decapitated and all other leaves stripped off. The naked stems were sprayed with the fungicide Benlate (0.6 g l^{-1}) (50 % Benonyl -Du Pont, Northside Garden, NSW, Australia) and the insecticide Metasystox (1 ml l^{-1}) (Payer Co., Botany, NSW, Australia) three to five days prior to harvesting. Stem pieces, 3-5 cm long, each containing a single bud, were thoroughly washed with 5% Decon and given a hot water treatment at 50°C for 2 hours. Excised buds were then surface sterilized in 70% ethanol for 1 min, rinsed in 4% sodium hypochlorite, (NaOCl) for 5 min and then washed three times in sterile distilled water. Buds were then separately heat treated at 61°C for 30 min in a half strength MS medium, pH 5.3, containing the anticontaminants Benlate (100 mg l^{-1} benomyl), Nystatin (25 mg l^{-1}), and Carbenicillin (100 mg l^{-1}). The heat treated buds were grown in culture, until 8 to 15 cm long, on an agar-MS medium containing NAA (2 mg l^{-1}), malt extract (500 mg l^{-1}) and the antioxidant diethyldithiocarbamic acid (250 mg l^{-1}). The antioxidant was used to control browning due to the oxidation of phenolic compounds released from tissue into the culture medium. Roots were then developed on shoot-sprouted buds by transferring them to tubes containing sterile distilled water.

The application of severe heat and disinfectant treatments (Wagih 1990) ensured at least 90% clean bud cultures of which 75% were regenerated into plants phenotypically identical to the mother cultivar. Controls involving no treatment could not be assayed, as yeast contamination of cultures could only be successfully overcome by heat treatment. Treatment of 3-5 cm long setts at 50°C for 2 hours before excision of buds significantly increased the production of uncontaminated plantlets.

1.2 **Embryogenic Callus Cultures**: Embryogenic callus cultures from field-grown FDV-infected and healthy sugarcane plants of cultivar NCo310 were successfully established (Wagih 1990). Callus that developed from the young rolled leaves immediately above the apical meristem was grown and maintained on an MS medium supplemented with 2,4-D (3 mg l^{-1}), and coconut water (100 ml l^{-1}) for shoot development. Shoots (8 to 15 cm long) were then transferred to an MS medium supplemented with sucrose at a high concentration (60 g l^{-1}) until roots were developed.

Healthy plants were successfully regenerated from embryogenic callus explants originating from healthy plants (Wagih 1990). However, in the same study, callus from infected material failed to initiate shoots when subcultured to shoot initiation media. Growth of callus from diseased plants was apparently normal until it was transferred to the differentiation media. After a few days the calli turned brown and died back from the top of the callus. Eventually this callus turned black with no sign of any phenolic release. These results suggest that FDV expresses its harmful effects only in the differentiating host callus cells. The necrotic substances produced could be transmitted to healthy callus by callus contact. The severity of callus necrosis gradually declined with the progressive monthly subcultures of callus and this resulted in successful plantlet regeneration from the 5th and 6th subcultures. Among the regenerants from the embrygogenic callus culture, morphological variants were occasionally identified. These variants included plantlets with wide, thick and short leaves, thin long leaves, and dwarf and albino shoots.

2. DIAGNOSTIC TECHNIQUES

2.1 **Enzyme-linked Immunosorbent Assay:** The Double Antibody Sandwich (DAS) form of ELISA (Voller *et al.* 1977) was used by Wagih

(1990) to detect FDV sugarcane tissue samples. All ELISA reagents were handled in siliconsied sterile vials, and polystyrene micro ELISA plates (Dynatech Laboratories Inc., 900 Slaters Lane, Alexandria, VA 22314, USA) with flat bottom wells being used throughout. Testing was restricted to the inside 6 rows and 10 columns of the ELISA microplate and the placement of tested samples was at random. A buffer control and a healthy control were set up in each plate. The following standard conditions were used. Wells were synsitized by adding to each well 200 µl purified immuno-gamma globulim (IgG) in a coating buffer (1.59 g l^{-1} Na_2CO_3, 0.02 g^{-1} NaN_3 at pH 9.6). The FDV-specific IgG was essentially prepared as described by Clark and Adams (1977). Plates were covered with spent plates or lids and incubated with a moist paper towel inside a plastic box at 37°C for 4 hours. Non-adsorbed IgG was rinsed from wells by washing (3 min) in PBS buffer containing 0.05% Tween 20. Coated plates were kept at -20°C. Aliquots (200 µl) of test samples (1:5 w/v extraction buffer) were added to each well and the plates were incubated at 4°C overnight in a moist atmosphere in a plastic box. Wells were rinsed as before and an aliquot of 200 µl per well of enzyme-labelled IgG in conjugate buffer (PBS-Tween with 2% PVP and 0.2% ovalbumin) was added. Plates were again covered, placed in a plastic box, and incubated at 37°C for 6 hours. Unreacted enzyme-labelled IgG was rinsed from the wells by the standard rinsing procedure described above, and added was a 300 µl aliquot per well of freshly prepared substrate solution (0.5 mg ml^{-1} nitrophenyl phosphate in substrate buffer containing 97 ml diethanolamine, 800 ml distilled H_2O and 0.2 g NaN_3 per litre at pH 9.8). Plates containing the substrate mixture were covered and kept at room temperature for 1 hour. The reaction was stopped by the addition of 50 µl of saturated NaOH to each well. Quantitative measurements of the colour developed were spectrophotometrically assayed at 405 nm wavelength using a computerized microplate ELISA reader. A polymerase chain reaction (PCR) system was developed (Smith *et al.* 1992) to amplify FDV ds RNA *in vitro* to a detectable level by biotinylated probes. This system may be complicated and out of reach of non-professionals. The finding that hydrated setts for a few weeks could, in 100% of cases, amplify FDV particles in setts to levels detectable by ELISA offers a cheaper, less complicated and more practicable method for diagnosis in mass screening and quarantine inspections of FDV-infected materials.

A sensitive and specific ELISA for FDV detection has been developed (Wagih 1990). The assay was able to detect FDV in extracts prepared from FDV-induced gall tissue at a dilution end point of 1:5000 (w/v), FDV-infected non-galled leaf tissue meristem tips and all axillary buds of infected plants, first and second expanded leaves of infected developing setts, and in fresh or frozen (-80°C) samples of early developing roots and shoots from infected materials. In contrast, previously reported ELISA for FDV detection (Rohozinski *et al.* 1986) was slightly less sensitive than the nuclei acid probes of Skotiniski *et al.* (1986) in detecting the virus, as it failed to demonstrate the presence of FDV in leaf tissue other than in FDV-induced galls.

The use of the ELISA technique developed by Wagih (1990) for the detection of FDV in *in vitro* regenerated plants indicated that bud culture coupled with heat treatment enables the production of FDV-free plant. These negatively indexed plants remained true negatives for a period of at least 12 months, confirming the validity of the diagnostic technique used. Use of ELISA on callus samples from the 6 progressive callus subcultures revealed a gradual decline in virus titre. Callus from the 6th subculture showed similar ELISA readings to those of the healthy control. By contrast, the 5th callus subculture had a very low detectable virus titre although regeneration of healthy plants from such tissue was always possible. It is highly likely that these healthy plantlets were regenerated selectively from FDV-free calius areas that occurred due to the increased rate of virus degradation or to the inability of virus replication to keep pace with callus growth.

2.2 **Molecular Cloning and Dot Blot Assay**: Cloning of viral cDNA segments and dot blot assay were carried out as outlined by Wagih (1990). Viral ds RNA was extracted by two methods. The first was similar to that described by Vander Lubbe *et al.* (1979) in which ds RNA is selectively precipitated using 0.3 M sodium acetate. The second method was that of Morris and Dodds (1979), which is based on the differential binding of the ds RNA to cellulose in the presence of various concentrations of ethanol.

The extracted ds RNA was denatured using 20 mM MeHg in a total volume of 50µl at room temperature for 10 min. Reverse transcription for the first strand cDNA synthesis was carried out as described by Gubler and Hoffman (1983).The second strand cDNA synthesis was conducted using *E. coli* DNA polymerase I. The ds cDNA obtained was tailed with homopolymer (dCTP) using Terminal deoxynucleotidyl Tranferase (TdT) as described by Maniatis *et al.* (1982).The C-tailed ds cDNA was inserted into a plasmid, PUC8 (BRL) or PUC9 (Pharmacia), that had been linearized by nicking at the *Pst.I* restriction site and tailed with dGTP to give oligo dG tails. Transformation of competent cells of *E. coli* was performed as outlined by Hanahan (1983). "Dot blot" abd "Southern blot" hybridization involved the immobilization of denatured viral nucleic acid on a nitrocellulose use membrane and its hybridization with ^{32}P-labelled cDNA probes as described by Maniatis *et al.* (1982).

Using FDV-infected material from the Bureau of Sugar Experiment Stations BSES), Brisbane, Australia, Wagih (1990) was, for the first time, able to successfully clone an FDV-specific 450 bp region from the ds RNA genome of the FDV for the purpose of diagnosis. Subsequently, Smith *et al.* (1992) amplified a similar probe (450 pb) by a polymerase chain reaction for use in the diagnosis of the same virus. Wagih (1990) developed an NAHA using ^{32}p-labelled probes for FDV genomic segments of ds RNA.The mixture of plasmid probes from 5 clones with inserts ranging from 310 to 450 base pairs was more sensitive than the probe from each of the 5 clones alone. These inserts were larger and four times more sensitive than those cloned by Skotnicki *et al.* (1985). The successful cloning of the largest inserts may have been due to the more efficient denaturation treatment of viral ds RNA using 20 mM MeHg, resulting in larger single stranded RNA templates. The high sensitivity of the probe mix may be attributed to the fact that their larger size can specifically recognize more of the viral RNA. The probes were able to detect as little as 25 pg FDV RNA. However, when NAHA was compared with ELISA for the detection of FDV, ELISA proved to be superior, being 1.5 times more sensitive. Besides the extreme sensitivity of ELISA, the technique has several other advantages over NAHA.These include relative simplicity, high degree of sensitivity, rapidity, suitability for use with crude extracts and safety. Additionally, ELISA does not require as much skill as does NAHA.

PRACTICAL IMPLICATIONS

The technology discussed here for the successful production of FDV-free sugarcane may have numerous practical implications for sugarcane agriculture world wide and in the Pacific region and Papua New Guinea in particular.The following are some of the possible practical implications:

(1) The *in vitro* propagation techniques described here in combination with ELISA may be used for the rapid production of FDV-free sugarcane plants. However, the possible development of agronomic, physiological and/or cytological mutants in the regenerated plants should be closely monitored.

(2) ELISA can be used as an inexpensive and rapid field test for the detection of FDV if visual rather than spectrophotometric assessment of results is followed. The ELISA test can also be of great benefit for studies on FDV epidemiology.

(3) The tissue culture techniques and ELISA can be used in the development of a series of propagation and screening procedures for use in national and international quarantine analyses of sugarcane.Their use should reduce the period required for quarantining sugarcane from 1 or 2 years to several weeks while still keeping the risk of accidental introduction of FDV into virus-free areas to a minimum.

(4) The *in vitro* propagation techniques reported here could be used in national sugarcane breeding programs.The use of bud and callus cultures would decrease the time of the breeding cycle for producing new cultivars, which traditionally takes 12 to 14 years (Barba *et al.* 1977). Also, the *in vitro* techniques can be used to speed up field evaluation of newly developed sugarcane cultivars.

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THE PRICE ELASTICITY OF DEMAND FOR PAPUA NEW GUINEA EXPORTS OF COCOA AND COFFEE

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ABSTRACT

The price elasticity of demand for Papua New Guinea exports of cocoa and coffee is calculated using the perfect substitutes model of world trade. Econometric estimates are made of the world price elasticity of demand for cocoa and coffee. These estimates are combined with data on Papua New Guinea's world market share, supply responses in competing countries, and price transmission elasticities in consuming and producing countries to calculate own-price elasticities of demand of at least -11 for cocoa and -12 for coffee exports. These estimates show that Papua New Guinea can safely increase production of cocoa and coffee without fear of causing prices, and export revenues, to fall significantly. If protection for import-substituting industries increases domestic costs, cocoa and coffee producers will be made worse off because they are unable to pass these extra costs forward to foreign consumers.

Key Words: *Elasticity of demand; cocoa; coffee; Papua New Guinea.*

INTRODUCTION

If a country exports a product facing an inelastic export demand by the rest of the world, increasing supply will simply lower prices and reduce export revenues. The best policy, in this case, is to exploit the inelastic demand by restricting supply and forcing up prices. It may also be sensible to switch attention towards substituting for imports as a means of increasing employment and incomes, and improving the balance of payments. Higher domestic costs often result when tariff or quota protection is given to import substitution industries: studies suggest that a ten percent tariff increases exporters' domestic costs by at least five percent (Clements and Sjaasted 1984, Chiao and Scobie 1989). If exporters face an inelastic demand they have sufficient market power to pass some of these costs forward to overseas consumers. Therefore, the cost increases caused by import protection do not have their usual taxing effect on exporters, although they may still cause losses for domestic consumers.

It has traditionally been assumed that this inelastic export demand does not characterise Papua New Guinea (PNG) and other Pacific Island economies. Instead, these countries are presumed to face elastic demand curves and have no influence on world prices because of their small contribution to world production and trade (Lam 1979, Gimbol 1992). Increased import protection is not economically sensible for such price-taking countries because it simply transfers income from exporters to import-competing producers.

Recent policy decisions to close the PNG border to imports of cement and tinned fish and to increase tariff levels to ten percent raise the question of whether policy makers in PNG have rejected old assumptions and now perceive export demand to be inelastic. For instance, it seems unlikely that policy makers would deliberately want to help large, foreign-owned industries (e.g., fish canners) take income away from smallholder exporters (e.g., cocoa producers), yet this is what is implied by high import protection in a small price-taking economy. In searching for economic - as opposed to political - reasons for changes in import protection policy, it is necessary to re-examine the evidence on the elasticity of export demand.

Some analytical support for a revised (i.e., inelastic) view may be provided by Kauzi (1992)

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who has estimated a price elasticity of demand for total Papua New Guinea exports of -0.326. This means that a one percent reduction in the price of PNG exports (perhaps following devaluation) would increase the quantity demanded by only 0.3 percent. This inelastic demand suggests that cutting prices does not make sense because the quantity response is so low that total revenue falls. Therefore it is a matter of some importance for economists to establish which assumption about export demand elasticity is the most appropriate. This paper contributes by estimating the elasticity of demand for exports of cocoa and coffee. These two crops are selected because they generate more employment and have more favourable price trends than any of the other tree crop exports (Gibson 1992).

METHOD

The perfect substitutes model of world trade is used. This model is appropriate for homogeneous commodities such as cocoa and coffee that are traded on organised international markets (Goldstein and Khan 1985). The quantity of world exports (X_w) equals the sum of country i's exports (X_i) and the exports of the rest of the world (X_r). Thus, country i's export price elasticity of demand $(\eta_x)_i$ can be related to the world price elasticity of demand for exports $(\eta_x)_w$ and to the price elasticity of export supply $(\varepsilon_x)_r$ in the rest of the world:

$$(\eta_x)_i = (X_w/X_i)(\eta_x)_w - (X_r/X_i)(\varepsilon_x)_r \qquad (1)$$

Equation (1) was derived by Horner (1952) and has been frequently used to estimate export demand elasticities. Examples include Colombian coffee (Johnson 1970), Ghanaian cocoa (Blomqvist and Haessel 1972) and New Zealand meat and dairy products (Scobie 1973). Gardiner and Carter (1988) provide a complete survey.

One objection to equation (1), which has been raised independently by Bredahl, Meyers and Collins (1979) and Cronin (1979), is the assumption that world commodity markets are operating freely. Rather, it may be the case that consumers in importing countries and farmers in cocoa and coffee producing countries face local prices that are insulated from world price fluctuations. Several policies could ensure this: variable export taxes and subsidies, state operated marketing boards buying at administered prices, and variable levies or quotas in consuming countries.

The economic effect of such insulation is to reduce the export demand elasticity facing Papua New Guinea. If consumers and competing producers face insulated prices, they will respond less to price changes made by PNG exporters because those price changes will not be completely transmitted to them. As written, equation (1) assumes perfect price transmission, so the elasticity of prices in each country, with respect to PNG export prices ($\varnothing_{rji}$), is equal to one and therefore makes no explicit appearance in the equation. With imperfect price transmission ($\varnothing_{rji}$ <1 for at least some of the j countries) the estimate of $(\eta_x)_i$ falls and at the extreme of $\varnothing_{rji}$=0 for both consuming countries and competing exporters, $(\eta_x)_i$ falls to zero and PNG faces totally inelastic export demand. The following parameters are needed for estimating equation (1) for Papua New Guinea exports of cocoa and coffee:

- own-price elasticity of world demand for co coa (coffee)
- own-price elasticity of supply by all cocoa (coffee) producers, except PNG,
- Papua New Guinea's share of world cocoa (coffee) exports.

Over 75 percent of cocoa and coffee is consumed in non-producing countries so exports should be an acceptable measure of total world demand, and supply elasticities for producing countries should equal export supply elasticities. A survey of previous studies provided estimates for $(\eta_x)_w$ and $(\varepsilon_x)_r$, and the author's estimates of $(\eta_x)_w$ were also used.

Estimates are also required for the $\varnothing_{rji}$, the transmission elasticities. These provide information regarding the appropriateness of the free market assumption underlying equation (1). If it is assumed that PNG export prices are based on some overseas market price, such as the New York "Other Milds" coffee market price, estimates of the price transmission elasticity from world prices to domestic prices in each of the j countries can be used instead of estimating $\varnothing_{rji}$. Estimates of world price transmission elasticities are provided by a recent study (Mundlak and Larson 1992).

Behrman (1968) estimated cocoa demand elasticities for major importing countries. The weighted average own-price elasticity was -0.24 and the income elasticity was 0.8. UNCTAD (1974) estimated an own-price elasticity for world cocoa demand of -0.41. Islam and Subramanian (1989) estimated the own-price elasticity of demand for total cocoa exports by all developing countries as -0.19 and the income elasticity as 0.18.

UNCTAD (1974) estimated own-price elasticities of coffee demand as -0.92 for Western Europe and -0.49 for the United States. Singh and de Vries (1977) estimated the own-price elasticity for the U.S. as -0.22 and for the rest of the world -0.26. Akiyama and Duncan (1982) estimated own-price and income elasticities for eight groups of countries and weighted the results to give elasticities for the world. The own-price elasticity was -0.23 and the income elasticity was 0.45. Islam and Subramanian's (1989) preferred own-price elasticity was -0.27 and the income elasticity was 0.47. Yeboah (1991) estimated a very low own-price elasticity of world coffee consumption of -0.09 and an income elasticity of 0.66.

There is substantial variability in the elasticity estimates made by previous authors. This is caused by different data samples and time periods, and especially by the use of different econometric equations. The more recent estimates seem to have smaller own-price elasticities but income elasticities follow no coherent pattern. To provide more robust and up-to-date elasticity estimates, developed country demand for cocoa and coffee was econometrically modelled. Developed countries import over 90 percent of world exports of cocoa and coffee, and consume 80 percent of cocoa production and 70 percent of coffee production (FAO 1992). Thus, they provide a good representation of world demand. Ordinary least squares regression was used with an autoregressive, distributed lag specification:

$$Q_t = \alpha_1 Q_{t-1} + \beta_0 + \beta_1 P_t + \beta_2 P_{t-1} + \beta_3 Y_t + \beta_4 Y_{t-1} + u_t \qquad (2)$$

where: Q = per capita consumption of cocoa (coffee)
P = real price of cocoa (coffee)
Y = real per capita income
u = random error
t = time period.

By applying appropriate restrictions to α_1 and β_i equation (2) encompasses nine econometric specifications commonly used by economists (Hendry 1989). It especially allows for the fact that people only partially adjust their consumption, within one time period, to changes in prices and incomes. The long run response of consumption to price changes and to income changes is given by $(\beta_1 + \beta_2)/(1-\alpha_1)$ and $(\beta_3 + \beta_4)/(1-\alpha_1)$. Equation (2) forms a general starting point and more restricted equations can be estimated if the data are consistent with those restrictions.

Estimates of supply elasticities for cocoa, coffee and many other agricultural crops have been surveyed by Askari and Cummings (1977). Short run own-price elasticities of cocoa supply range from 0.15 to 0.68, with corresponding long-run elasticities ranging from 0.45 to 1.81. Short-run supply elasticities for coffee range from a low of 0.07 for Colombia and 0.10 for Brazil, to 0.28 for other Latin American countries and 0.29 for Indonesia (Askari and Cummings 1977, Akiyama and Duncan 1982). The long-run supply elasticities calculated by Akiyama and Duncan are quite high: 0.96 for Colombia, 1.05 for Indonesia, 1.10 for Brazil, with a weighted world average of 0.74 (the corresponding weighted short-run elasticity was 0.12).

Variability in supply elasticities may be explained by the share of each country's exports contributed by the crop. Short-run supply elasticities tend to be low when a crop makes a major contribution to exports; high prices only bring an increased harvesting intensity because most available land is already being used for the crop. It is also felt that smallholders can not bring new areas into production as quickly as can estates (Singh and de Vries 1977). Also, when the crop is an important source of income for a large number of smallholders there is more chance that government will prop up prices to maintain household incomes during times when world prices are low. This will reduce the downward supply response.

Estimating a 'world' supply elasticity is likely to be less successful than estimating a world demand elasticity because the substitute products are

less well defined on the supply side. In some countries cocoa is competing for land with palm oil, in others with coconuts, and in others with Robusta coffee. In some countries there is almost no competition for coffee growing land whereas tea competes in others. Therefore, equation (1) is estimated using three assumed values of $(\varepsilon_x)_r$: 0.1, 0.3, and 0.7. These correspond to short-run, inelastic; short-run, elastic; and long-run, average values of the supply elasticity. This allows for the temporal aspect of the elasticity of demand facing Papua New Guinean exports. There is less market power in the long-run because other countries can respond to high prices by bringing new areas into production.

Transmission elasticities from world agricultural prices to domestic prices have been estimated by Mundlak and Larson (1992). They find that for most crops and most countries, most of the variation in world prices is transmitted to domestic prices, contrary to the popular belief. The average price transmission elasticity of coffee prices in 23 producing countries was 0.65 and for 15 cocoa producers (although Ghana and Ivory Coast were not in the sample) it was 0.86. Less evidence was presented on the price transmission in consuming countries, except an estimate of 0.86 for coffee prices in the United States. Price transmission should be close to perfect for consuming countries because they have no domestic cocoa and coffee producers to protect with variable levies or quotas. Therefore, assuming values for $\varnothing_{rji}$ of 0.65 in producing countries and 0.8 in consuming countries is likely to be quite conservative. Equation (1) is estimated using both these conservative assumptions and the free market assumptions ($\varnothing_{rji}$=1).

DATA

Data on aggregate developed country population, cocoa and coffee imports (quantities and unit values in US$), and consumption (imports adjusted for exports and stock changes), were obtained from FAO's AGROSTAT.PC database. The FAO definition of developed countries includes the OECD, minor European states, Eastern Europe, Israel, and South Africa. The food import unit value index for the whole world (1979-81=100) was used to deflate cocoa and coffee unit values. Unit values for substitute and complement products (tea, sugar) were also collected.

The income variable used was the weighted average real GDP per capita for OECD countries, expressed in a common set of international prices (Summers and Heston 1991). Although only applying to a subset of the countries that consumption is modelled for, the per capita income variable is the best available because of the unreliable nature of GDP estimates in the formerly centrally-planned economies. Data were available for the period 1961-1988.

ESTIMATION RESULTS

Variables are in logarithms so coefficients can be interpreted directly as elasticities. Equation (2) was estimated over the period 1962-1988 (with 1961 data used for the *t*-1 terms). Initial results for the model of per capita cocoa consumption were:

$$Q_t = \underset{(0.17)}{0.53}Q_{t-1} - \underset{(0.03)}{0.14}P_t + \underset{(0.05)}{0.04}P_{t-1} + \underset{(0.04)}{1.08}Y_t - \underset{(0.36)}{0.75}Y_{t-1} - \underset{(1.11)}{2.82}$$

$R^2 = 0.93$, $F_{(5,21)} = 56.45$, AUTO(1): $F_{(1,20)}=0.01$

ARCH(3): $F_{(3,15)} = 0.37$, NORM: $X^2_{(2)} = 0.58$

HETERO: $F_{(10,10)} = 0.49$, RESET(3): $F_{(2,19)} = 1.37$

The figures in brackets are standard errors. R^2 and F are conventional 'goodness of fit' statistics: the model explains 93 percent of the variation in per capita cocoa consumption and the group of coefficients are statistically, significantly different from zero. AUTO(1) is the lagrange multiplier test for first-order autocorrelated residuals (which give biased standard errors and biased and inconsistent coefficient estimates when there is a lagged dependent variable, as here). Unreported tests showed that higher order autocorrelation was not present. HETERO and ARCH are the lagrange multiplier tests for heteroscedasticity (due to squares of the variables, and due to lagged, i.e., autoregressive, terms), which also biases standard error estimates. NORM is the lagrange multiplier test for normality of the residuals (non-normality invalidates the inferences from other test statistics). RESET(3) tests for misspecified

functional form by adding squares and cubes of the predicted values to the set of regressors and testing if the added variables have statistically significant coefficients.

The initial model satisfied all diagnostic tests. There was no evidence of excluded relevant variables. Real unit values for sugar, coffee, and tea were each added to the model. Estimated coefficients were not statistically significant (the most significant addition was sugar, $p<0.23$). The estimated coefficients suggest that previous cocoa consumption has a strong influence on current consumption. Prices and incomes are also very influential. A one percent increase in the real cocoa price will reduce consumption in the same period by 0.14 percent. The long-run price elasticity is -0.21, with a standard error of 0.06.

The only simplification of the initial model that did not involve imposing restrictions that were rejected by statistical tests was the removal of the P_{t-1} term. The resulting model also satisfied all diagnostic tests. The long-run elasticities were almost unchanged, with an estimate for the own-price elasticity of -0.22 (standard error 0.05). Thus, an estimate of -0.21 for the world price elasticity of demand for cocoa exports seems to be supported by this data.

Initial results for the model of per capita coffee consumption were

$$Q_t = \underset{(0.56)}{-0.06}Q_{t-1} \underset{(0.11)}{-0.15}P_t \underset{(0.05)}{-0.03}P_{t-1} + \underset{(0.61)}{1.22}Y_t \underset{(0.49)}{-0.75}Y_{t-1} \underset{(1.56)}{-3.03}$$

$R^2=0.83, F_{(5,21)}=20.64$, AUTO(2): $F_{(2,19)}=2.93$

ARCH(1): $F_{(1,19)}=1.01$, NORM:$X^2_{(2)}=1.85$

HETERO: $F_{(10,10)}=5.44$, RESET(3): $F_{(2,19)}=1.39$

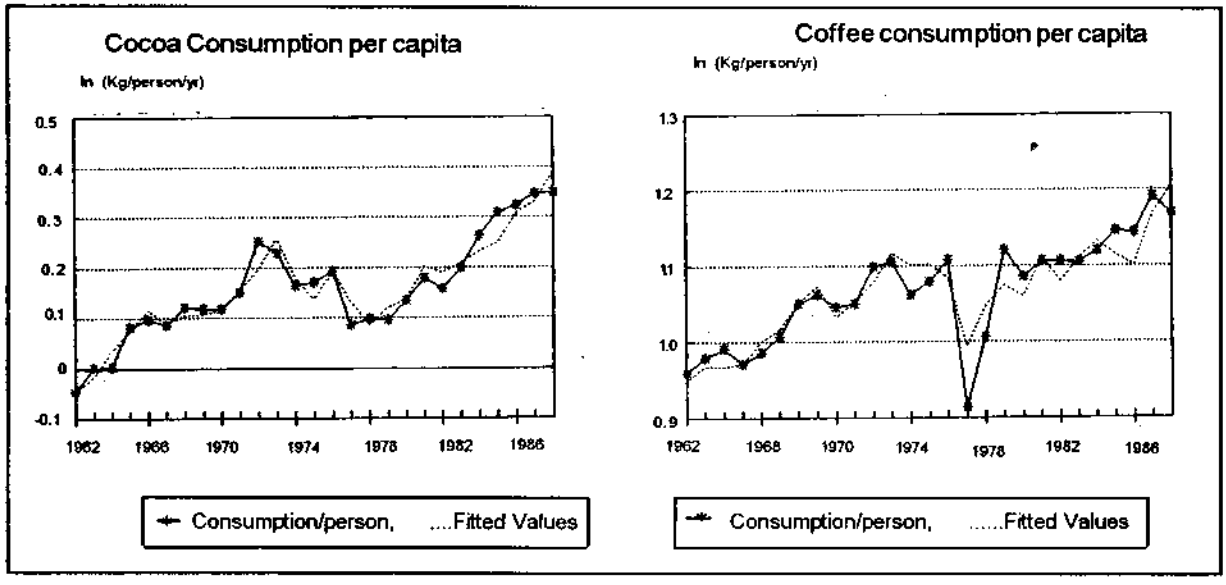
The standard errors are calculated using the White (1980) estimator, and are robust to the heteroscedasticity that is indicated by the diagnostic test HETERO (the null hypothesis of constant error variance is rejected at $p<0.01$). The regression residuals are also autocorrelated ($p < 0.08$). No further problems are indicated by the other diagnostic tests although the model explains less of the variation in coffee consumption than it did for cocoa consumption ($R^2=0.83$).

The source of these misspecifications is the sharp fall in coffee consumption in 1977. Figure1 shows the actual and predicted consumption for both coffee and cocoa. The predictions track actual consumption closely, except for coffee consumption in 1977. Frost damage to the 1976 Brazilian crop caused production to fall by 70 percent, reducing world production by 23 percent and causing world exports to fall by 20 percent the following year. With the resulting three-fold increase in real prices the model predicts an eight percent fall in per capita consumption, whereas consumption actually fell by 18 percent Thus the largest regression residual occurs in the period of highest prices and this creates heteroscedasticity. Autocorrelation also results because the 1977 shock influenced future consumption so the regression errors are related to their previous values. These violations of the assumptions regarding the ordinary least squares error term suggest either that the model should be re-specified or that robust estimators should be used.

The problem of autocorrelated residuals was handled by two different methods. The first assumes that the unobservable random errors are truly autocorrelated and uses the generalised least squares estimator. This imposes a transformation on the variables so that the resulting residuals are not autocorrelated. Treating the auto correlation as a second order process, the coefficient estimates for α_1, β_1 and β_2 were 0.40, -0.16 and 0.08. This implies a long-run own-price elasticity of -0.13 (=(-0.16+0.08)/(1-0.40)). The heteroscedasticity of the residuals was not altered by this transformation.

The second method assumes that residuals are autocorrelated because relevant lag lengths are excluded (Hendry and Mizon 1978). Setting lag lengths at *t*-2 ensured that the residuals were not autocorrelated. Four variable/lag length combinations were able to be deleted from this model: Q_{t-1}, P_{t-1}, P_{t-2} and Y_{t-2} (the test of the hypothesis that the coefficients on these terms were jointly zero was not statistically significant, $(F_{(4,17)}=1.10)$.

Figure 1. **Actual and predicted developed country consumption levels.**



The resulting model was:

$$Q_t = -0.34Q_{t-2} - 0.17P_t + 1.24Y_t - 0.69Y_{t-1} - 3.41$$

(0.16) (0.07) (0.37) (0.35) (0.44)

R^2=0.86, $F_{(4,21)}$=31.10, AUTO(1): $F_{(1,20)}$=0.11

ARCH(1): $F_{(1,19)}$=0.51, NORM: $X^2_{(2)}$=0.21

HETERO: $F_{(8,12)}$=3.24, RESET(3): $F_{(2,19)}$=1.27

The standard errors are robust to the heteroscedasticity that is indicated by HETERO. The long-run elasticities are -0.13 and 0.41. Several estimators that directly model heteroscedasticity were used on this specification of the model, included weighted least squares. Only when the heteroscedasticity was modelled as an ARCH(2) process, i.e., the variance of residuals is a function of the residuals lagged twice, did the long-run estimate of the own-price elasticity move from -0.13 (to -0.16). Thus, this data suggests that the world own-price elasticity of demand for coffee is no smaller than -0.13.

This estimate is smaller than those of Akiyama and Duncan (1982) and Islam and Subramanian (1989). One reason is the use of data from the 1980s. Figure 1 shows stable per capita coffee consumption during the early 1980s. In 1986 the real price rose to its second highest level ever but consumption fell only slightly. This was a much less elastic response than in the 1970s and this has influenced the econometric estimates. By 1990 real prices had fallen to one-third of their 1986 level but consumption only increased by 11 percent (from 3.14 to 3.50 kg/person/yr). Hence the elasticity (at the mean of these changes) is -0.11, which suggests that the world elasticity of demand for coffee is falling.

Table 1 shows the calculated values of $(\eta_x)_i$ resulting from Equation (1). Papua New Guinea's small share of world cocoa and coffee exports means that the estimated own-price elasticity is large, despite the small values of $(\eta_x)_w$ resulting from the econometric equations. Assuming perfect price transmission, the short-run, own-price elasticity of demand for cocoa exports is at least -14, and for coffee exports, at least -17. Allowing for imperfect price transmission, the elasticities fall to -11 and -12. Thus, even in the short-run, under conservative assumptions about the transmission of prices and

Table 1. **Estimates of demand for exports of Cocoa and coffee** [1]

	$(\eta_x)_w$	(X_w/X_i) [2]	(X_r/X_i) [2]	Assumed Value for $(\varepsilon_x)_r$ 0.1	0.3	0.7
Assuming Perfect Price Transmission ($\phi_{rji} = 1$)						
Cocoa	-0.21	46.97 [3]	45.97 [3]	-14.46	-23.65	-42.04
Coffee	-0.13	73.48	72.48	- 16.80	-31.30	-60.29
Assuming Imperfect Price Transmission (Producers: $\phi_{rji} = 0.65$, Consumer: $\phi_{rji} = 0.8$)						
Cocoa	-0.21	46.96 [3]	45.97 [3]	-10.88	-16.86	-28.81
Coffee	-0.13	73.48	72.48	-12.35	-21.78	-40.62

Notes: [1]Symbols are defined as for equation (1)
[2]Average of 1989-91
[3]World trade in cocoa beans only

the responsiveness of producers in competing countries, Papua New Guinea has no noticeable market power. Unilateral, one-percent increases in export price would reduce export demand for cocoa and coffee by over ten percent. Allowing more elastic long-run supply responses from competing countries shows even less market power because the estimated elasticities rise to -42 and -60 with perfect price transmission.

DISCUSSION

The price elasticity estimates in Table 1 show that cocoa and coffee exports face an elastic demand curve. This means that Papua New Guinea can safely increase production of cocoa and coffee without fear of causing prices, and export revenues, to fall significantly. Conversely, producers are not able to pass cost increases forward to overseas consumers. Any domestic cost increases resulting from protection for import substitution industries will therefore act as a tax on exporters who pay more for their inputs but receive no increase in the price of their output.

The elastic demand also means that the cocoa and coffee industries can be used as a benchmark for comparing with proposed new industries. There may be some proposed industries which make only a small contribution to increasing employment and incomes for PNG households. It may therefore be more efficient to direct the investment into expansion of cocoa and coffee production, seeing as the elastic demand implies an opportunity for increased exports by competitive producers. For example, if Papua New Guinea had maintained its 1979-81 share of the world cocoa bean market it would now be producing an extra 7800 tonnes of cocoa. This extra production would create a demand for approximately 1.9 million more unskilled labour days. This level of employment generation can be compared with the employment effects of projects directed towards the internal market, such as the cement and tinned fish factories, and rice import substitution. The capital intensity of import-substituting industries and the small size of the internal market put a limit on the number of jobs that can be created.

It may initially seem that the evidence of Papua New Guinea's falling share of world cocoa exports indicates a lack of competitiveness, sug-

gesting that it would be socially unprofitable to expand production. However, much of the lost market share was due to loss of production in North Solomons province following the civil disturbance there. There may have been an additional loss of market share due to falling cost competitiveness, although Papua New Guinea still has comparatively low on-farm production costs because agronomic conditions are better than in competing countries (Simmons 1993). If it is costs beyond cocoa producers' control which cause reduced competitiveness for Papua New Guinea, e.g., higher industrial input costs, higher infrastructure costs, then the essential message of the current paper is supported: the elastic demand facing cocoa and coffee exporters makes them vulnerable to cost increases in the domestic economy because buyers will move to other suppliers if prices are increased.

The estimated elasticities in Table 1 also support the traditional assumption that Papua New Guinea is a price-taker. This has important implications for the current policy of paying subsidies to tree crop producers. For price-taking countries, world markets determine producer prices in the long-run. The subsidies currently being offered have been set on a cost of production basis that has no necessary relation with the world market price (Fleming and Coulter 1992).The artificially high producer prices may discourage producers from taking the necessary steps to improve efficiency and reduce costs. There is some danger that when the subsidies are ultimately removed PNG producers will not be competitive suppliers to the world market.

This problem is exacerbated by the inelastic demand for cocoa and coffee (and the other tree crops) at the world level. The estimated values of $(\eta_x)_w$ are very low but the price elasticity of demand facing individual countries is almost always greater than one. It is therefore sensible for individual countries to use existing world prices to make decisions about the profitability of expanding production. However if all exporters were to simultaneously expand they would be made worse off because the low price elasticity of world demand causes prices to fall. In the absence of effective international agreements the tendency is for oversupply and low prices, due to this conflict between individual and collective action (Islam and Subramanian 1989). Therefore countries who wish to remain involved in cocoa and coffee production need to direct their efforts towards becoming competitive and reliable suppliers. That this can be achieved is illustrated by the experience of Indonesia and Malaysia who increased their share of world cocoa exports from zero and three percent in 1979-81, to five and nine percent in 1989-91.

The estimates in Table 1 also allow an inference to be made about the likely success of devaluation as a policy for improving the balance of payments. The Marshall-Lerner condition, which is a well known proposition in international trade theory, holds that devaluation will make the balance of payments *worse* if the sum of the absolute values of export and import demand elasticities is less than one (Goldstein and Khan 1985). For the 1989-91 period cocoa and coffee accounted for 13 percent of export receipts. Thus, even if the other 87 percent of exports faced absolutely inelastic demand, i.e., $(\eta_x)_i=0$, the weighted average export demand elasticity would be at least -1.53 in the short-run ($(\varepsilon_x)_r=0.1$), and -4.55 in the long-run ($(\varepsilon_x)_r=0.7$). Even without knowing what the price elasticity of demand for imports is, this elastic export demand suggests that devaluation could be used if policy makers wished to improve the balance of payments. This is in contrast to the conclusion of Kauzi (1992).

CONCLUSION

The price elasticity of demand for Papua New Guinea exports of cocoa is estimated to be at least -11, and for exports of coffee at least -12. In contrast to some recent analysis and policy decisions, the traditional assumption of Papua New Guinea being a price-taking country is supported. Expansion of production will not influence the prices received for exports. If import substitution industries are given protection and this causes increased prices, cocoa and coffee exporters will suffer reduced incomes because they have no power to pass costs forward to foreign consumers. Subsidies for tree crop producers help improve incomes but have the potential to create a high-cost, inefficient industry that will not survive intense competition on the world market.

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PESTS AND DISEASES OF SHADE TREES AND THEIR RELATION TO COCOA IN PAPUA NEW GUINEA

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ABSTRACT

In the 1950s, most of Papua New Guinea's cocoa was grown either under coconuts or a leguminous shade, Leucaena leucocephala *(Lam.). During the 1960s, increasing problems with pests of* Leuceana *transferring to the cocoa resulted in a gradual replacement of this shade with an alternative legume;* Gliricidia sepium *(Jacq.). Currently,* Gliricidia *is the preferred permanent shade for establishing cocoa where coconuts are not grown. Pests and other problems with* Gliricidia *are discussed and the recent problems with establishing high yielding hybrid coconuts as permanent shade are highlighted.*

***Key words**: Pod rot, vascular dieback, longicorns, mirids, pantorhytes, scolylids, shade management.*

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is native to South America where it is found as an under-storey tree of dense tropical rain-forest (Wood 1985). It is therefore adapted to grow under heavy shade, but like any other plant, still requires adequate light for photosynthesis. German settlers in 1905, introduced cocoa into Papua New Guinea (PNG) all of which were the Trinitario type (Green 1938, Moxon 1983).

Interplanting of cocoa with coconut was established in the 1920s (Green 1938, Gorringe 1966). Shade trials in the early 1950s looked at the major potential shade types, of which *Leucaena leucocephala* (Lam.) de Wit, and *Cocos nucifera* (L.) were selected as agronomically the most satisfactory for local conditions (Byrne 1971).

Various problems relating to shade type, shade density, incidence of pests and diseases resulted in alternative shades such as *Gliricidia sepium* (Jacq.) to be considered, and these have been recently reviewed (Smith 1985).

Recommendations on shade requirements for cocoa were formulated, following Smith's 1985 review (Smith 1985, Moxon 1992 a). Coconut shade, particularly the high yielding hybrid variety was recommended as permanent shade for cocoa with *Gliricidia* as the temporary shade.

This review concentrates on the history of changes in shade species and touches on particular pests and diseases presently categorised to be of major economic importance in the cocoa industry within Papua New Guinea (Anon. 1992, Moxon 1992 a). Points are also raised on the present problems of shade density requirements and types of positive or negative associations within the shade, pest and disease complex. Reference is made to present pest and disease control recommendations which are diametrically opposed to each other (Bailey 1979, Smith 1981 a, Smith 1981 b, Moxon 1983).

HISTORY OF SHADE REPLACEMENT

The initial recommendation for a cocoa shade tree in the 1950s was *L. leucocephala* based on Green's work (1938). Problems of insect pests and to a lesser extent proliferating seed production (Urquhart 1961), which were difficult to eradicate, resulted in preference for the agronomically more suitable *G. sepium* in the Oro Province during the early 1970s (Baker 1972).

L. leucocephala has now been further reduced in priority as a shade for cocoa with the arrival in

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1986 of a South American Psyllid pest of *Leucaena*, *Heteropsylla cubana* Crawford (Hem: Psyllidae) (Moxon 1986, Arura 1989). Feeding of the psyllid on *Leucaena* can cause complete defoliation leading to death of the tree and has been observed to devastate shade in cocoa plantations. A predatory ladybird *Curinus coeruleus* (Muls.) (Col: Coccinellidae) was introduced and tested in quarantine for control of the Psyllid but not released due to its wide host preference (Moxon 1986).

A number of leguminous shade species were studied during the 1930s, particularly as temporary shade species (Green 1938, Byrne 1971). These include *Crotalaria anagyroides* Kunth; *Tephrosia candida* (Roxb.), *Tephrosia vogelii* Hook. and *Flemingia congesta* (Roxb.).

C. anagroides and the two *Tephrosia* species were susceptible to pink disease (Smith 1981 a). *F. congesta* was not recommended because it was found to be an alternative host of the mirid *Helpeltis clavifer* (Walker) (Hem: Miridae). It was also hard to remove after permanent shade was established. Other shades which were considered for permanent shade include species of *Albizia*, *Casuarina* and *Erythrina* (Henderson 1954, Smith 1985).

Gliricidia shade has been the recommended shade since 1980 in areas known to have outbreaks of pests feeding on *Leucaena* (Moxon 1983). However increasing high management costs in regulating such a vigorous growing species, resulted in *Gliricidia* being recommended only as a temporary shade for cocoa establishment, with coconut, as the permanent shade (Sitapai 1983).

In recommending coconuts, preference was given to high yielding hybrid varieties. The cross between the Malaysian Red Dwarf (MRD) and Rennel Island Tall (RIT) from the Solomon Islands was evaluated (Brook 1985).

A greater economic return per unit area could be obtained from this intercrop establishment (Sitapai 1983, Brook 1985). Catastrophic pest damage on the hybrid coconut particularly in the Islands Region by the indigenous Rhinoceros beetles, *Scapanes australis* (Boisd.) (Col: Dynastidae) and the Black Palm Weevils, *Rhynchophorus bilineatus* (Montrouzier) (Col: Curculionidae) has halted the distribution of this hybrid throughout Papua New Guinea and led to the closing of both government and commercial hybrid coconut production centres (Woruba 1987, Ovasuru 1990).The Black Palm Weevil usually enters the coconut via damage caused by rhinoceros beetles, either *S. australis* or *Oryctes rhinoceros*. *R. bilineatus* lays its eggs in the damaged tissue and its larvae destroy the apical region resulting in the death of the coconut. The initial approach to controlling the rhinoceros beetle pests involved routine checks and treatment with lindane (gamma BHC) granules to frond axils of young palms up to five years old (Smith 1981 a, Morin 1992).

A recent and more promising approach is the use of a pheromone identified for the black palm weevil.The compound is a 4-methyl-5 - hydroxynonane (Oehlschlager *et al.* 1992). After identification of the specific isomers involved in the compound, it may be possible to use it as a control measure as well as for monitoring the populations of *R. bilineatus*.

Due to the continuing pest problems on *Leucaena* and coconut the high management *Gliricidia* shade is now being used both as a temporary and permanent shade.

GENERAL SHADE REQUIREMENTS OF COCOA

Shade trees are required to act as a buffer against change in the cocoa canopy. This would act as a lateral protection, as a windbreak, and overhead shading to control the amount of solar radiation and humidity. Shade requirement usually diminishes as the cocoa tree grows older and forms an interlocking canopy. Both the shade trees and cover crop can be used to reduce competitive weeds and the latter, to reduce soil erosion (Wessel 1985). Shade trees also affect temperature and relative humidity around the plant which in turn affects transpiration (Wessel 1985).

Generally cocoa requires shade throughout its life but shade is more important in the first three to five years than when the trees are mature and achieve a closed canopy. Yield has been stated, to some extent, to be inversely proportional to shade density (Smith 1985). Charles (1961)

also showed that there was a clear negative correlation between yield and shade density.

Height of the shade tree and the distance between cocoa canopy with shade canopy has a strong influence on the type and severity of insect pests and incidence of diseases in a cocoa block in PNG (Smith 1985). Pest problems on cocoa are far fewer when cocoa is grown under the tall coconut shade than the relatively low *Leucaena* and *Gliricidia* shade trees, though the precise reasons for this are unknown. Urquhart (1961) also stated that there is no evidence of competition between cocoa and coconut when intercropped at optimum spacing.

PESTS AND DISEASES OF IMPORTANCE TO PNG COCOA

Over 300 insects species (Szent-Ivany 1961, 1963) and over 47 diseases (Shaw 1965) have been recorded on cocoa in Papua New Guinea. However, only about 10 pests (Moxon 1992 a) and 4 diseases (Anon.1992) can be categorised as important economically. Important pests include defoliating caterpillars (Table 1), Mirids, Trunk Longicorns, the cocoa web worm *Pansepta* and *Pantorhytes* (Table 3).The diseases include, Vascular Streak Dieback (VSD), *Phytopthora palmivora* (Pod rot, stem canker and seedling blight), Pink diseases (Table 3) and root diseases (Table 3).

MAJOR PESTS AND DISEASES OF SHADE TREES

The major pests of *Leucaena* are the *Leucaena* Psyilid, *H. cubana* (Moxon 1986, Arura 1989) (Table 2) and the defoliating caterpillar, *Tiracola plagiata* Walker (Lep. Noctuidae) (Catley 1962, Moxon 1992 a). Major pests of *Gliricidia* are the grey weevils of which only the biology, ecology and control of *Hypotactus ruralis* (Col: Curulionidae) is clearly understood (Moxon 1983, 1992 b). Major pests of coconuts are the Rhinoceros beetles and the Black Palm Weevils and on restricted localities *Sexava* and *Promocotheca* (Bedford 1976, Ismay & Dori 1985, Ovasuru 1990, Morin 1991 and Woruba 1987) (Table 2). Major disease outbreaks are not common on any of the shade species in Papua New Guinea (Table 1 & 2) though root rots such as *Phellinus noxius* can be an occasional local problem.

ASSOCIATIONS WITHIN THE INSECT, PATHOGEN AND SHADE COMPLEX

The fluctuation in the pest status of a number of the insects recorded and often not categorised as important, seems to have been partly influenced by the species of shade tree and the shade densities involved.

Mirids such as *H. clavifer* and *Pseudodoniella* spp. (Hem: Miridae) become a problem when there is inadequate shade (Smith 1981 a) (Table 3). Too much shade removal promotes water shoot production which increases mirid feeding.

H. clavifer and *Pantorhytes* are positively associated with cocoa grown under *Leucaena* or without shade but negatively associated with cocoa grown under coconut shade (Room & Smith 1975). It has been observed (Baker 1972, Moxon 1983) that the crazy ant *Anoplolepis longipes* (Jerdon) (Hym: Formicidae) and the arboreal kurakum ant *Oecophylla smaragdina* (F) (Hym: Formicidae) elimates *Pantorhytes* from the cocoa under coconut shade. Smith (1985) also refers to negative associations between ants and *H. clavifer*. Pantorhytes and mirids have remained the most important pest of cocoa since the 1950s (Szent-Ivany 1961, Moxon 1992 a).

Populations of crazy ants, *A. longipes*, are known to be unstable (Room & Smith 1975) but may persist longer arboreally due to the presence of honey producing homopterans such as mealybugs and scab insects often abundant on *Gliricidia* shade tree. Sometimes efficient tending of *Coccids* results in unusually high populations of mealybugs such as *Planococcus pacificus* (Hem: Pseudococcidae) which sometimes may be directly injurious to the cocoa tree and reduce photosynthesis from sooty mould (Lewis *et al.* 1976). The crazy ants then harass *Pantorhytes* and mirids on the cocoa tree. In some areas this beneficial association has been disturbed by improper use of insecticides. The Kurakum ant, *O. smaragdina* is negatively associated with the coconut *Amblypelta cocophaga*

Table 1. **A Lists of pests and diseases of major shade trees and of which cocoa is also a host.**

Shade Species	Pest / Disease spp.	Order: Family	Author
Leucaena sp.	**Pests**		
	Ectropis sabulosa Warrengren	Lep: Geometridae	Smee 1963
	Hyposidra talaca Walker	Lep: Geometridae	Smee 1963
	Tiracola plagiata Walker	Lep: Noctuidae	Catley 1962
	Ferrisia virgata (Cockerell)	Hem: Pseudococcidae	Szent-Ivany & Catley 1960
	Planococcus citri (Risso)	Hem: Pseudococcidae	Szent-Ivany 1956
	Neotermes papuana Desuus	Isop: Kalotermitidae	Moxon 1992 a
	Diseases		
	Phytophthora palmivora (Butler) Butler		Newhook & Jackson 1977
	Corticium salmonicolour Berkley & Broom		Shaw 1963
	Phellinus (*Formes*) *noxious* (Corner)		Thrower 1965
Gliricidia sp.	**Pests**		
	Ceroplastes chiton Green	Hem: Pseudococcidae	Shah 1976
	Neotermes sp.	Isop: Kalotermitidae	Smee 1963
	Hypotactus ruralis	Col: Curculionidae	Moxon 1992 a
	Paractus sp.	Col: Curculionidae	Moxon 1992 a
	Cyphopus sp.	Col: Curculionidae	Moxon 1992 a
	Oribius sp.	Col: Curculionidae	Moxon 1992 a
Cocos nucifera			
	Diseases		
	Phytopthora palmivora (Butler) Butler		Muthappa 1987
	Rigidoporus (Formes) lignosus		Shaw 1965

Table 2. **Major pests of recommended shade trees.**

Shade Species	Pest Species	Order: Family/Subfamily	Author
Leucaena leucocephala	*Heteropsylla cubana* (Crawford)	Hem: Psyllidae,	Arura 1989
	Tiracola plagiata Walker	Lep: Noctuidae	Catley 1962
Gliricidia sepium	*Hypotactus ruralis (Fst.)*	Col: Curculionidae	Moxon 1992 a
Cocos nucifera	*Scapanes australis* (Boisduval)	Col: Dynastidae	Bedford 1976
	Oryctes rhinoceros Linnaeus	Col: Dynastidae	Bedford 1976
	Rynchophorus bilineatus (Montrouzier)	Col: Curculionidae	Morin 1991
	Sexava Wilemse	Orth: Tettigoniidae	Morin 1991
	Promecotheca papuana Csiki	Col: Hispinae	Ismay & Dori 1985

China which causes some degree of premature nutfall (Stapley 1971).

The establishment of cover crops such as *Pueraria* has been observed to improve the foraging of *Oceophylla* on coconut shade (Stapley 1971).

Outbreaks of the defoliating caterpillar *Tiracola plagiata* Walker (Lep: Noctuidae) (Catley 1962, Dun 1967) on cocoa in the Oro Province in blocks under *Leucaena* shade resulted in a shift to rubber, coconut, *Erythrina* and thin forest as shade. Consequently *T. plagiata* damage to cocoa decreased due to the reduced use of *Leucaena* as shade. *Achaea janata* (Lep: Noctuidae) (Room & Smith 1975) on the other hand increased as a result of *Leucaena* shade removal.

Cocoa planted under coconut, rubber and bush remain free from serious infestations of both *T. plagiata* and *A. janata* (Anon. 1968).

Glenea sp. (Col: Cerambycidae) becomes a problem when there is too much shade (Smith 1981 a) (Table 3). Heavy shade also results in growth of high jorquette on the seedling (Dennis & Keane 1992).

Grey weevil such as *Hypotactus ruralis* (Fst.) (Col: Curculionidae) retard growth and deform the growing point of young cocoa seedlings, and sometimes devastate young *Gliricidia* shade (Moxon 1992 b). Grey weevil pests are problems on cocoa throughout the country (Moxon 1983).

Pansepta teleturga Meyrick (Lep: Xylorictidae) is a problem when there is inadequate shading and becomes severe in areas of complete shade removal (Byrne 1971).

The giant termites *Neoterme* sp. (Isop: Kalotermitidae) build nests in stumps of cocoa and *Leucaena* shade trees from where a New Ireland species invades adjacent cocoa trees through the root system (Anon. 1965). The species *N. papuana* Desnus commonly invades through dead wood of cocoa tree where they tunnel into the green timber (Smith 1981, Moxon 1992 a).

Scolytid beetles have been associated with bark canker on cocoa in Papua New Guinea (Prior & Smith 1981). Thirteen species have been recorded in Papua New Guinea (Anon. 1983, Ismay & Dori 1985) of which the genera *Xyleborus* and *Xylosandrus* are most common. The presence of weeds or heavy shade may also increase the attack of the Scolytid beetles (Entwistle 1972). Weeds and cover crops however may sometimes act as a barrier to the flightless insects such as *Pantorhytes* and grey weevils.

Vascular Streak Dieback, Phytopthora Pod Rot (Ppr), Pink (bark) and root diseases (Table 1 & 2) are most damaging in overshaded conditions (Keane & Turner 1972, Thorold 1975, Dennis & Keane 1992).

General recommendations on the management of cocoa diseases include the use of light to moderate shade levels (Anon. 1992).

Light shade creates drier conditions which reduce the number of pods lost to Ppr and increases flowering. It also creates low humidity, increases aeration which simultaneously reduces sporulation of Ppr. The same light shade condition slows down and delays the onset of VSD disease epidemic and reduces spread and incidence of Pink disease (Anon. 1992, Dennis & Keane 1992) (Table 3). More light penetration into the canopy encourages vegetative growth which improves tolerance to VSD (Anon. 1992).

Pink disease can use both *Leucaena* and *Gliricidia* as alternative hosts (Anon. 1992).

Root diseases (Shaw 1965, Anon. 1992) invade dead shade stumps and most commonly provide the source of inoculum to adjacent cocoa trees via the root systems though aerial infection on stumps is also possible.

Generally, good management of shade in a cocoa block will reduce conditions suitable for disease spread and establishment (Anon .1992).

Shade types and density affect cocoa pollinators. Planted shade seems to be less favourable to pollinating midges than thin jungle. Bees are more frequently associated with cocoa flowers in the sun on the edge of blocks and midges prefer heavy shade (Young 1982).

COMPLETE SHADE REMOVAL AND SPACING

Complete shade removal may increase the cocoa yield (Charles 1961, Wessel 1985) and reduce some of the pests and diseases. However *Helopeltis*, *Pantorhytes* and *Pansepta* become serious problems (Entwistle 1972). In Malaysia, Lim (1978) reported that complete shade removal excepting around the block boundaries increases mirids, thrips and defoliators.

The yield increase is difficult to maintain over a long period because of the imbalance between available nutrients in the soil and the rate of photosynthesis (Charles 1961). Fertilizer input to maintain health and yield of the tree will be laborious and costly. Complete shade removal therefore shortens the economic life of the tree, creating a condition which causes premature decline in yield (Wessel 1985).

In Papua New Guinea yield differences between 17 and 30% were in favour of the unshaded plots, in October and September 1992 (Anon., in press). It is suggested that the difference may have been due to less Ppr in unshaded plots and competition for nutrient and light between the cocoa and shade trees in the shaded plots.

Spacing of cccoa and shade trees has also considerable influence on the effect of certain pests and diseases (Byrne 1971). The light environment of cocoa can be modified by the standard planting of shade trees especially coconuts in rows along an East-West direction for the maximum use of sunlight in the shaded condition (Jayasuriya 1987).

In the Papua New Guinea situation, it is essential that some shade should be used. Without shade weeds become a problem particularly if the canopy is not closed. Competition for nutrients with the weeds occurs and the grey weevil population will increase if grasses are established. More regrowth of water shoots attracts mirids and enables their number to increase rapidly.

Complete shade removal will result in a greater input into the management and control of pests and diseases, and shorten the economic life of a cocoa tree.

Table 3. **Shade density recommendations for the control of pests and diseases.**

Pest Species	Over-shade	Light-shade	No-shade	Author
TRUNK LONGICORNS				
Glenea aluensis Gahan	-	+	++	Smith 1983, 1981 a
Glenea elegans Oliver	-	+	++	Smith 1983, 1981 a
MIRIDS				
Helopeltis clavifer (Walker)	++	-	—	Smith 1981 a
Pseudodoniella laensis Miller	+	+	-	Smith 1981 a
Pseudodoniella pacifica China and Carvalho	+	+	-	Smith 1981 a
PANTORHYTES				
Pantorhytes sp.	++	--	-	Smith 1981 a
PANSEPTA				
Pansepta teleturga Meyrick	++	--	-	Byrne 1971
SCOLYTIDS				
Xyleborus sp.	-	+	++	Entwistle 1972
Xylosandrus sp.	-	++	+	Entwistle 1972
Diseases				
POD ROT				
Phtophora palmivora (Butler) Butler	—	++	+	Anon. 1992
VSD				
Oncobasidium theobromae Talbot & Keane	-	-+	+	Dennis & Keane 1992
PINK DISEASE				
Corticium salmonicolour Berkley & Broome	-	+	+	Anon. 1992

- Not recommended - problems will arise
-- Worse problems will arise
+ Recommended
++ Better than ideal

Present control measures of pests and diseases are conflicting. Recommendations for control of the mirid, *Pansepta*, *Pantorhytes* and sometimes Scolytid beetle borers are diametrically opposed to control of Longicorns, Ppr, Pink disease and VSD.

VSD is a problem when the shade is heavy and or nil shade which however will increase weed problem but on the other hand accelerates flowering. Pollinators prefer heavy shade as opposed to thin shade.

CONCLUSIONS

Establishment of light shade will simultaneously reduce incidence of Ppr, Pink disease and reduce and delay the onset of VSD disease epidemics. It will also reduce Longicorn and scolytid beetle populations. Light shade however will simultaneously encourage the build up of populations of *H. clavifer*, *A. janata*, *Pantorhytes* and *Pansepta*.

Leucaena shade is a host for *Pantorhytes*, three species of defoliating caterpillars, and is an alternate host of Pink disease, root rots and termites. *Leucaena* produces many seeds which readily germinate and are difficult to eradicate. The recent arrival of the *Leucaena* psyllid which severely damages and can kill the trees, further reduces its value as a shade.

Gliricidia is a vigorous growing plant that requires regular pruning with high management costs. In the young, i.e, establishment phase *Gliricidia* is attractive to adult grey weevil, termites and is an alternative host of Pink disease. However it harbours homopterans that provide a food source for the Crazy ant which has been beneficial against important cocoa pests such as mirids and *Pantorhytes*.

Coconut shade, particularly the hybrid variety gives more return per unit area when intercropped with cocoa and as a tall shade produces conditions unsuitable for a number of cocoa pests and diseases.

Complete shade removal, although causing a temporary increase in yield, is not an ideal long term economic practice. A greater input is also required in managing and controlling disease and pest problems.

The predatory ant, *Oecophylla* favours coconuts for establishing its leaf nests and affects beneficially both cocoa and coconut pests. Severe damage by rhinoceros beetles and Black Palm Weevils on coconut shade has halted continued planting and distribution of hybrid coconut seedlings to farmers. A coconut breeding programme is currently engaged in producing and evaluating superior coconut hybrids from local materials. These materials may have some degree of resistance or tolerance to the indigenous *Scapanes* and *Rhynchophorus* beetles. Some farmers are therefore using *Gliricidia* as temporary and permanent shade while some are using existing local tall coconuts as permanent shade.

To simultaneously control major pests and diseases, critical shade levels will have to be established, with a consideration of agronomic factors as well as other aspects of the cocoa ecosystem, and farming practices.

In Papua New Guinea, this has led to conflicting recommendations which are further complicated by the range of environments under which cocoa is grown with local fauna of pests and diseases. However coconut would appear to be the most acceptable permanent shade with *Gliricidia* as a temporary shade. Loss and damage to coconuts, both hybrid and local talls by debilitating rhinoceros beetles and Black Palm Weevils remains a serious constraints in areas where beetle damage is high. Until effective control measure for the beetles are developed, coconuts, particularly the high yielding variety, cannot be recommended as a permanent shade for many areas of Papua New Guinea.

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SURVEY RESULTS FOR PNG COCOA BEAN QUALITY FACTORS

Barnabas Toreu[1]

ABSTRACT

The quality factors of cured cocoa beans are essential for a primary producer to understand to meet the requirements of manufacturers. In this paper, results of a survey carried out on some of the important physical and chemical quality factors which contribute to the assessment of the quality status of PNG cured cocoa beans for the export market are presented.

***Key words**: cured cocoa beans, shell content, moisture content, bean weight, pH, acidity.*

INTRODUCTION

Since chocolate is sold in one of the most competitive food markets in the world, manufacturers demand high standards in the initial "quality" of cured cocoa beans that are produced by cocoa growers. This is understandable since the quality of the processed products depends very much on the initial quality as well as the types of cocoa beans available.

The word "quality" is often used to describe several important aspects (quality characteristics) of cocoa beans required by manufacturers. In a limited sense it is often referred to as the intensity of the chocolate flavour.

The need for primary producers to understand manufacturer's requirements and the criteria by which they assess the suitability of cured cocoa beans for processing into various chocolate products is, therefore, most essential.

A number of factors are taken into consideration in the selection and/or grading of cocoa beans by manufacturers. These can be divided as follows:-

a.) those that influence flavour (chocolate flavour) as determinned sensorialy:

- acidity, bitterness, astringency, and/or other "off-flavours" such as smoky and mouldy flavours.

(b) Those physical characteristics which affect the edible material and thus the quality, i.e. bean size, shell percentage, fat and moisture content.

-The butter fat hardness and/or its melting behaviour which affect mouth feel and flavour release in chocolate products, as well as maintaining the quality of these products during storage.

(c) The purity of the raw cocoa bean product which implies the absence of foreign flavours or contaminants, e.g., toxic chemical residues that may be due to improper use of agricultural chemical (pesticides), etc;

The three categories of quality (quality factors) considered together often affect the value of a particular cocoa bean supply in relation to other "cocoas". The actual price at a given time is however, a factor of the prevailing market situation.

Though cocoa butter is by far an important quality criteria in the cocoa trade, chocolate manufacturers are equally concerned that cocoa liquor used along with deoderized cocoa butter in the manufacture of chocolate products is also high in chocolate flavour intensity.

Chocolate flavour is a property which can neither be precisely defined nor can it be assessed objectively. Assessment of this property is by tasting. Defects in flavours (or presence of "off"-flavours, e.g. mouldy, smoky, acidic, bitter and

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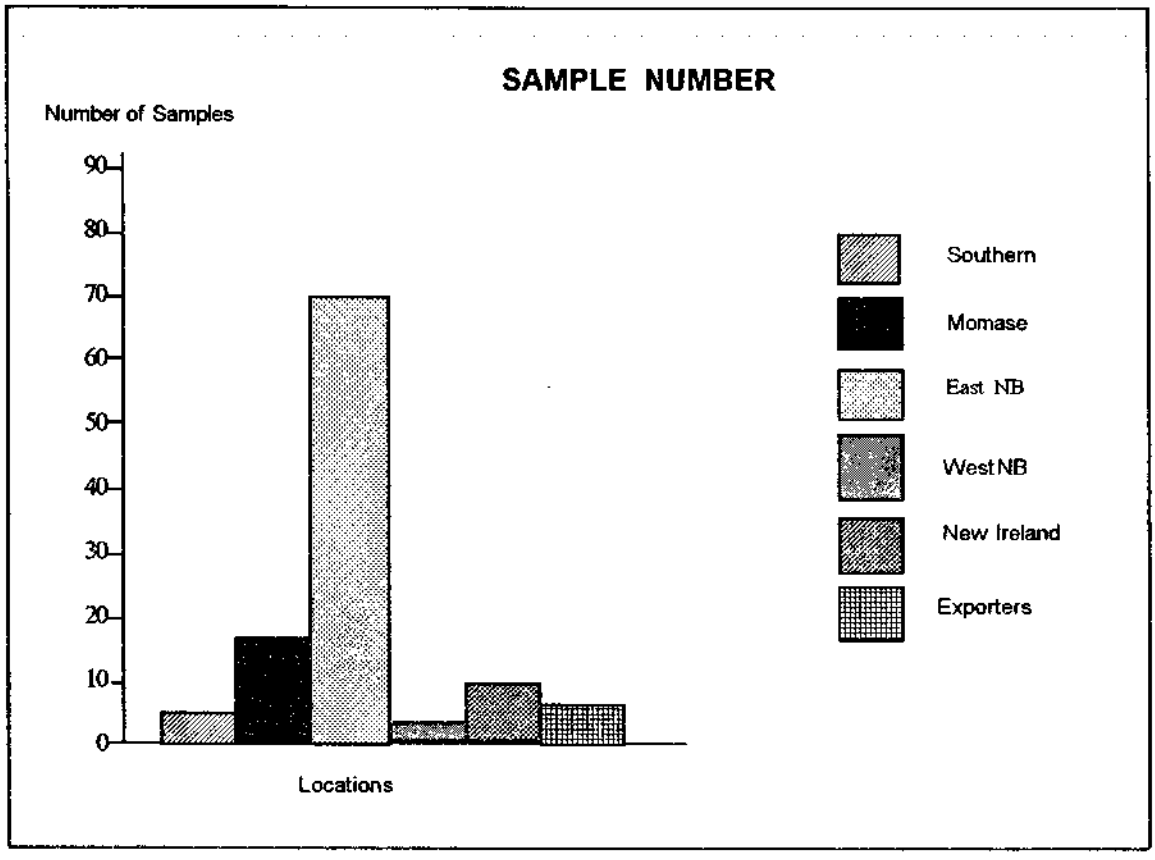
Figure 1. **Number of cocoa bean samples analysed for the areas surveyed.**



astringent flavours) can also be detected through tasting. These often lower the level of acceptability of such cocoa bean products and are frequently the cause for rejection of cured cocoa beans.

As for the physical characteristics of cocoa beans (i.e. bean weight, shell percentage, fat content, moisture content), these properties can be measured objectively.

In this note, results are presented for some of the physical and chemical characteristics of PNG cocoa beans obtained in the survey carried out in 1992. The survey was attempted in order to establish some base line measurements of important physical characteristics which might be contributing to the quality status of cocoa beans destined for the export market.

One of the important physical properties listed above, the fat content, was not tested due to the lack of required facilities. Other quality indicative measurements, namely pH and Titratable acid (T.A.), were included.

REGIONS AND PROVINCES SURVEYED

Regions and provinces covered in the survey were Southern Region (Gulf, Central and Milne Bay Provinces), Momase Region (West and East Sepik and Madang Provinces), East New Britain, West New Britain and New Ireland. Exporters were also included.

Cocoa bean samples were collected randomly from fermentaries in Provinces, mainly by Cocoa Board Inspectors and some staff members of the Cocoa Quality Improvement Project (CQIP). Cocoa samples were considered to be mostly of export quality. These were put into calico bags and forwarded to the Cocoa Quality Laboratory at Keravat for analysis. The results are presented in figure 1-6.

As shown in Fig 1, a large number of samples were collected from Rabaul and Gazelle area of East New Britain Province, since fermentary owners were reached quite easily by road. Only two samples were analysed from West New Britain; the rest of the samples received were, unfortunately, not adequate for analysis and were discarded. Small numbers of samples were also obtained from two Rabaul-based Cocoa Exporters, namely Commodity Development Pty Ltd and Ag Mark.

DISCUSSION

Comparatively, cured cocoa beans from the Southern region were less acidic in terms of the pH and Titratable acid measurements obtained. As well as these, the shell content was also found to be consistently lower than that found in the other areas of the survey. Each of the quality factors measured may be discussed as follows:

Bean weight

It is normally accepted that the average weight of a dried fermented bean should not be less than one gram. This assessment is known as the "bean count" and simply expresses the number of beans per one hundred grams.

The mean value for bean count of 79.08 (approximately 79 beans per 100 grams) does indicate that the bean size is relatively large. This is most preferable from the manufacturer's point of view, provided that this is consistent throughout the cropping seasons. There are some degrees of variation in bean size measurements among and within each area (as revealed in Fig 2). This is, however, still well within the accepted limits and is not a cause for concern.

Bean size variation is a factor which can always be expected as it is not only genetically controlled but can also be influenced to a certain degree by a number of environmental and physiological factors. (e.g. climate, rainfall, soil fertility, and tree age).

As observed in West Africa, in the wet season bean weight increases in excess of 1 gram (Wood and Lass 1985). In Peninsular Malaysia there were periods of drought which resulted in low bean weight. Another point worth noting (Wood 1985) is that, when the bean weight exceeds 1 gram, there is little change in shell percentage and fat content, but in beans weighing less than 1 gram, the shell percentage increases and fat content decreases. As will be seen later, PNG beans suffer from high percentage of shell, which may imply a situation of slightly lower fat content in such beans, compared to those with lower shell content.

Shell Content

The shell content for cocoa beans in the areas surveyed is invariably high (Fig 3).

Manufacturers tend to prefer beans with low shell content since cocoa bean shells virtually constitute waste products. The shell content measurements yielded a mean value of 16% as obtained in the survey. This is rather high compared to Ghanaian beans which are usually reported to contain about 11-12% shell content. This marked difference is mostly due to the different planting materials grown in these countries.

Both the bean count and shell content are factors not likely to be affected to any great extent during the course of a normal fermentation process as practised throughout the cocoa growing Provinces. Any major improvement, especially the percentage shell content, can be achieved only through a plant breeding program.

% Moisture

The moisture as well as pH and T.A. measurements, are factors which are always going to be influenced greatly by the individual farmers, especially in the individual processing method.

High moisture values often result when a farmer does not adequately dry his/her cocoa beans. This condition is conducive to invasion by mould and should be prevented as much as possible. This can be achieved by adequately drying the cocoa beans to a safe moisture level of 6-7%. Mouldy and smoky flavours are equally unacceptable to manufacturers and may be much more undersirable than those defects associated with excessive residual acidity. This survey

found that the occurrence of underdrying of beans is greater than that of overdrying. It was estimated that 33% of beans registered moisture values of 8% and above, whereas only about 2 to 3% of samples recorded moisture values below 6%.The range of moisture levels obtained are as shown in Fig 4.

Cocoa beans which have been excessively dried often shatter when pressed even lightly between the fingers.This should also be avoided as cocoa beans dried to this stage may not be very presentable. Rapid drying should also be avoided as it tends to make beans retain excessive amounts of acetic acid which is deleterious to flavour.

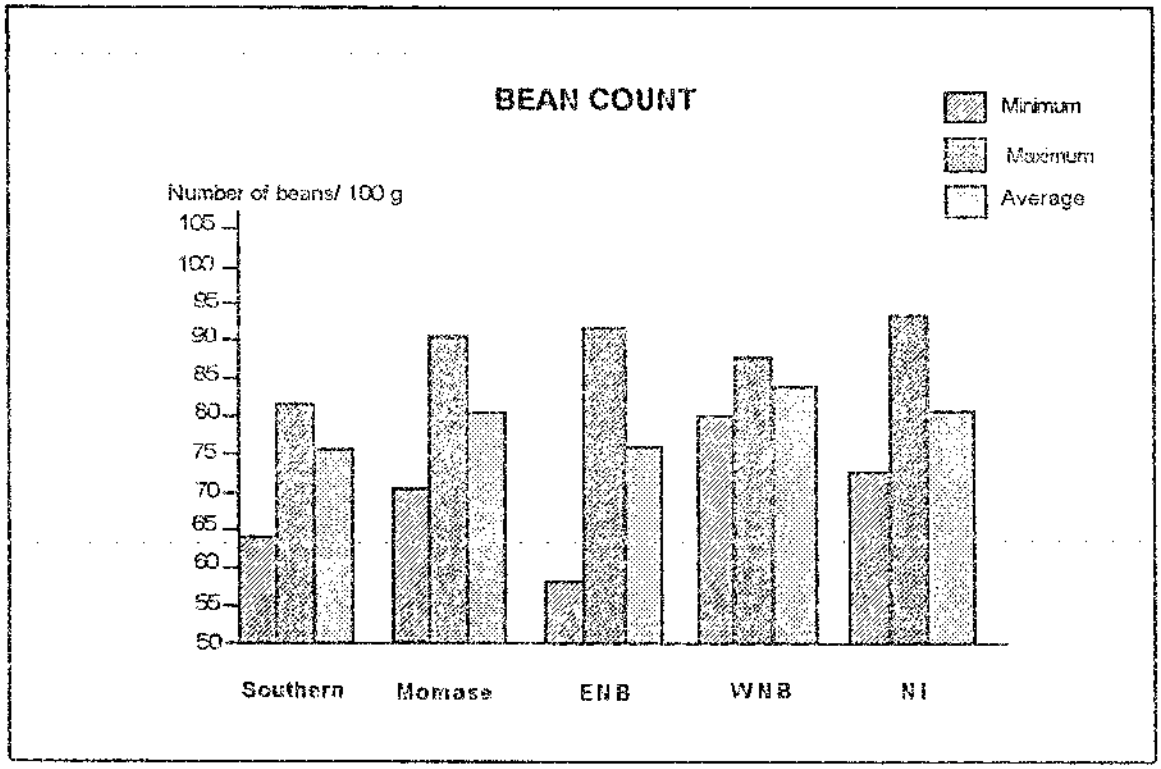
Acidity (pH and T.A. Measurements)

pH and T.A. measurements are both useful indicators of acidity. All cocoa beans are acidic to a certain degree, most to an extent that is acceptable to chocolate manufacturers. However, when the amount of acid in the beans is excessive, there will be an adverse effect on the flavour of the finished products.

In spite of the large range of pH values observed, the average values do indicate that the PNG beans are quite acidic in nature. From the survey, the mean pH value obtained was about 4.9.This is certainly acidic compared to pH values from Ghanaian beans which range from about 5.1 to 5.5 pH units. (It should be further noted that the relative strength changes 10 fold for each unit change in pH).

Figures 5 and 6 show the range of T.A. and pH values obtained. As often argued, high pH values do not necessarily indicate acceptable flavour.The measurement is of the degree of acidity and not of flavour, and should be treated with care. As a matter of fact pH values of well over 5.5 for PNG cocoa beans usually indicate a condition of over-fermentation which again is not acceptable, because of resulting "off"-fla-

Figure 2. **Bean count of cocoa in the areas surveyed.**



vours (mouldy odours) that are detectable.

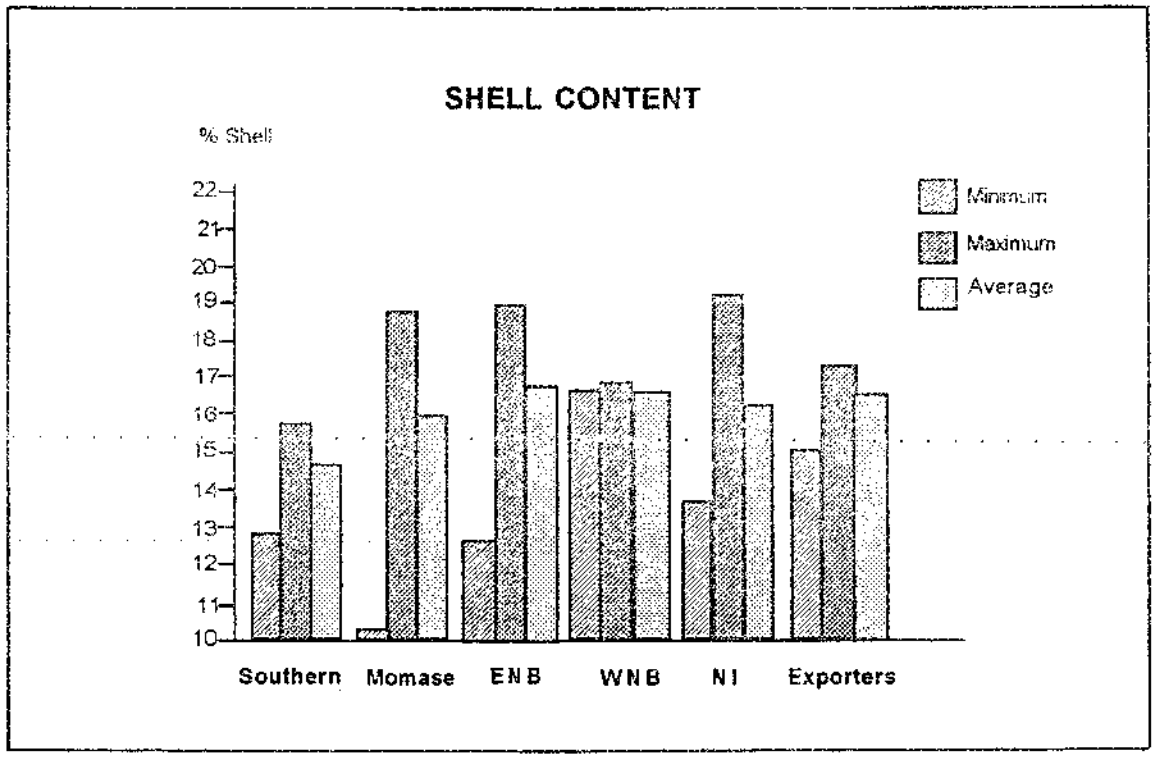
In practice, pH and T.A. measurements have been very useful in monitoring changes in bean acid level during the course of the fermentation process, and in such trials they have been found to be highly correlated.

For a comparison of the acid level in cured cocoa beans from different sources, measurement of total titratable acid is thought to be more useful than pH (Shepherd 1982). Doubts have infact been expressed (Carr & Dougan 1977) on the use of pH as an effective measurement of perceived acidity in chocolate derived from the cocoa beans. T.A. measurements on the other hand, have been shown to correlate very well with measurement of perceived acidity.

Both pH and T.A. measurements cannot, however distinguish between the individual acids that combine to produce total acidity. In cocoa beans there are a number of organic acids that contribute in varying degrees to total acidity (i.e. oxalic, citric, tartaric, succinic, malic, lactic, formic, acetic and butyric acids). Their contribution to the cocoa bean acidity phenomena depends on factors such as the degree of dissociation, buffer effects and relative concentration within the beans. It is felt therefore, that these factors warrant further investigations. Two of these acids, acetic and lactic, have been implicated in excessive acid flavour. In figure 5, the range and mean T.A. values expressed as milliequivalent per gram citric acid is presented. (note: 1 meq of citric acid is equivalent to 60.028 mg anhydrous citric acid).

The mean T.A. value of 0.18 meq/g (18 meq/100 g citric acid) obtained from the survey is considered to be relatively higher than that of the Ghanaian beans which usually have an average T.A. value of about 0.12 to 0.14 meq/g (12-14 meq/100 g citric acid). These differences in acid content could account for some of the differences, especially the acidic flavour, as per-

Figure 3. **The shell content for cocoa in the areas surveyed.**



ceived sensorially in the cocoa beans. It has, infact, been suggested (Lopez and Flavian 1984) that 12 to 15 meq NaOH/100g, could be a margin to aim for. According to their experiences, this value is in keeping with the desired pH range of 5.1 to 5.8 and the taste assessment results which showed reasonable acidity. On the basis of the fact that, in acid-base titration, one milliequivalent of a base will neutralise one milliequivalent of an acid, the average value of 18 meq citric acid per hundred gram of sample found in the survey samples would require an equal amount of base i.e. 18 meq of NaOH per hundred gram of sample.

CONCLUSION

With the absence of figures on fat content which was not studied at the time of this survey, little can be said about this very important quality factor. It is reported elsewhere that PNG cocoa bean does have an acceptable level of fat. The problem is in fact with the characteristically high shell content which tends to reduce the fat yield. The average shell content of about 16 percent obtained in the survey is very high compared to other world cocoa varieties. This, therefore, calls for relevant research to be undertaken through a breeding program to ensure that lower shell content and a correspondingly higher fat content are achieved. It is important to note also that any increase in fat yield would very likely lead to an increase in the price that manufacturers are prepared to pay since it is the most important economic criteria to both the chocolate manufacturers and the pressing industry.

In terms of the degree of acidity, the results clearly showed that PNG cocoa is high in acidity. Whether or not this is a serious economic factor will always remain a question for discussion.

There are definitely wide ranging demands from manufacturers for different cocoa flavours. The high acidic cocoa as produced in PNG continue to find its place in the international market along

Figure 4. **Moisture content of cocoa beans.**

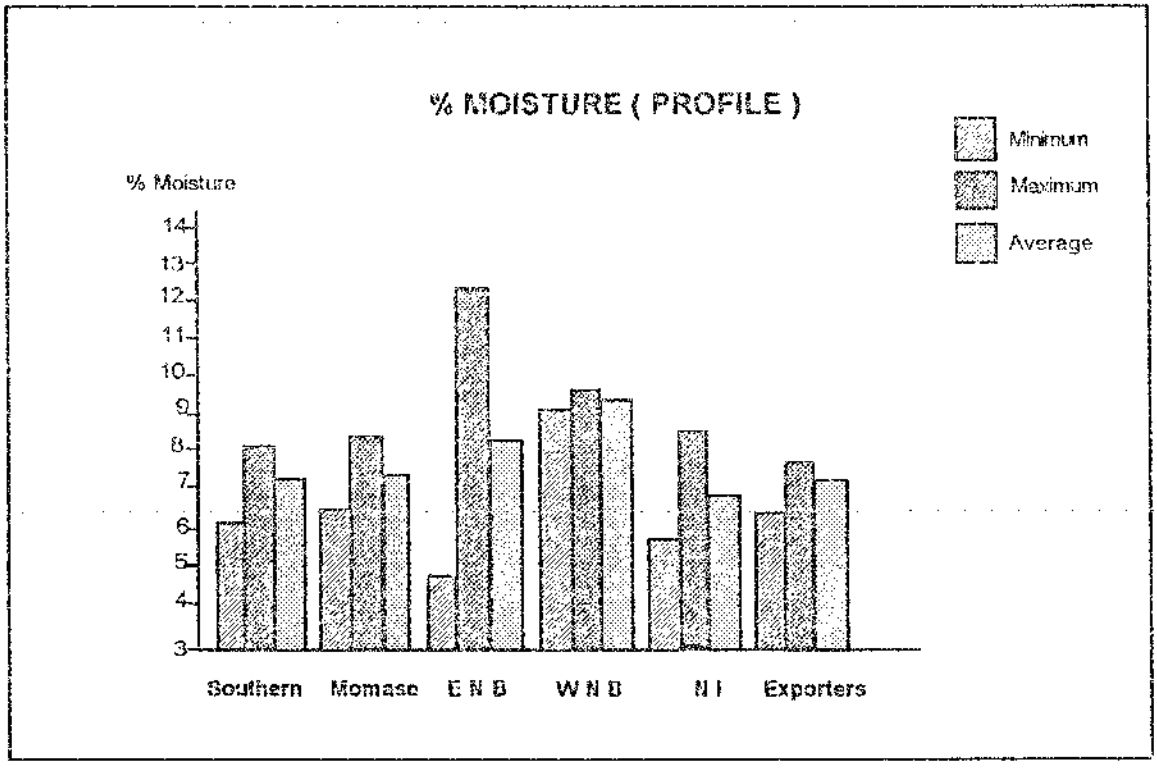


Figure 5. **T.A. profile of cocoa beans for areas surveyed.**

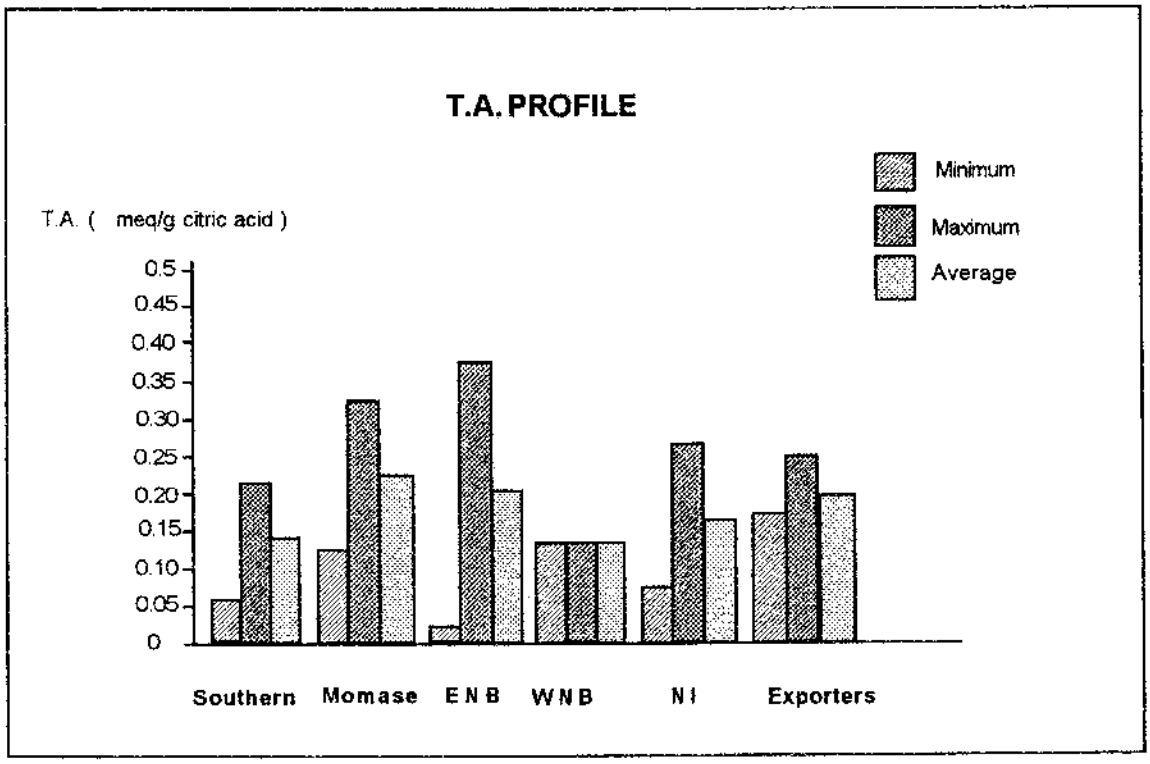
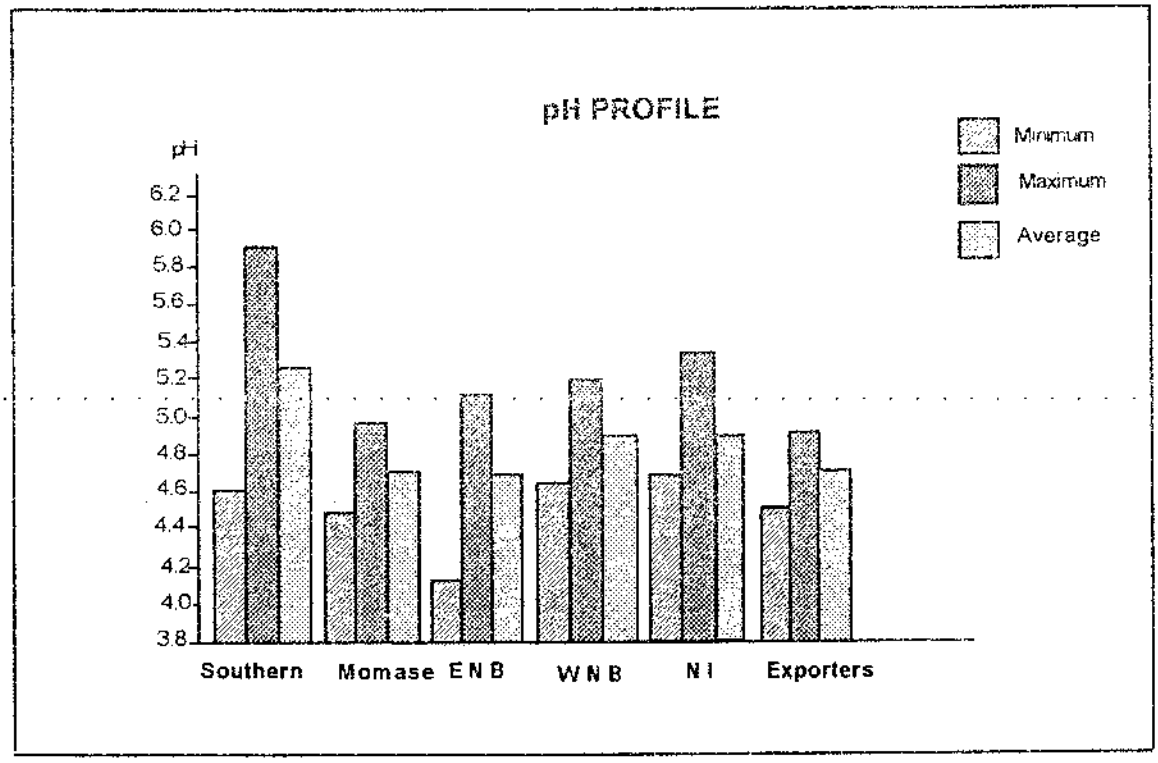


Figure 6. **pH profile of cocoa beans for the areas surveyed.**



with those "cocoas" from other countries which may be regarded as low acid beans. This does imply that PNG cocoa beans could be used by manufacturers in one way or an other.

It is clear that the question of flavour will always remain a subject of discussion, as indeed it seems to relate more to some specific flavour attributes (supplementary flavours) which each manufacturer seeks in his/her specific chocolate product. It may not always be possible for primary producers to know the specific requirements of each manufacturer in such a competitive market as this. For this reason the best the primary producers can do is to ensure that the cocoa bean supply is not masked to any great extent by any off-flavours including excessive acidity.

ACKNOWLEDGEMENTS

The Cocoa Quality Section and the Cocoa Quality Improvement Project acknowledge with gratitude the ongoing assistance provided by the Cocoa Board Inspectors in collecting the samples, and to the owners of fermentaries and the two cocoa exporters (Commodity Development Pty Ltd and Ag mark) for providing the cured cocoa bean samples in this survey.

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THE CURRENT STATUS OF THE PINK DISEASE (*CORTICIUM SALMONICOLOR*) OF COCOA IN PAPUA NEW GUINEA: A REVIEW

John K. Konam[1] and William Waine[2]

ABSTRACT

The Pink disease caused by Corticium salmonicolor *(Berk.& Broome) is increasing in prominence in some cocoa growing areas in Papua New Guinea. The characteristic symptoms, its distribution, host plants, aetiology and epidemiology are discussed.The need for hygienic cultural treatment of individual tree is stressed.The localization of the conditions of the disease in restricted areas is attributed to the local environment and the prior existence of the pathogen on other host plants. It was once a relatively insignificant cocoa disease but is now becoming more prominent in some parts of Papua New Guinea. It can be locally severe in young cocoa requiring thorough and careful treatment.*

***Key words**: Pink disease, symptoms, host plants, aetiology, epidemiology, distribution.*

INTRODUCTION

Little information is available in the literature on Pink the disease of cocoa caused by the fungus, *Corticium salmonicolor*, a fungus of the subdivision Basidiomycotina. The disease is commonly localized on the bark of host plants.Thwaites first noted the disease in 1873 on coffee tree bark (Schneider-Christians *et al.* 1983 a). It is now reported from many cocoa producing nations.The limited literature available on this disease probably reflects its relatively low incidence in the past and its low impact on cocoa production. However serious economic losses can be experienced, especially on young cocoa trees in localized areas.

There are no reports on economic loses caused by the pink disease in the Pacific Islands.This can be attributed to the fact that those who are involved in cocoa production often treat this disease as of minor economic significance (Henderson 1954, Brown and Friend 1973). In Papua New Guinea the prominence of the disease has increased reflecting the extensive planting that has taken place recently (Anon. 1987). Turner (1987) remarked that the disease has reappeared as a serious problem, particularly in North Solomons, with outbreaks in New Ireland Province, the Bainings and Pomio areas of East New Britain.

This paper reviews some of the literature available and discusses the writer's views on the current status of the disease in Papua New Guinea.

SYMPTOMS

Four different stages of the disease can be observed in the field.The first stage is often referred to as the cobweb stage which relates to the cobweb-like appearance of the mycelium (Fig. 1) and can be hard to detect. A silky whitish mycelium develops on young branches in particular.This growth can be boosted by humid and moist conditions. Under favourable conditions the mycelium can grow at the rate of 8 cm a week (Anon. 1989).

The second stage is called the Sterile Pustule stage which is characterized by the formation of pale pink to whitish pustules about 1 to 8 cm

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Figure 1. **First stage - Cobweb Stage**

Figure 2. **Second stage - Sterile Pustules Stage**

Figure 3. **Third Stage - Corticium Stage**

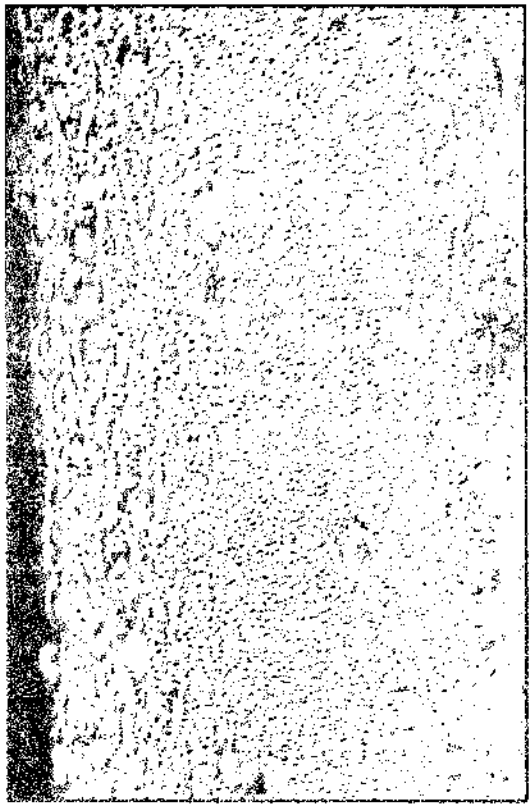

Figure 4. **Fourth Stage - Necatar Stage**

PHOTOS: *COURTESY OF PNG COCOA AND COCONUT RESEARCH INSTITUTE, 1991.*

behind the tips of the advancing hyphae of the 'cobweb' (Fig. 2).The pustules can develop longitudinally with small crack lines on the bark on both the upper and lower aspects (Henderson 1954). Unlike pustules on other hosts, those on cocoa have masses of cells packed one beneath another and do not separate easily in water (Anon. 1989).

The third stage is called the Corticium stage and is characterized by a bright pinkish-orange coloured crust developing on the lower aspects of the infected branches (Anon. 1989 and 1992). The colour makes this stage easy to identify (Fig. 3). With increasing age and intensity of infection the crust can reach a length of up to 2 metres. The crust is formed by the bascidiocarp of *C. salmonicolor* which is hard when touched. The pink colour can fade to white and the crust can crack into small pieces with the onset of drought or due to ageing.

The final stage is an asexual stage called the Necatar stage. It is characterized by orange pustules on the top aspect of the infected branch with small empty crater-like pockets through the bark with a diameter of 1 to 1.5 mm (Schneider-Christians *et al.*1983 b).The pustules contain conidia which can be easily separated and dispersed by water.

The characteristic diagnostic features of this disease includes the dark brown leaves and the pink crust which can remain attached to the tree for a considerable time on the affected branches (Brown and Friend 1973). Pink disease rarely causes death of mature trees but can kill those under the age of five years (Anon. 1983). Internally the wood of the affected branches becomes dry and brown. The leaves at the tip of the affected branches can turn dark brown and die, but commonly adhere to the branch (Fig. 4). The infected branch often shows split bark, withered leaves and dead infected areas (Henderson 1954; Brown and Friend 1973).

DISTRIBUTION

Though it has a wide distribution, extending as far as the Caucasus in Europe and the South Coast of New Zealand (Schneider-Christians *et al.* 1983 a; Seth *et al.* 1978), its main distribution is throughout the humid Tropics (Brown and Friend 1973). Sharples (1936) considered the causative fungus to be native in most areas but has spread to introduced host species such as cocoa.

In the Pacific Islands it was first reported on cocoa in Fiji by Morwood (1956). The causative pathogen was then called *C. litaco fuscum.* Johnston (1960) reported the disease from the Solomon Islands. Schneider-Christians *et. al.* (1983 a) reported the disease from Western Samoa.The disease was reported in Papua New Guinea by Henderson (1954) and Shaw (1963). Apparently, the disease is more prominent in certain areas than others in Papua New Guinea (Turner 1987) although the disease has a wide distribution in the country (pers. comm., visiting Field Officers). The prominence of the disease can be attributed to the local weather patterns, environment and prior existence of the pathogen on other host crops before cocoa was introduced.

HOST PLANTS

There are more than 100 different host plants. Some of the tropical host plants are: *Amherstia nobilie,* soursoap, custard apple, hoop pine, jackfruit, tea, *Cassia sp.,Hibiscus*, many *Citrus sp., Crotolaria, Tephrosia* and *Loquat, Gardenia,* silky oak, *Herma*, mango, cassava, pepper, African tulip tree, Cocoa, Rubber, pigeon pea, coffee, citrus, *Gilricidia sp., Leucaena sp.* and Avocado and many unidentified roots. (Henderson 1954; Brown and Friend 1973; Seth *et al.* 1978: Anon. 1991).

AETIOLOGY

Many aspects of the epidemiology and aetiology of the disease are uncertain, with conclusions reached from subjective observations and deductions becoming accepted as proven in the absence of adequate experimentation. The lifecycle of this fungus would appear to be uncomplicated and is largely governed by the weather. Under wet conditions, the basidiospores upon landing on a susceptible part of the plant, particularly young bark, will germinate producing whitish mycelium. Spore germination can be vigorous in the presence of sucrose (J. Dennis

and W. Waine, pers comm.) simulating the effects of honeydew on cocoa bark. In a humid and moist environment, the mycelium can grow at a rate of 8 cm per week (Anon. 1989). With a prolonged wet weather, the mycelium can form pale pink to whitish pustules behind the tips of its advancing hyphae. Given time and with increasing intensity of infection the pinkish pustules can produce a basidiocarp which is often bright pinkish-orange in colour and crust-like. This crust contains basidiospores which are sexual spores and have the potential of initiating a new infection.

In dry weather, the pink colour can fade to white and forms empty crater-like pockets containing basidiospores which maintain viability of the fungus during unfavourable conditions. With excess water, the basidiospores are easily released to complete the cycle.

EPIDEMIOLOGY

The basidiospores of the fungus (9-12 µm x 6-7 µm) develop on the pink crust and may be dispersed by wind or rain (Brooks 1953; Brown and Friend 1973; Schneider-Christians *et al.* 1983 c; Anon. 1989).

It is common for the crust to be sterile and devoid of spores (Sharples 1936; Shaw 1963) but when fertile, the pink incrustation is rather thick and has uniform surface with scattered basidia bearing the basidiospores. When dry, the pink incrustation cracks into larger pieces than the sterile incrustation (Sharples 1936).

Under a cold environment, the fungus can produce conidia on bright orange-red pustules that protrude through the bark on the upper aspects of the infected branches (Brown and Friend 1973).

Luz and Ram (1980) state that wet and humid environment with shade and cool temperatures promote the disease but Schneider-Christians *et. al.* (1983 b) found that a humid environment alone may not promote the disease. This suggest that all environmental parameters may collectively pre-dispose the plant to the pathogen and that if one factor is less favourable the pathogen itself may not become established.

Rao (1974) found that basidiospores of *C. salmonicolor* were only released during or after a rainfall. The disease incidence on rubber and eucalyptus was abundant in areas of high rainfall (Sharples 1936, Seth *et al.* 1978). The qualitative and quantitative dependence of basidiospore release on the amount and time of rainfall certainly exists but light rainfall (<1.5mm) of short duration (< 2 hrs) can result in the greatest number of spores being released (Luz *et al.* 1985). Schneider-Christians *et al.* (1983 b) and Luz *et al.* (1985) found that rain fall may play an important role in the dispersion of the initial inoculum but was not the primary physical agent of the pink disease dissemination during its period of major activity. It is unlikely therefore, that rain is the sole agent of spore dispersal. Hence wind and insects could be the possible agents of dispersal (Simmonds 1931; Rao 1972; Mordue and Gibson 1976).

Basidiospore production can be prolonged if enough moisture and shade are available (Luz *et. al.* 1985). Free water availability is important for spore release from the basidium and for germination of basidiospore (Rao 1972, Schneider-Christians *et al.* 1983 b, Luz *et al.* 1985). Basidiospore production is favourable within the temperature range of 18 to 32°C and that the disease is most prevalent in densely shaded areas, particularly under natural bush shades (Rao 1974).

It has been suggested that young plants are highly susceptible to the pink disease, particularly those 18-30 months old (Anon. 1983). This susceptibility may be correlated with the phase of growth which is marked by considerable development of woody tissue. In the older plants, the disease commonly occurs on young branches undergoing lignification.

CONTROL

Chemical: Chemical and cultural control of this disease are widely practised. In some countries, fungicidal sprays and paints such as tar or bordeaux mixture are used to treat the disease on rubber.

Potassium is shown to have some physiological role in the process of lignification and it has been suggested that susceptibility to pink disease

may be associated with nutritional stress where a low level of Potassium may be particularly critical (Anon. 1983). Lower disease incidence has been reported in plots that were treated with fertilizers than in untreated plots (Anon. 1983). Therefore, the disease may be dependent upon the soil fertility and thus the manipulation of soil nutrients be important in the control of this disease.

In Malaysia, Calaxin was reported to be effective in controlling the pink disease on rubber (Wastie and Yeon 1972). It is often used as a paint which can remain active for up to 4 months. It was found that brush-on formulations incorporating Calixin with natural rubber latex as a binder promised positive results. Yeon and Tan (1974) reported a similar finding in Western Samoa where brushed-on formulation incorporating calixin with natural rubber latex as a binder was used. However, in Western Samoa there have been indications of phytotoxicity despite the control conferred by the treatment (Anon. 1983). Thus Calixin may have disadvantages as a control agent.

In practice, copper gives very good control and is the cheapest fungicide available. In Papua New Guinea, promising results are reported from field trials on young cocoa with Calixin and bordeaux mixture (J. Dennis, pers. comm.). Attempts at using PA injection did not provide a feasible protective measure at Karu Development in the New Ireland Province (Anon. 1989). Curative and prophylactic spraying and painting with copper-based fungicides can be partially effective but does not kill the fungus thus suggesting the need for integrating chemical control with cultural control methods. However many host crop plants of this disease are cultivated in this country and thus eradication of the pathogen is impractical as the pathogen will always take refuge in the various host plants available. It is likely that this reservoir will be the source of future outbreaks of the disease.

CONCLUSION

It is most likely that this disease has existed in all the cocoa growing areas of Papua New Guinea for decades. The low impact of the disease on cocoa production in most cocoa growing areas of Papua New Guinea suggests the need to develop control strategies that require minimal effort for controlling the disease. Such control measures could be the use of biological control systems or the use of moderately resistant genetic material which will suppress and maintain the pathogen's population at low levels at a minimum cost. Future research should be orientated in this direction.

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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

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