REVIEW OF SWEET POTATO DISEASES AND RESEARCH IN PAPUA NEW GUINEA

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ABSTRACT

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

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

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

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

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

INTRODUCTION

1. Background

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

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

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

2. Diseases Caused by Fungi

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

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

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Table 1. Important diseases of sweet potato.

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

Table 2. Minor diseases of sweet potato.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.6 Postharvest Diseases

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

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

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

3. Diseases Caused by Phytoplasmas

3.1 Sweet Potato Little Leaf or Witches' Broom

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

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

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

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

4. Diseases Caused by Viruses

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

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

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

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

4.1 History of Viral Tests

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

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

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

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

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

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

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

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

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

5. Diseases Caused by Bacteria

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

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

6. Diseases Caused by Nematodes

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

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

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

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

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

CONCLUSION

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

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

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

* local varieties

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

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

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

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APPENDIX 1.

Microorganisms Recorded on Sweet Potato in Papua New Guinea

(i) Records of Fungi

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

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

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

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

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

A. sesami - Kokoa 2002)

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

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

Alternaria sp. - Dieback (Joughin and Thistleton 1987)

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

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

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

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

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

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

Aspergillus repens - Tuber rot (Shaw 1984)

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

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

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

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

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

Botryosporium longibrachiatum - Stem rot (Shaw 1984)

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

Ceratocystis fimbriata - Unstated (Shaw 1963)

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

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

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

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

Ceratostomella fimbriata - Unstated (Shaw 1963, 1984)

Cercospora sp. - Leaf spot (Pearson 1979)

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

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

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

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

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

Corticium rolfsii - Collar rot (Shaw 1984)

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

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

Cylindrocarpon destructans - Tuber rot (Waller 1984)

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

Diaporthe phaseolorum - Tuber rot (Shaw 1984)

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

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

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

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

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

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

Fusarium sp. - Dieback (Joughin and Thistleton 1987)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

G. cingulata - Stem rot (Waller 1984)

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

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

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

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

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

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

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

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

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

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

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

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

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

Penicillium crustosum - Tuber rot Shaw 1984; Kokoa 2001)

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

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

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

Penicillium islandicum - Tuber rot Shaw 1984; Kokoa 2001)

Penicillium simplicissimum - Tuber rot Shaw 1984; Kokoa 2001)

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

(ii) Records of Phytoplasmas

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

(iii) Records of Viruses

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

(iv) Records of Bacteria

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

(v) Records of Nematodes

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