
**Fusarium wilt of banana in Australia**

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**Summary**

Approaches to manage outbreaks of fusarium wilt of banana in Australia and current research towards long-term disease management strategies are summarised in this paper.

Keywords: Fusarium wilt, banana, Australia.

**Introduction**

The first recorded description of the fungal disease of banana known as fusarium wilt or 'banana disease' was made in 1876 by Dr Joseph Bancroft from the 'Soyar' banana variety (thus 'Soyar Banana', AAA) in Brahmap, Queensland, Australia (Bancroft 1876). Since this time, production of the popular banana varieties in Australia (Cavendish, Lady Finger, Dacron and Sunga) has been constrained, at times severely, by various strains of fusarium wilt. The Australian banana industry is primarily based on the Cavendish (AAA) group with only 12% of local domestic markets for the Lady Finger variety (Fuchs Nudus, ABB from the Pink subgroup). Figures released in 1995 for the Australian banana industry showed 2400 growers with a total of 17,300 hectares under production in the states of Queensland, New South Wales and Western Australia and the Northern Territory (ABGC 1996). Annual production was in the order of 250,000 tonnes of fruit (574 million kg).

Early research on fusarium wilt of banana in Australia was largely carried out by the Queensland Department of Primary Industries (QDPI) and more recently also through the New South Wales Department of Agriculture, Queensland University of Technology, The University of Queensland, The University of Western Australia and other State and Territory government departments. Australian researchers have worked closely with banana growers and extension staff to focus research on industry priorities and ensure adoption of research outcomes. Over the past decade the human and funding commitment to better understanding and managing this disease have been considerable. Currently in Australia, there are annual disease surveys (including plant pathologist, molecular biologists, horticulturists, tissue culturists, physiology, agronomists, and biotechnologists) assisted by some 2000 new (fusarian) national and international (well involved) in various aspects of research on fusarium wilt of banana. This paper summarises some
of the current research and approaches to management of Fusarium wilt of
forages in Australia.

Pathogen diversity and distribution

Techniques used to characterise other fungi (Corey et al. 1987)
have been adapted and used to divide the strains of FOC into meaningful
subgroups in order to identify the different strains of this pathogen found in
Australia (Bentley et al. 1994, Kesh et al. 1996, Maier et al. 1996, Pegg et al. 1996). These subgroups were identified by means of a variety of
molecular characterization techniques. In the past decade, these methods
have been refined and many more subgroups identified than those previously
reported (Bentley et al. 1994a, this proceedings). The diversity and distribution of populations of FOC in Australian pastures is now well characterized with several FOC subgroups identified in vegetative compatibility groups of L. leucocephala,
volatile production, DNA amplification fingerprint (DAF) techniques and
field observation of pathogenicity.

The two FOC pathotypes belonging to VCGs 0123 and 0212 are non-volatile
producing and are widespread throughout eastern Australia. Strains in this
very closely related non-volatile producing, VCGs 0123 and 0122 are
narrowly distributed in a small number of areas in northern Queensland and
New South Wales (NSW) and in Carnarvon in Western Australia, respectively
producing race 4 pathotypes belonging to VCGs 0212, 0129 and 0212 and are
present restricted to the Saroa-grown regions of southern Queensland and
northern NSW. These have not yet been recorded in the major Carnarvon-
production areas of northern Queensland or the emerging production areas
of Carnarvon and Busselton in Western Australia to date. Sources in the
Northern Territory. The strains of FOC known as ‘harmful’ race 4 have
recently (1995, 1996 and 1997) been confirmed at three sites near Darwin in
the Northern Territory. Isolates of this Carnarvon-comparable strain of FOC
produce volatile metabolites and belong to the VCG 0212 or 0212 (see
paper by Corey and Phillips in these proceedings). These are the only
recorded cases of this strain of FOC in Australia although it is widespread in
the states of Kalbarri and perth region of Western Australia in citrus.

The application of molecular methodologies, we have been able to
confirm the stable nature of VCGs of FOC in Australia over time (see paper
by Bentley et al. in these proceedings). From VCG and DNA fingerprint data
from isolates from other origins, we have also been able to surmise that this
pathogen did not originate in Australia but was rather introduced by man
and spread over the likely origins and distribution of these pathogen. Also,
the extensive DNA fingerprint library has been used to develop VCG
capable primers in order to develop a DNA detection system for the common
strains of FOC. In addition, strains of FOC have also been characterized by
restriction endonuclease analysis of the intergenic spacer (IGS) region of the ribosomal DNA (see paper by Bentley et al. in these proceedings).

Disease management strategies

Management of this disease in Australia is based around three key strategies: 1) early detection and containment of outbreaks of banana wilt and application of protocols to prevent introduction of FOC into disease-free production districts; 2) adoption of disease management strategies for farms with banana wilt to maintain production; and 3) conduct research to evaluate and develop long term disease management strategies for the Australian banana industry.

1. Prevention, detection and containment

Local quarantine measures are in place in banana production areas of Australia to restrict the movement of banana planting material (particularly suckers and rhizome pieces). Australian banana growers require permits to move planting material to facilitate root quarantine work. If vegetation material is used (e.g. suckers or rhizome pieces) this must be from a certified source of "clean" planting material. These protocols appear to have been successful in preventing the Cavendish cultivar race 4 strain of FOC (VCGs 0120 and 0129) from becoming established in the production districts of north Queensland where the majority of the Australian Cavendish industry is located. In Australia, banana growers and local department of agriculture officials are encouraged to avoid specimens from any plant suspected of FOC wilt to the DPI weed control laboratory for analysis. This enables new outbreaks to be mapped and the distribution of the different strains of FOC to be monitored, and any new or exotic strains of FOC to be detected (e.g. the new strain in a Cavendish plantation in the Northern Territory that were caused by VCG 0120/16 see paper by Costil and Pilkington in these proceedings).

2. On-farm disease management

Provided the strain of FOC involved in an outbreak of banana wilt is not a quarantine or exotic strain or the property concerned is not beyond a defined local quarantine zone, banana production is allowed to continue. Australian banana growers are advised to follow simple yet practical measures to contain and the spread of the disease and to control the productive life of the plantation.

After removing possibilities for spreading the pathogen to other farms (e.g., drainage of planting material or irrigated soil and, if possible, contaminating or diverting contaminated drainage water), the primary concern is to minimize the spread of FOC within the affected farm. The common procedure in Queensland and New South Wales is to dig up all affected plants from the infected block and, if an otherwise healthy block is to immediately inject the affected plants with
buticide (e.g., Nufinup®/ glyphosate) and let them die in situ without further chopping or disturbance of the plant. Often a single or double ring of healthy plants around the affected ones may also be injected or otherwise treated with herbicide and allowed to die in place. This has the useful effect of containing the pathogen and reducing its spread. However, clearing the affected area and also reducing the population of the fungus at that site by killing its preferred host plant. It is important that the affected plants and the soil around them be disturbed as little as possible to minimize any disturbance and movement of soil will increase the chances of moving the pathogen. Picking or removing the areas that suggest workers or visitors to keep out, reducing the risk of contaminated soil accidentally being moved to farms or machinery or in vehicles. If appropriate, these areas also need to be fumigated or other means, e.g., bags and sealed sheets, used to control the spread of the pathogen throughout the plantation, particularly in wet weather.

If POC has infected some plants at a site, it is very likely to be present in some of the soil surrounding those plants. Any suckers that subsequently emerge from the herbicide-treated plants must also be treated in order to kill the pathogen completely. Where it is feasible, it is helpful to cover the infected patches with a plastic sheet or cover, ensuring that the herbicide is applied to the surface of the soil after the banana plants die. Where practical, plastic sheeting may also be used to cover the affected areas to prevent new bamboo growth and changing the order to which the plantation blocks are worked so that infected patches are worked after disease-free ones.

Such measures are simple but if they are carried out immediately and with a high degree of vigilance, growers have an excellent chance of minimizing the pathogen's reproduction and movement within and to other plantations.

Banana growers must not be tempted to use planting material from known infected plantations. If suspected, the affected blocks must be considered an unacceptable risk.

When a plantation block has many wilted plants dispersed throughout, it is advisable to remove the plants as quickly and carefully as possible. This is usually done by digging them out and then digging out the surrounding soil to remove the pathogen. To clear the affected areas and prevent other plants from becoming infected, the soil and nursery waste from that plantation soil remains as a source of POC for some time after, possibly for several decades.

If disease-free areas are available, disease control is very important to prevent the spread of disease. The key to
The disease, known as fusarium, is a fungal infection that can affect a wide range of plants. The symptoms include stunting, discoloration, and death of the plants. The disease is spread through contaminated soil, water, and plant material. The following are some measures to prevent the spread of fusarium:

1. **Sanitation:** Ensure the area is free from fusarium. This can be achieved by:
   - Using only certified disease-free vegetative planting material or tissue-cultured plants to initiate new plantations. The location of the nursery and the surrounding area should be carefully considered.
   - Placing new blocks or plantings at a distance from affected or suspected blocks to avoid the spread of the disease.
   - Keeping irrigation water that drains from disinfested blocks away from new or adjacent blocks if possible.
   - Providing nursery blocks or areas to facilitate the early detection of new outbreaks.

2. **Chemical Control:** The use of fungicides is recommended to control fusarium. The fungicide product should be applied to the affected plants to prevent the disease from spreading further. The application should be done at least every 2 weeks, starting 2 weeks after planting and continuing until harvest.

3. **Monitoring:** Regular monitoring of the plantations is important to detect the disease early and take appropriate action. This can be done through visual inspection, using diagnostic tools, or by conducting chemical tests.

4. **Education:** Educating workers about the disease and its control measures is crucial. This includes providing training on proper handling of plant material, the use of fungicides, and the importance of maintaining a disease-free environment.

By implementing these measures, the spread of fusarium can be minimized, and the health of the plantations can be preserved.
the environment associated with their use and can cause corrosion of equipment and vehicles if used over long periods. Fumigants offer a far safer alternative and does not require registration for use in Australia. It is also biodegradable and does not cause corrosion. No agents should be seen as a substitute for the physical removal of contaminated soil or infected plant matter from boots, vehicles or equipment, but rather as giving optimum results of 'sterilisation' when used in conjunction with cleaning or washing practices. Where Fumigants is not available, efficacy trials will need to be conducted with other equivalent agents to determine effective substitutes. Adopting more hygienic farm practices not only retards the spread of disease, but also reduces disease and costs as well.

Anecdotal evidence from Australian plantations suggests that fumigants that are used to "kill" plants (e.g., excessive applications of nitrogen) also increase the incidence of bionisation will in affected plantations. In most past, extreme conditions and practices have exacerbated the interaction between the host plant, the pathogen and the prevailing environmental and growing conditions. Modern agriculture practice often interfere with that balance and indiscriminately harms the spread and intensity of disease such as bionisation. Despite the balance between the natural cycles of the plant, its own defense mechanisms will keep the pathogen at a low level as possible. Where growers wish to maintain productivity or sustainable returns as an extension to this, they often resort hypoponization of nutrients, fertilizers, but this in turn can lead to suctioning in bunch size, fruit quality and financial return.

As for many diseases, resistant or tolerant banana varieties offer the only long term and environmentally acceptable solution for control of this disease. Where such varieties have not been available, plantation owners have managed the disease on susceptible varieties for many years through a combination of bioponization and disease management practices along with soil detection and containment of new outbreaks. Conversely, if inoculated practices are followed (e.g., no movement in taken to all), the disease will continue to spread around the farm and eventually to neighboring farms.

3. Research towards long-term disease management strategies

3.1 Field trial evidence: Extensive field evaluations have been conducted in Australia to identify sources of resistance to 'race' 1 (VCG 0124/5) and 'race' 7 (VCG 0124/5) in Australian and advanced hybrid (including tetraploid domesticances and triploid S/LK). Some desert bananas have been imported through the Australian Quarantine and Inspection Service (AQIS) and established at field sites in northern NSW and southern Queensland. The site chosen for field evaluation were commercially productive plantations that developed high levels of bionisation with different inoculum (VCG 0124/5 at Caldog and Farrowah and VCG 0124/5 at Whambean).
Once they have cleared the post-entry quarantine process, tissue culture-derived plants are raised in petri-dish setting in glasshouses until the 4th leaf stage (or approximately 30-50 cm in height) when they are taken to the field site for planting during the October to November period as part of the commercial production routine and inspected monthly for the development of external symptoms of Fusarium wilt until at least harvesting of the first ratoon crop is completed (fortnightly inspections are made during the warmer summer months of December to February). Trial designs and reference cultivars are available in the INIBAP guideline (Oyade 1996).

Specimens of infected plants are sent to the INIBAP quarantine facility for isolation and VCG analysis. This process confirms the disease but also enables monitoring to ensure that no other strains (VCGs) of the pathogen have been introduced to the site. Over many years of testing diverse new germplasm at the field sites, we have not recovered any strains of FOC that either are different from, or more virulent than, those that were originally present. After harvest of the first ratoon bunches, surviving plants are cleared out of the plots and new plants are used to replace any that succumb to Fusarium wilt disease and recolonize sites for evidence of vascular colonization due to FOC. The INIBAP rating scheme for Fusarium disease is used (Oyade 1996). In collaboration with the INIBAP Laboratory of Plant Pathology under the direction of Dr. Gosnell, plant crop and first ratoon bunches from varieties growing in the FOC trial sites are sent for post-harvest fruit quality evaluations.

Four standard hybrids have shown good levels of resistance to FOC at both the first and ratoon field evaluation sites in Australia. These are FHIA 11, commercially marketed as Gold Finger in Australia), FHIA 18 and SH 3460-10 (known as ‘High Nearer’ in South Africa) from the FHIA breeding programme in Honduras, and the ‘Kakuna’ derived plantation variety (Mill 526-1) which was bred by the BFA breeding programme in Nigeria. ‘TNR 1299-1’ appeared to be more compromised by the cold winter conditions in sub-tropical production areas than those from FHIA varieties. While SH 3460-10 showed few external symptoms consistent with FOC infection at the first site and produced good bunches, when the plants were internally examined many were found to be infected with FOC with diseased vascular tissues apparent in the rhizomes and pseudostems. In contrast very few plants of SH 3460-10 at the first site showed internal symptoms after destructive sampling. The tetraploid banana varieties FHIA 17 and SH 3465, also from the FHIA programme, showed resistance to race 1 of FOC but more than one-third of the plants of both these varieties became diseased at the first 4 evaluation site. Conversely, the FHIA variety SH 3060 was susceptible to race 1 of FOC, with more than half the plants tested developing symptoms within the first 12 months, but this variety showed good resistance to race 1 of FOC, as does availability. The disease varieties on 03-22, PC 12-05 and PV 03-48 developed by the EMBRAPA-CNPFF
breeding programme in Brazil showed good levels of resistance to race 1 of POC in our trials.

The field evaluation of three tropical dessert varieties from the CIARAD-FLORAS breeding programme in Cordoba, Cordoba (BBSA 999, 970 and 954) could not be completed since these varieties all developed pronounced symptoms of banana streak virus (BSV) at both field sites during 1996. In line with Australian banana industries, all plants were destroyed and will not be able to be retransplanted until BSV free genotypes become available. This is most unfortunate since two of the varieties (BBDA 997 and BBDA 994) were showing little evidence of fungus wilt symptoms at the time of their destruction. The BBSA 970 plants, however, developed disease symptoms at both evaluation sites.

Varieties that have completed evaluation bear have shown little resistance to either race 1 or 4 of POC in our trials include FIBA 02, FIBA 05 and FIBA 06.

The breeding lines FIBAs 02 and 05 bear promise to be highly resistant to black sigatoka (Phytophthora parasitica) (J. Rixon, pers. comm.) and are currently being evaluated in Australia against race 1 of POC with Lady Finger, Gold Finger, FIBA 19 and SH 3640-10 for comparison. It will be monitored at the race 4 site in future trials.

Although the trial design for assessing POC reaction is different to that for leaf performance evaluations (Ono et al. 1998) Lady Finger, FIBA 19 and TMB 255-1 developed very little yellow sigatoka leaf spot (Phytophthora muscula). However, the POC field evaluation trials which are not exempt for leaf disease, significantly more leaf spot was apparent on SH 3640-12 at both field sites.

3.2 Reviewed research: We are still a long way fro understanding and applying effective, long term biological control mechanisms for POC. In current research projects in Australia, biological agents are being investigated for their potential to improve the vigour of banana-cultivar derived banana plants and their resistance to POC nematodes. Micropropagated bananas are increasingly being used by the Australian banana industry as a source of disease and pest-free planting material. Recent work has shown that micropropagated bananas are more resistant to POC (G. West, pers. comm.) and are less tolerant of Rhizoctonia solani (G. West, pers. comm.) and nematodes [Halusciak, pers. comm.] and are more resistant to fungi than conventional planting material.

Projects currently under way aim to isolate beneficial microorganisms from plantations growing in wet and nematode suppressive soils with the goal of introducing POC to micropropagated plants at the nursery stage before planting in amended fields, in order to obtain more vigorous
plants that are better able to utilize nutrients and with greater protection against disease.

Plantations of the Lady Finger variety in southern Queensland and northern NSW where race 3 (VUG 1606/3) is known to be prevalent have been planted at sites where disease does not develop or has developed only slowly over time. Now described as having 'well suppressive' soils, conventional vegetable plantings maintained on such soils are now referred to as 'well suppressive' soils may be protected by the presence of beneficial microorganisms such as fungi and bacteria that are not available to micropropagated plants that are raised in an open environment.

In an attempt to better understand how the mechanisms operate in these soils, research is underway into the microorganisms present in these soils. In particular, the studies being conducted through the DPI and CRCIPP are investigating mycorrhizal fungi, non-pathogenic strains of F. oxysporum, and bacteria that are present as endophytes in the roots of banana plants in well suppressive plantations. Several hundred isolates have been tested, from the roots of newly grown plants. Twenty endophytic strains of F. oxysporum have been obtained for testing. Of these, four isolates have provided additional levels of protection for mature Cavendish banana plants inoculated with race 4 of FOC in glasshouse trials. None of the strains afforded the plant immunity from disease and none of the isolates tested to date have afforded Lady Finger plants significant levels of protection against race 1 of FOC. The size of the collection of endophytic strains and the lack of significant protection against race 1 of FOC is not surprising given the development of the endophytic isolates. New protocols for a reliable, small plant test would expedite these studies. Ultimately, the isolates which give the greatest levels of protection to plants in the glasshouse, will be introduced to tissue cultured plants and then assessed in disease field conditions.

One hundred and thirteen bacterial isolates have been recovered from the banana root system and examination of plants growing at FOC suppressive sites. Thirty isolates have been selected for initial evaluation based on results from four tests that included inhibition of FOC, in vitro, disease suppression of resistant banana cultivars, and correlation to disease in the field. Protocols for assessing the potential of these bacteria to protect tissue culture-derived Lady Finger plants against infection by race 1 of FOC are being developed. So far 13 isolates have been tested and of these, one strain, has been shown to provide partial protection to Lady Finger plants in glasshouse trials. These studies are continuing to test the potentiality of the results. Also, mycorrhizal cultures are presently being collected from banana roots and maintained for incorporation into banana plants.

In associated projects, Dr. John Johnston and Mr. Tony Pattison in cooperation with Dr. Mike Smith and Ms. Linda Smith of the DPI, have isolated 30 non-pathogenic isolates of F. oxysporum from banana roots.
growing in soil which is suppressive to K. stellaris. These isolates are currently being tested for their ability to inhibit reproduction of K. stellaris on banana plants in pots. Thus far, at least one isolate has inhibited nematode reproduction but is affected by plant age and relative inoculation levels of the fungus and the nematode. Biologically, bacteria isolated from suppressive soils will also be assessed for their ability to reduce nematode reproduction.

Biofertigant crops such as Vetch (Vicia villosa L.) or mustard (Brassica L. spp) have been shown to have a deleterious effect on some soil-borne fungal pathogens in Australia (Adams & Hardy 1999, Kebreab et al. 1999) where they are used as a green manure crop in crop rotation strategies. However, their potential to reduce the populations of FOC in soil and the long term effect on populations of FOC in soil after incorporation of such crops has not yet been investigated. While such steps may not be applicable in perennial production systems, they may have potential to treat affected areas before replanting, with different crops or in allowing the production of sustainable yet highly disease tolerant strains to continue in areas where FOC control and alternative varieties are not acceptable.

Biological options for disease control would be particularly appropriate for sustainable agricultural practices, particularly where they offer an alternative to the use of chemicals such as nematocides and fungicides. To undertake studies into biological agents for disease control in banana will require a long term program of research in collaboration with experts in other disciplines such as soil microbiology, biochemistry and plant physiology.

5.5 Systemically Acquired Resistance: Research efforts are currently underway through the DPI in Australia and with colleagues in South Africa to investigate plant resistance mechanisms (such as SARDP) for their efficacy in protecting plant roots, rhizoma, culture (stolon) banana plants from FOC attack and the development of systemic resistance (SAR). Preliminary evaluation of these agents against FOC in bananas is yet to be completed. However, early results with banana cultivar-determined plantlets in controlled environment chambers have shown that the application of SARDP prior to inoculation provided significant levels of protection against root 4 of FOC for at least six weeks after inoculation. This study will also provide new information on the potential of this treatment for use in the field. Further research and development of SAR and SAR resistance can be maximized by ‘booster’ treatments of BDN throughout the season.

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