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Fusarium Wilt of Banana – An Integrated Approach to Disease Management

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ABSTRACT

"The only satisfactory long-term answer is the growing of resistant varieties" is often touted as the solution to Fusarium wilt. Unfortunately such a mind-set can lead to insufficient emphasis on biosecurity and other aspects of a holistic approach to disease management. Often farmers and scientists are living in false hope of what resistant varieties might offer them in the future. There are still many regions of the banana growing world that are free of Fusarium wilt as well as many locations that are free within those regions that are affected. More stringent quarantine, awareness programs and clean planting material schemes are needed urgently, particularly in parts of Asia and Oceania to prevent and/or minimize further spread of the pathogen. Studies have been underway for sometime now on the use of antagonistic microorganisms but greater understanding is needed of the optimum soil environmental conditions necessary for rapidly proliferating and maintaining their numbers in the field. The idea that these microbes need to be specially fed is often not well appreciated. Further studies are also necessary of the impact of GA on resistance and of natural plant resistance activators. There is also a need to clarify issues of disease resistance and tolerance from an horticultural point-of-view. Disease screening trials in north Queensland have indicated that moderately susceptible varieties such as Lady Finger (AAB, Pome) may be commercially productive in infested soils provided appropriate crop management measures are in place. More extensive screening of hybrids from breeding programs is required to enhance both the identification and utilization of hybrids with resistance to Fusarium.

Keywords: crop management, Fusarium wilt, *Musa*, Panama disease, variety

INTRODUCTION – FACING REALITY

In September 2007, along with many other international banana researchers, I visited South Africa for the International Banana Crop Protection Symposium. I also had the opportunity to visit some banana farms and get an appreciation of the industry in the company of the South African banana expert John Robinson. One of the major problems facing the South African industry is 'subtropical race 4' Fusarium wilt which severely affects Cavendish bananas which make up 100% of the local industry. The disease has been present for more than 20 years and despite considerable research, including varietal screening, no particular remedy has yet been found to combat the disease. The result has been that some growers have been forced out and there have been major shifts in production to areas free of the disease. Special attention has been given to clean tissue culture planting material (**Fig. 1**) and quarantine/exclusion to prevent entry of disease onto new farms. Water dips have been constructed to prevent entry of contaminated soil on vehicles entering clean farms (**Fig. 2**). The water dips are treated with Sporekill®.

The experience of the South Africans has given lesson that new varieties like Goldfinger and PKZ have not been their salvation and soil additives have not solved their problem. Rather it has been the combination of clean planting material, clean fields and effective quarantine which has maintained the industry.

Many production locations around the world that do not yet have a Fusarium wilt problem (**Figs. 3-5**) often do not realize how fortunate they are. They are often unfamiliar with the disease and in essence are somewhat complacent, not realizing how easily it can strike if safeguards are not in place. It is the aim of this paper to draw attention to the basics, which if applied, can help to minimize the further spread of the insidious menace of Fusarium wilt.

Fig. 1 The banana industry in South Africa has embraced tissue culture in its fight against *Foc* because only tissue culture plantlets can be guaranteed free of *Foc*.

THE DISEASE TRIANGLE – IMPLICATIONS FOR INTEGRATED DISEASE MANAGEMENT

The disease triangle is a major paradigm in plant pathology and denotes that the existence of a disease caused by a biotic agent absolutely requires the interaction of a susceptible host, a virulent pathogen, and an environment favourable for disease development. Conversely, plant disease is prevented upon elimination of any one of these three causal components. Thus considering Fusarium wilt from this perspective is helpful for anyone trying to better manage the disease. It also draws attention to the need for an integrated approach which is unfortunately often lacking.

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Fig. 2 Vehicle water dips using Sporekill® solution to prevent *Foc* entry have been widely adopted in South Africa.

Fig. 3 Fusarium wilt is widespread in Asia – Pisang Awak diseased plants are common in Vietnam.

Fig. 4 Typical cross-section of pseudostem infected with Fusarium wilt showing characteristic symptoms of brown to black discolouration of the water-conducting tissues.

The host

1. ***Varietal resistance.*** "The only satisfactory long-term answer is the growing of resistant varieties has long been touted as the solution to Fusarium wilt" but such a mindset has many problems. Every variety has its own set of advantages and disadvantages (Daniells 2000). "Many people are pinning their hopes on new and wonderful varieties solving their many problems in banana production. In the past these varieties were to come from conventional breeding approaches. More recently genetic engineering has been much touted as necessary and able to solve all our problems" (Daniells 1998). However, most new varieties that have been developed or offered as replacements for those affected by the disease are different in eating characteristics to those being replaced and unfortunately it is no small task to change the eating preferences of millions of consumers. New varieties are only part of the solution and I believe that farmers and scientists are often living in false hope of what Fusarium wilt resistant varieties might offer them in the future. Some of the implications of my statement concerning pros and cons of varieties are as follows:

a) Some varieties will only be resistant to some vegetative compatibility groups (VCG)/races but not to others. Thus, these type of varieties may have application in some situations and not others.
b) New VCG's/races may be introduced so varieties resistant now may not be so in the future.
c) Varieties resistant to Fusarium wilt may be susceptible to Sigatoka leaf diseases or some other disease. High Noon (SH-3640.10; **Fig. 6**) is a good case in point. It is a good tasting variety and one of the very few resistant to subtropical race 4 in southern Queensland but it is susceptible to yellow Sigatoka (*Mycosphaerella musicola*). For this latter reason the Australian Nurseryman's Fruit Improvement Company (ANFIC) who owns the rights to it in Australia withdrew it from sale (Daniells 1999). We need not to be so quick in dismissing possible candidates because of a certain fault – after all no

Fig. 5 Pisang Raja in Indonesia infected with Fusarium wilt tropical race 4 showing typical leaf yellowing and death of lower leaves.

Fig. 6 High Noon in Australia has resistance to subtropical race 4 but is susceptible to yellow Sigatoka – no variety is perfect.

variety will be perfect.

d) A corollary to this last point is that the main problem may shift from Fusarium to another disease or pest e.g. FHIA-18 is resistant to race 1 and subtropical race 4 as well as black Sigatoka but in north Queensland it appears to be relatively susceptible to Mycosphaerella speckle (*Mycosphaerella musae*) and in Samoa to rust (*Uredo musae*). We may have to prepare growers for a new set of problems.
e) Farmers and scientists can not afford to be complacent just because they are growing a so-called resistant variety. Quarantine and clean planting material still needs to be strongly adhered to.
f) An holistic approach is needed covering exclusion/control measures.

Additionally the fact that very few varieties have so far proven resistant to tropical race 4 reinforces the urgent need for upgraded quarantine measures including disease-free planting material schemes and greater attention to non-varietal solutions. With so few varieties being 'resistant' we may need to examine our screening procedures (Carlier *et al.* 2002) to be sure we are casting our net wide enough prior to the trial and are not too tough on the candidates during the screening trial. Perhaps the inoculum pressure to which the candidates are exposed is unrealistically high. Mak *et al.* (2000) have also questioned standard screening procedures "…too high a pathogen concentration in the 'hot spot' may limit the potential of selecting moderately tolerant plants".

In the late 1990's I evaluated 5 varieties (Ducasse, Lady Finger, Sugar, Pisang Ceylan and Williams) for resistance to race 1 (VCG 0124) in the coastal north Queensland environment (Daniells 2001). The trial was planted because race 1 was a major problem for growers of the variety Ducasse (ABB, Pisang Awak; **Fig. 3**) in north Queensland but farmers growing Lady Finger in the same region seem to have no problem despite both varieties being demonstrated to be susceptible to race 1 (VCG 0124) in southern Queensland. The varieties Sugar (AAB, Silk), Ducasse (ABB, Pisang Awak), Lady Finger (AAB, Pome) and Pisang Ceylan (AAB, Mysore) all showed Fusarium wilt symptoms but there were degrees of susceptibility. Our conclusion was "It is probably possible to grow Lady Finger (and Pisang Ceylan) without major Panama disease [=Fusarium wilt] problems provided one starts with clean planting material, and plants are properly looked after on well drained soils which do not contain high levels of pathogen inoculum i.e. do not plant Lady Finger immediately into a block of say Ducasse which has been severely affected by Panama disease".

This indeed has been the testimony of one grower of Lady Finger on the wet tropical coast of north Queensland. After losing crops of Ducasse to Fusarium wilt (70% of plants diseased) he put the blocks down to fallow (weeds/grass) for 2-3 years before replanting with clean sucker/bit material of Lady Finger. The blocks of Lady Finger are now ranging in ages from 2-5 years but only about 1 in 200 plants of Lady Finger comes down with external symptoms of Fusarium wilt (yellowing/wilting etc.) which is quite manageable. A lot more plants show internal symptoms (vascular discolouration) but yields are quite satisfactory. What are the implications of this? It may be useful to study such a population of plants to better understand the factors contributing to the occasional loss of plants to the disease. Also if we are too quick to discard 'susceptible' varieties in screening trials we may be missing out on some significant production opportunities. Conversely producing Lady Finger in this way will tend to harbour the disease by periodically providing hotspots where inoculum levels of the pathogen build up so enhancing the chances of further spread to other sites and to more susceptible varieties.

Mona Lisa (FHIA-02, SH-3486) is another variety presenting a similar situation to Lady Finger. Mona Lisa is an excellent variety with good resistance to Sigatoka leaf diseases but race 1 screening trials in southern Queensland have shown it to have internal symptoms (vascular discolouration) of the disease usually without external symptoms. To date it has been discarded from commercial consideration in Australia but are we being too dismissive?

This is quite an interesting dilemma. It is of particular concern where the VCG in question is in the tropical race 4 category which threatens the Cavendish plantations around the globe. In this case 'tolerance' (the disease is harboured) may not be satisfactory but with so few varieties showing 'immunity' will we have this luxury? Certainly in Queensland we would not permit the growing of 'tolerant' varieties in sites infested with tropical race 4, were it present.

Where the banana fruit are to be marketed the more similar in taste is the new variety to what it is to replace the better (Daniells 2006). This makes resistance from somaclonal variation so attractive. Likewise it is hoped that genetic engineering will have similar application i.e. inserting genes without disrupting other characteristics too much. Recent glasshouse studies have demonstrated resistance to Fusarium wilt in genetically modified Cavendish but field studies to examine yield and fruit attributes have still to occur (James Dale pers. comm. 2008).

2. ***Clean planting material.*** In Australia we have the Quality Banana Approved Nursery scheme (QBAN) which was originally administered in Queensland by the Banana Industry Protection Board (BIPB). This scheme ensures that all suppliers of banana plants are accredited as following the necessary practices. The scheme has been in operation since the late 1980's. In Queensland the planting of bananas is controlled by the Banana Industry Protection Act. This legislation is aimed at controlling the spread of pests and diseases of bananas and provides the legal power to enforce quarantine with heavy fines possible for non-compliance.

Tissue culture is the preferred source of clean planting material but as I have pointed out previously (Daniells 1997) "shortcuts at the nursery stage can result in Fusarium wilt infection prior to field planting" through the use of either contaminated potting mix or water "thus spreading the pathogen to new areas". For many years leading up to the 1990's the BIPB administered a clean planting material scheme with approved suppliers of Lady Finger sucker/bit material. In hindsight it was a time bomb waiting to go off with many cases of new Fusarium wilt attributable to the dispersal of 'clean' Lady Finger suckers to new areas (Ken Pegg, pers. comm.). Properly managed tissue culture is definitely the way to go. Another dimension to clean planting material is that a subsidized scheme can be set up to help disperse clean planting material thus diluting the population of Fusarium infected plants in a district so reducing the chances of further disease spread. If a good range of varieties is made available through such a scheme people are less likely to contravene quarantine in trying to bring 'special' varieties from elsewhere which may be infected with exotic races of Fusarium.

3. ***Type of planting material.*** However, studies by Mike Smith (Smith *et al*. 1998) have shown that tissue culture plantlets are more susceptible to infection by Fusarium wilt. If the pathogen is thought to be present in the ground to be planted then using disease-free tissue culture plants to establish disease-free nurseries of sucker/bit material will be the appropriate way to go. The results of IMTP Phase 2 (Orjeda 2000) indicate that some of the hybrids are yielding quite well despite seemingly susceptible ratings in terms of vascular discolouration. The use of tissue culture plants rather than sucker/bit material in the IMTP trials (Orjeda 1998) is probably increasing disease infection and expression. Therefore the suitability of tissue culture plants for such trials must be questioned.

4. The use of ***plant resistance activators*** is a field with considerable potential. Every plant has a latent defence system and more and more products are becoming available that induce these defences. Results with rhizome injection of carbendazim were noted to be variable and potassium phosphonate gave some disease control on Williams Cavendish (Ploetz and Pegg 2000). Pegg and Langdon (Ken Pegg, pers. comm.) obtained excellent results with Lady Finger (AAB) and acibenzolar in growth cabinet tests against race 1 and subtropical race 4. It also worked against subtropical race 4 in Cavendish. Greenhouse studies (Dann and Muir 2002) investigating the effect of potassium silicate fertilizer on pea seedlings found that less lesions of the fungal pathogen, *Mycosphaerella pinodes* occurred for the silicon-amended mix. The results suggested associations in pea between available silicon in growth media, accumulation of silicon within the plant, early activation of host defences and subsequent resistance to fungal pathogens, with potential for reduction and control of diseases. Considerable work is currently underway on the use of plant resistance activators which should continue. As well the impact of gibberellic acid on resistance needs to be investigated.

5. Is there such a thing as '***mature plant resistance***'? This was an observation often associated with the reaction of variety Mysore (AAB) in southern Queensland trials. The plant crop would be wilted but subsequent ratoons were apparently healthy. Did the plant acquire resistance over time or was there a shift in the population of soil microbes during the passage of time?

The environment

1. ***Minimizing environmental stresses*** to the banana plant such as cold, poor drainage and nematodes is likely to be beneficial. There is a suggestion from the story above about variety Lady Finger being more tolerant of Fusarium in north Queensland compared to southern Queensland that colder weather in the south may be playing a part. The basic theory is that resistance is a rate-related phenomenon. The time between initial infection or invasion by the pathogen and the resistance response by the host plant determines the success or failure of the pathogen. The response time in turn is determined by the ability of the host plant to mobilize immediate and stored energy reserves to drive the resistance response. Plants that are capable of maintaining energy reserves in excess of their immediate primary metabolite needs (growth and reproduction), will be able to rapidly manufacture the necessary resistance compounds or secondary metabolites to meet the pathogen challenge. The other possibility to explain the different responses is that north Queensland soils are naturally suppressive to the pathogen but this hardly seems likely when one considers the quick demise of the more susceptible varieties such as Ducasse.

2. ***Managing the microbial population*** in the soil will influence the behaviour of the pathogen. Many studies have been underway on this since the mid-1990's. However, as yet there has been little successful implementation of such an approach in the field. The same can be said for most crops, with the introduction of biological control microorganisms remaining largely experimental. Such biological control of Fusarium wilt will no doubt be successful in the laboratory and glasshouse and perhaps even short-term in the field. However, the challenge is to keep it working long-term which is what is required for a perennial crop. On this point it may have more immediate application for disease susceptible varieties if the bananas were grown as a single-cycle crop. But perhaps in the research to date we have missed an important point and that is the need to better manage the population of antagonistic microbes both naturally occurring and introduced elite lines. Such microbes will require the provision of a suitable carbon source to the soil specifically for the purpose of proliferating ("exploding")/maintaining their population. Also a carefully selected fertilizer program to ensure 'balance' – definitely not too much nitrogen and avoidance of fertilizer such as potassium chloride and careful use of agrichemicals generally so as not to disrupt microbial populations. And generally improving soil physico-chemical aspects generally (e.g. CEC, AWC, water infiltration rate and soil tilth) goes without saying.

3. Excessive use of nitrogen fertilizer is thought to increase infections and symptoms of Fusarium wilt of bananas. In pot inoculation experiments, heavy applications of nitrogen greatly increased the number of individual infections of the rhizome, as compared with plants not receiving nitrogen (Rishbeth 1957). It appears that the more rapidly roots are growing, the more liable they are to infection. Interestingly Willingham (2003) in reporting on the effect of nutrition on anthracnose in avocado indicated that the effect of excessive nitrogen fertilizer has been to decrease the production of defence compounds by pushing more energy towards primary metabolism (e.g. growth) and away from secondary metabolism (which includes production of defence compounds) as mentioned earlier.

4. Flood-prone areas are an especial risk in the production of susceptible varieties. Infested stools and contaminated soil and water could be deposited on the plantation from upstream before or after planting leading to disease infections. These in turn can lead to subsequent disease outbreaks further downstream.

The pathogen

1. ***Exclusion.*** The pathogen spreads in infested plant (including pseudostems and bunch stalks), planting material, contaminated soil (on farm implements, vehicles, tyres or footwear) and water (including irrigation).There are still many regions of the banana growing world that are free of Fusarium wilt as well as many locations that are free within

those regions that are affected. These regions can potentially be kept free of the disease via stringent quarantine and clean planting material schemes. Unfortunately the disease is continuing to spread.

Countries that do not have Fusarium wilt have a distinct advantage in the production of Fusarium wilt susceptible varieties such as Silk (AAB, Maca) which is much prized in many countries. Countries without Fusarium wilt need to increase their vigilance to ensure they continue to be free of the disease. Most farmers that have been devastated by Fusarium wilt would wish they had the advantage of hindsight. If only they had given more attention to disease-free planting material and had quarantine strategies in place to prevent the entry of contaminated soil and water.

In Australia we grow about 1900 ha of Lady Finger (AAB, Pome, Prata). Its production in southern Queensland and New South Wales has been plagued for many years by Fusarium wilt race 1. However, there still remain many potential production areas that are free of the disease. "We are optimistic about Lady Finger bananas despite their susceptibility to race 1 of Panama disease and the historical spread of this disease through southern Queensland and northern New South Wales growing areas. If new production areas are selected and established with tissue cultured plants and quarantine procedures enforced, Lady Finger bananas can be grown successfully for many years to come." (Daniells and O'Farrell 1988). In recent years a very significant Lady Finger industry, > 300 ha in area, has become established on the Atherton Tableland, north Queensland . However, there have been recent outbreaks of Fusarium wilt there presumably due to insufficient controls on the movement of contaminated soil on to properties.

This example with Lady Finger shows the strength of market forces. While Lady Finger can continue to be grown successfully somewhere it will be much preferred to Fusarium wilt resistant substitutes. Queensland DPI began evaluating Goldfinger (FHIA-01, SH-3481) in the early 1990's. It was released to industry in the mid 1990's but there are currently only about 100 ha of it grown commercially in Australia despite its resistance to Fusarium wilt and yields twice that of Lady Finger in the absence of the disease. The crucial thing is that Goldfinger does not taste the same (most consumers of Lady Finger would say "nor as good") as existing varieties in the marketplace. It is no simple task to change the tastes of millions of consumers. Bananza (FHIA-18, SH-3480) which is better eating than Goldfinger is so far much less advanced in its development with commercial plantings of only 7 ha in Australia at this stage.

2. ***Minimize soil inoculum levels.*** As mentioned earlier pathogen inoculum levels in the soil need to be minimized. Wherever there is an infected host plant disease inoculum levels will skyrocket. Thus infected plantings should ideally be eliminated as quickly as possible and with as minimal a soil disturbance as possible, grassed over and left to fallow so that disease inoculum levels plummet and so that there is less potential offsite movement of both infected planting material and contaminated soil and water. In the case of tropical race 4 zero diseased plants would be the acceptable level in Queensland. This raises the issue of trial sites and the need for them to be very secure so that our research isn't contributing to further spread of the disease. The Northern Territory government has a secure A$350,000 field research facility for tropical race 4 screening trials. Even this secure facility has to ponder the potential movement of contaminated soil on birds such as Magpie Geese which might be attracted to the site. All bases need to be covered.

3. ***Determine the VCG.*** To date >20 vegetative compatibility groups (VCG's) or VCG complexes have been reported in *Foc* (Ploetz and Pegg 2000). Exactly what VCG's are present in a particular situation needs to be known as this will influence the disease reaction and the appropriate course of action. You may have Fusarium wilt affecting Lady Finger and assume it is a race 1 type but you might just have tropical race 4 which has far greater ramifications and not know it. VCG testing is a must.

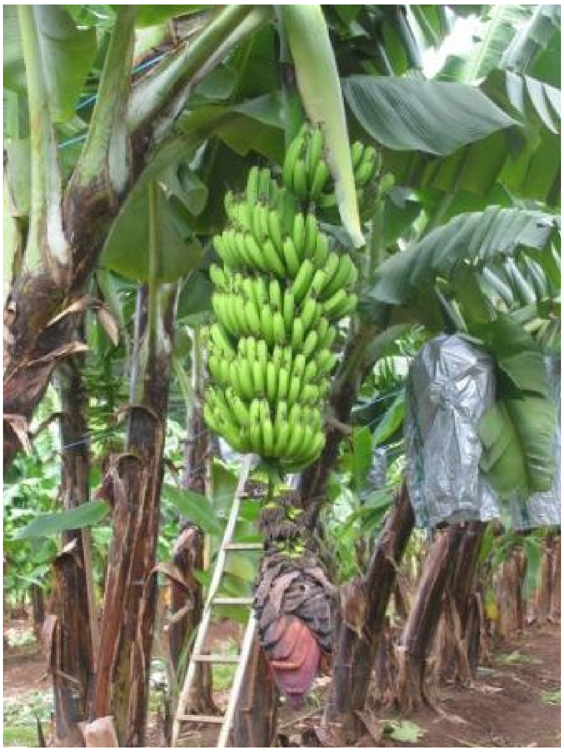

Fig. 7 Somaclonal variants of Cavendish such as Formosana have partial resistance to tropical race 4 and has proven popular in Taiwan.

MORE EXTENSIVE HYBRID SCREENING NEEDED

In 1992, I called for more extensive hybrid screening from breeding programs. "Not all countries have the same spectrum of pests and diseases. Thus disease susceptibility of some varieties is not important in some locations. For example Panama disease is not present in such South Pacific countries as (Western) Samoa, Tonga (now present) and the Cook Islands. Hybrids that are susceptible to Panama disease, which may be suitable for this region, would be discarded by most breeding programmes" (Daniells 1993). There still remains an opportunity to do much more in this area. Large sums of money, sometimes from international funding agencies have been expended on the banana breeding programs but the selection criteria are much too severe. This results in many costly missed opportunities. I understand that FHIA-18 was actually sent to Cuba by mistake. It now happens to be grown there in Cuba on some 5500 ha and is also deemed to have considerable potential in many other areas. What else lies buried in breeding programs? Release of products from breeding programs has been hindered in recent years by change in ownership and issues with banana streak virus but wider screening would nevertheless make a big difference.

Considering that very few varieties are currently showing resistance to tropical race 4 and given the fact that no variety is perfect anyway I believe there is a great need for casting the net wider in identifying candidates for testing in key locations around the world. I would suggest that there be greater horticultural input into the existing breeding programs in helping to identify this broader range of candidates. Ideally someone with a broad perspective of world needs and opportunities should be involved in interacting with each of the breeding programs on a regular basis.

Because of the apparent success of selecting somaclonal variants resistant to Fusarium wilt in Taiwan (**Fig. 7**) it would be worthwhile to systematically screen more somaclonal variants from elsewhere. Genomic investigation of any of the resistant offtypes may be interesting as there may be only a few genetic differences which could perhaps be identified and utilized in other ways in plant improvement programs.

CONCLUSION

A quote from Jim Deacon (1984) has some relevance "In the words of one farmer, Panama (disease) is like a terrorist – you do not see it until it strikes, and then it's too late. These recommendations (for action) are your anti-terrorist measures." Let's make the world a safer place for bananas!

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