International Banana Symposium

*Banana Improvement, Health Management, Use Diversification and Adaptation to Climate Change*

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**Abstracts**

Co-organized by:

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Cover photo of a dwarf selection of Kluai Namwa (Pisang Awak, ABB) taken by A.B. Molina

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International Banana Symposium: Banana Improvement, Health Management, Use Diversification and Adaptation to Climate Change
SESSION 1:

CLIMATE CHANGE: POTENTIAL IMPACTS AND MITIGATION APPROACHES

Oral Presentations

Banana Growers Facing Climate Change in Asia and the Pacific: Planning Adaptation to Uncertainty, Weather Variability and Extreme Events

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Bananas prosper as a plantation and smallholder commercial crop in Asia under a wide range of climatic conditions. The humid tropics of Asia experience relatively uniform temperatures in the range of 22-28°C with well distributed annual rainfall between 1500-2500 mm, considered optimum for banana. Growers with the support of scientists and production service providers have been very successful in adapting banana cultivation methods for a wide range of other climates considered suboptimum, including the monsoon tropics and the wet and dry subtropics. Climate change will bring new challenges to the banana plant and to growers, scientists and service providers. Globally, annual average temperatures will increase improving conditions for banana in subtropics and at higher altitudes, while changes in precipitation patterns are projected to be more variable. We propose that adapting to climate change requires going beyond averages to analyze both moderate weather variability and extreme events. These include: in monsoon areas increasing frequency of droughts, heat waves and excess rain; in subtropics cold snaps and frosts; and in humid tropics more frequent droughts, heat waves and storms which bring high winds and excess rains. The Banana Asia Pacific Network (BAPNET) can facilitate a regional response to plan adaptation to climate change. Steps include mapping current production areas and documenting production techniques, generating homologue and analogue zones crossing national boundaries, identifying critical seasons and elements of weather variability by zone and building inventories of...
current practices useful for more resilient banana production and more effective recovery practices. A socio-ecological production framework is proposed to identify appropriate stakeholders needed to address practices and policies targeted by ecological level ranging from cultivar selection to field and farm agroecosystem management and beyond to local and regional landscape approaches. Plans need to address social, institutional and human capital, infrastructure and finance.

**Advances and Challenges of Banana Production Systems Towards Sustainability of Production and Mitigating Effects of Climate Change**

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Banana production for local consumption and export is a vital component of communities in tropical and subtropical regions globally. Like other agricultural systems banana production faces the challenge of maintaining and improving sustainability to continue to contribute to the financial and social well-being of these communities. While the definition of sustainability is much debated, four key themes occur frequently: i) maintenance or repair of the natural farm resources; ii) meeting farmers’ goals and aspirations to provide sustenance or financial benefit; iii) efficient use of production inputs; and iv) minimization of impacts on the environment and communities. Like the banana production system, these challenges are linked through complex interactions between socio-economic and bio-physical factors. Therefore, an integrated research and development approach that takes account of the complexity of the banana production system is appropriate to develop meaningful solutions or improvements. Commercial banana production in tropical Australia is dealing with aspects of these sustainability challenges. It is facing increased public and government scrutiny because of its proximity to two UN World Heritage listed areas, the Great Barrier Reef and Wet Tropics Rainforests. The production region is experiencing regular cyclonic activity and has experienced significant production and economic losses in recent years due to the impact of tropical cyclones. These environmental and climatic constraints, and high labour costs require innovative solutions for the Australian banana industry. As a result, the Australian banana industry has supported research and development projects to develop improved farm practices to manage nutrient and sediment losses affecting water quality, optimize nutrient inputs, reduce pesticide use and manage the impact of tropical cyclone damage.
Assessment of the Potential Impact of Climate (Temperature) Change on Traditional East African Highland Beer Bananas in East Africa

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*Musa* AAA-EA beer bananas are mutants of the *Musa* AAA-EA green cooking genotypes. Field data in Uganda show that the proportion of beer-bananas to green cooking-bananas increases with altitude, the cooking highland bananas reverting to beer-bananas. Observations indicate that low temperatures in high-altitude zones may be responsible for the reversion. Under the prevailing climate change scenarios, (increasing temperatures), beer genotypes could disappear. If this was to be the case; the green-cooking progenitors could dominate some production systems which would have livelihoods implications for communities currently dependent on beer-banana production. Two studies were carried out. One study in 24 representative sites of Uganda assessed whether the cooking progenitors could be occupying similar zones with beer genotypes and hence partially supporting the reversion due to low temperatures. Cultivar distributional ranges in Uganda were compared to studies on *Musa* diversity distribution in Rwanda and south Kivu in the DR Congo. The second study analyzed the morpho-physiological attributes of 148 accessions but removing the physiological characteristics to see whether beer accessions could remain coherent or be scattered among other accessions. In Uganda, beer-bananas form 19% of *Musa* AAA-EA, of which 1% occur below 1350 meters. Beer-bananas in Rwanda and South Kivu in DR Congo occur above 1500 meters and their proportion was higher than the cooking genotypes. Yet beer genotypes like ‘Entundu’, ‘Enyamaizi’ and ‘Ensika’ were widely distributed with no regard to altitude and temperatures in the three agroecologies. Besides, majority of cooking putative *Musa* AAA-EA were not occupying similar zones where beer-bananas were occurring and hence not fully supporting the concept of reversion due to low temperatures. Most beer-bananas still formed a coherent cluster of their own when grouped on the basis of 61 morphological traits without the astringent characteristics. It is imperative to say that beer genotypes are probably evolving through a combination of farmers’ selections and changing climatic factors such as temperature.
Assessment of Growth, Physiology and Water-Use Efficiency of Wild and Edible *Musa balbisiana* Germplasm Under Drought Conditions

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Banana, one of the world’s leading fruit crops, is predicted to be highly vulnerable to drought conditions brought about by climate change. Selection and development of banana genotypes with drought resistance/tolerance is one of the mitigating measures for addressing this problem. This study aimed to generate data to evaluate the earlier reports that *Musa balbisiana* (BBB) is drought tolerant. Such data will prove useful in crop improvement. Thirty-five wild and edible *M. balbisiana* genotypes from the Philippines and Southeast Asia germplasm collection were evaluated for their response to drought stress. Tissue-culture derived seedlings were established, and subsequently grown under well-watered and terminal drought conditions in the greenhouse. Drought treatment was imposed on 3-month old seedlings by withholding water for 2-3 weeks. Water use, growth and physiological responses were closely monitored. Results showed that drought produced significantly different degrees of reduction in the total dry matter and above-ground biomass. Root volume and root weight were reduced from 84 to 47% and 77 to 35%, respectively. Based on the root-shoot (RS) ratios, only few banana genotypes allocated more biomass to the roots under drought, while most of the other test entries showed reductions in RS ratio. Significant genotype differences in terms of relative leaf fold (RLF) and stomatal conductance were observed. RLF values after drought imposition increased as the soil moisture content decreased. Stomatal conductances were significantly affected by the interaction between genotype and time of sampling. The genotypes differed in their water use efficiency which generally increased under drought condition. Water-use efficiency correlated positively with total plant dry weight, root length, root volume, root weight, leaf weight and relative leaf folding. Increased water-use efficiency is also attributed to decreased plant height, specific leaf area, and the number of cigar leaves formed during drought.
Computational Prediction, Identification and Expression Profiling of MicroRNA Against Drought Stress in Banana

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MicroRNA (miRNA) is a form of single-stranded, non-coding RNA that regulates the expression of genes involved in plant development and stress/defense-related mechanism at post transcriptional level. Identification and selection of reference miRNA is critical for relative quantification of miRNA expression studies. Hence, the present study was carried out to select the suitable reference miRNA and identify miRNAs involved in drought stress response in banana. Computation based miRNA prediction from EST library derived from drought stressed banana plants resulted in the identification of three miRNAs namely miR156c, miR399 and miR169. Complementary DNA was synthesized using multiplexed stem loop RT reaction from different organs (leaf, sheath, corm, flower-bud and bract) and drought-stressed leaf tissues at different time intervals (every 48 hrs starting from 0-24 days after stress). Presence of miRNA was confirmed by amplification with specific primers and sequencing. Out of these three, only miRNA 156c was found to have constant expression across various tissues and drought stressed leaf tissues through real time polymerase chain reaction (PCR) analysis. This study suggests that miRNA 156c could be used as reference miRNA for drought studies. Using this reference, the expression profiling revealed that miRNA 399 is up-regulated in drought-tolerant cultivars. This paper deals with miRNA quantification, related problems and validation across contrasting genotypes for drought stress.
CBF1 From *Arabidopsis thaliana* Confers Enhanced Tolerance to Low Temperature in Banana (*Musa acuminata* cv. Ladyfingers)

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C-repeat/dehydration-responsive element binding factor 1 (AtCBF1) plays important roles in plants responses to low-temperatures. Through genetic engineering, AtCBF1, driven by a cauliflower mosaic virus 35S promoter, was introduced into banana plants by Agrobacterium-mediated transformation of embryogenic cell suspensions (ECSs) of *Musa acuminata* cv. Ladyfingers (AA). The presence of AtCBF1 transgenes in regenerated plants was confirmed by polymerase chain reaction (PCR) and reverse transcription-polymerase chain reaction (RT-PCR), and the expression level of AtCBF1 was detected in transgenic banana plants by quantitative real-time polymerase chain reaction (qRT-PCR). Transgenic banana over-expressing AtCBF1 showed growth retardation, thicker leaves and higher chlorophyll content than non-transgenic plants. Ion leakage rate and malondialdehyde (MDA) contents were significantly lower in transgenic banana plants over-expressing AtCBF1 than in non-transgenic plants under low temperature stress. In addition, free proline, soluble sugars, and relative water content (RWC) were found to be higher in transgenic banana leaves. An obviously higher survival rate was observed among the transgenic plants in the cold hardiness. These results suggest that over-expression of AtCBF1 in transgenic banana plants plays an important role in improving cold-tolerance.
Resistance to Wind Damage of Some Introduced and Local Banana Cultivars in the Philippines

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Introduced and local cultivars were established in replicated plots at the experimental field of the University of the Philippines Los Baños, Philippines in July 5, 2010. Los Baños is located in Luzon island where occurrence of typhoon is common, causing damage to banana crops. The test cultivars included eight varieties from the International Musa Testing Program (IMTP) of Bioversity International and nine popular local cultivars. A dwarf variety from Thailand, ‘Kluai Namwa’, was also included. Cultivar selection was based on their importance as dessert as well as cooking types. Data on agronomic traits like plant height, stem girth, number of leaves and maturity were collected. Recurrent typhoons at the experimental location provided an opportunity to evaluate the resistance of these cultivars against wind damage. On May 8, 2011, Typhoon Bebeng (Aere) hit the experimental area. It had a sustained speed of 50 km/hr, and a maximum gusty wind of 67 km/hr as recorded by a meteorological station in the experimental station. The typhoon felled some test varieties due to pseudostem breakage. Data were collected on the percentage of plants from each variety that was toppled. Results showed that some varieties were severely affected while others withstood wind damage. FHIA varieties 17, 18, 23 and 25 were insignificantly affected with damage ranging from 0 to 4%. The popular local cultivar ‘Lakatan’ was severely damaged with 90 to 100% of plants felled. The Cavendish varieties manifested the following susceptibility to wind damage with percentage toppling down as follows, ‘Bungulan’ (80%), GCTCV 119 (60%), GCTCV 106 (20%). The tall cultivars ‘Cardaba’ (7%) and ‘Dippig’ (29%) showed less damage while the dwarf ‘Kluai Namwa’ was totally unaffected. ‘Cuarenta dias’, a local early maturing variety, was totally spared from typhoon damage because of its shorter fruiting cycle. In general, it was observed that plants with bigger stem girth and shorter plant stature were more resistant to wind damage.
Farm Practices to Manage the Impact of Severe Tropical Cyclone Damage on Banana Production – A Case Study From Tropical Australia

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The majority of Australian banana production occurs on the northeastern tropical coast between latitudes 16-18oS, and can experience tropical cyclone activity during the summer months. Damage from severe tropical cyclones has a significant impact on the livelihoods of banana producers and the associated farm labour, service industries and supply chains. The most significant impacts are the immediate loss of production and income for several months, the region-wide synchronization of cropping and the expense of recovering or replanting affected plantations. Severe tropical cyclones have directly affected the main production region twice in recent years – Tropical Cyclone Larry (Category 4) in March 2006 and Tropical Cyclone Yasi (Category 5) in February 2011. Based on TC Larry experiences, pre- and post-cyclone farm practices were developed to reduce these impacts in future cyclonic events. The main pre-cyclone farm practice focused on maintenance of production units and an earlier return to fruit production by partially or completely removing the plant canopy to reduce wind resistance. Post-cyclone farm practices focused on managing the industry-wide crop synchronization using crop timing techniques to achieve a staggered return to cropping by scheduling production to provide continuous fruit supply. With TC Yasi in 2011 some banana producers implemented these practices and this provided an opportunity to examine their effectiveness in reducing cyclonic impacts. Additional research and development activities have been conducted to refine our understanding of their effectiveness and improve their application for future cyclonic events. Based on these activities and farm-based observations’ suggested practice-based management strategies can be developed to help reduce the impact of severe tropical cyclones in the future.
Agricultural Resilience in the Context of Climate Change: Widening the Genetic Basis of Cultivated *Musa* to Manage Uncertainty

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In traditional agrosystems, agricultural resilience relies on the cultivation of numerous species of food crops, each containing a number of different varieties. Cultivated biodiversity indeed allows the agrosystem to flip into an alternative state of equilibrium in case of sudden change. In resilient systems, the extent of the within-crop species diversity, and of their genetic basis, is also an important component of resilience. Such biodiversity increases the chance that one of the varieties cultivated holds a “hidden” trait that would be expressed and of value in case of change. Despite a wide phenotypic variation, the genetic basis of the cultivated diversity of *Musa* is narrow, e.g. edible triploids are believed to have emerged from few sexual events in which similar parents could be involved. While recent models have highlighted several constraints that future agrosystems will have to face in the context of climate change (CC), a certain amount of risk also relies in the unexpected effects of CC. Currently, strategies focus on the incorporation of selected traits from the crop wild relatives (CWRs) compartment into the cultivated genepools through pre-breeding and breeding. However, this long-term approach implies the correct identification of the desired traits and, thus, does not
comprehensively account for risks linked to the uncertainty of CC effects. In this context, widening the genetic basis of region-specific cultivated gene pools would strengthen agrosystems in the face of change, by increasing the number of putative “hidden” traits within cultivated Musa. This could be achieved through two complementary approaches: first, by identifying gaps within cultivated gene pools and by filling these gaps through the distribution of selected accessions; and second, by allowing the random incorporation of new genes from CWRs into the cultivated gene pools through increased use of CWRs (number of species and of accessions per species) in pre-breeding and breeding.

**Banana and Plantain Breeding – A Review on Problems, Prospects and New Initiatives**

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Banana and plantains are considered as recalcitrant crops for improvement through conventional breeding. Plant based constraints encountered are male and/or female sterility, triploidy, low seed viability, poor hybrid progeny regeneration and few good quality progenies. Monopoly of Cavendish clones (>63%) have general issues; global dependency on single genotype, Grand naine (AAA), very narrow sexual recombination events leading poor genotypic variability in spite of large phenotypic diversity, market demands, emerging biotic and abiotic stress in the context of climate change etc., have made this crop very fragile in nature and calls for strategic planning for its improvement. Banana and plantain breeding objectives and methodologies have been conventionally dependent on pre-breeding creation of superior diploids and developing improved triploids, normally but not always, with a step of developing primary tetraploids. Although several man made hybrids have been crept into banana production systems, shrinking number of breeders and breeding programmes are a cause of concern. In spite of these constraints, the challenges are further addressed through various future programmes like broadening the utilization of crop wild relatives and edible diploids through evaluation for specific abiotic and abiotic traits, search for BSV integrant free BB types for direct use in breeding, developing mapping populations etc. Application of biotechnological tools like embryo culture and embryo rescue which have improved the success of regeneration of hybrid progenies, development of autotetraploids of desirable AB
genotypes, marker aided selections have shown success. This paper deals in detail about the better prospects in developing better performing banana and plantains.

**Exploitation of the Banana Genome: A Biologist’s Viewpoint**

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One of the key challenges facing our society in the coming decades is to ensure food security for the burgeoning human population, particularly in the face of scarcity of water, arable land production and climate change. This requires an environment-friendly, sustainable increase in agricultural production to deal with increasing food demands. One critical area in the drive towards intensification is that of crop improvement and the need to exploit genetic diversity for the introduction of novel traits for increased yields and quality. Recent technological developments in our ability to determine whole genome sequences (Next Generation Sequencing) are revolutionizing this area of research. The complete genome sequences of a number of crops and microbes are now available providing us with a complete catalogue of an organism’s genes and proteins. This serves as a powerful framework for the detailed dissection of complex biological processes, which in turn can then be used for the development of the tools necessary focused (molecular) breeding and selection strategies. Banana improvement is traditionally a slow process based on interspecific crosses and genome manipulations. Therefore, the recent availability of the banana genome offers tremendous potential to accelerate the processes of crop improvement via parental selection, gene mining, the discovery of trait—locus-gene association, marker development and functional gene annotation. Importantly, the plummeting costs of nucleotide sequencing means that resequencing of additional 1,2 varieties and species is now within the range of the majority of research groups. Such an approach have been undertaken in the study. The transcriptomes of a series of AAA, AAB and Fe’i varieties, as well as the genome of the wild diploid BB genome cultivar, have been re-sequenced. This was carried out as a first step towards understanding the genetic basis of differences in fruit nutritional quality traits. Here, an overview of these preliminary results and outline on how the data can be exploited and translated to crop improvement programs is presented. Finally, some of the remaining challenges will be outlined.
Appropriate Use of Banana ICM Production Methods As A Way for Safe Conservation and Exploitation of Musa Genetic Resources in Rwanda

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Implementation of banana integrated crop management methods was undertaken through performing basic operations comprising (1) weeding, (2) elimination of excessive suckers to keep an optimal density of three suckers around each mother plant, (3) proper application of organic fertilizers, (4) control of banana weevils with a trapping system, (5) suitable mulching and (6) control of various diseases. The approach was set up in farmers’ banana plots by beneficiaries themselves after they had been skilled through an appropriate FFS training. After a period of 2 to 3 months following the basic operations implementation, a rapid improvement of the banana health and overall morphological development exhibited by a strong intensity of green color on banana leaves were observed. Ultimately, that banana rehabilitation process resulted in a highly significant increase of banana productivity whatever the considered variety. In fact, production data recorded from four different farmers’ banana varieties revealed that the number of fingers per bunch had increased five times while the average weight per bunch had increased seven times reaching in some cases more than 120 kg/bunch. It is in that frame that all the varieties treated through this ICM based banana rehabilitation process are safely maintained and efficiently exploited by farmers as their productivity is interesting at the economic view point. This performance of different varieties is seen as an efficient and accessible way for conserving banana biodiversity while the exploitation based on intercropping different banana varieties contributes to a sustainable control of pests and diseases by reducing pathogen spread and decreasing selection pressure on pathogen populations. Hence, it can be considered that adopting ICM approach in banana production systems contributes to a safe conservation and use of Musa genetic resources.
Systematic Study of the Banana Family (*Musaceae*) in Thailand

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Thailand is located at the heart of mainland Southeast Asia. Extensive expeditions throughout the country during the past eight years revealed a wide diversity of the *Musa* family which consisted of 10-16 species among 74-75 species found pan tropical worldwide. Previous investigations of hundreds of banana accessions collected around the country have uncovered two native genera based on morphological and molecular characters: *Musa* and *Ensete*, and one exotic monotypic genus, *Musella*. Apart from one new native *Musa* species found last year in Thailand, a number of putative taxa await to be studied and described. Several approaches have been used including morphometrics, anatomy by light and scanning electron microscopes, and analyses of genome sizes, chromosome numbers, palynology, biogeography, and molecular biology of these specimens. A manuscript on the family *Musaceae* is being prepared for the Flora of Thailand project and the diagnostic characters which will be proposed for the banana identification include, e.g. shapes of leaf base, rachis positions, aestivation and colour of male bracts, among other critical ones. The conclusions on banana taxonomy would not only note unquestionably the vast diversity of the family in this region, but also mark the importance of the fertile lands hosting the endangered bananas and urge for urgent conservation of their vulnerable germplasm and their natural habitats.
Quantitative Proteomic Analysis Reveals that Antioxidation Mechanisms Contribute to Cold Tolerance in Plantain (Musa paradisiaca L.; ABB Group) Seedlings

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Banana and its close relative, plantain, are globally important crops and there is of considerable interest in optimizing their cultivation. Plantain has superior cold tolerance compared to banana. Thus, a thorough understanding of the molecular mechanisms and responses of plantain to cold stress has great potential value for developing cold tolerant banana cultivars. In this study, we used iTRAQ-based comparative proteomic analysis to investigate the temporal responses of plantain to cold stress. Plantain seedlings were exposed for 0, 6 and 24 h of cold stress at 8°C and subsequently allowed to recover for 24 h at 28°C. A total of 3,477 plantain proteins were identified, of which 809 showed differential expression from the three treatments. The majority of differentially expressed proteins were predicted to be involved in oxidation-reduction, including oxylipin biosynthesis, while others were associated with photosynthesis, photorespiration and several primary metabolic processes, such as carbohydrate metabolic process and fatty acid beta-oxidation. Western blot analysis and enzyme activity assays were performed on seven differentially expressed, cold-response candidate plantain proteins in order to validate the proteomics data. Similar analyses of the seven candidate proteins were performed in cold-sensitive banana to examine possible functional conservation and to compare the results to equivalent responses between the two species. Consistent results were achieved by Western blot and enzyme activity assays, demonstrating that the quantitative proteomics data collected in this study are reliable. Our results suggest that an increase of antioxidant capacity through adapted ROS scavenging capability, reduced production of ROS and decreased lipid peroxidation contribute to molecular mechanisms for the higher cold tolerance in plantain. To the best of our knowledge, this is the first report of a global investigation on molecular responses of plantain to cold stress by proteomic analysis.
Conserved and Novel MicroRNAs Expressed in Banana Roots During Abiotic Stress

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As a staple food for millions of people in developing countries, banana is an important crop for world security. World production of banana is hampered by both pathogens and harsh cultivation environments and, as with other crops, likely to be adversely affected by climate change. However, information about the biological process associated with stress response is scarce. In this study, salinity as a model stress factor to study gene expression of miRNA and miRNA in *Musa acuminata* cv. Berangan (AAA Genome) was used. Small RNA libraries were constructed from *in vitro* banana roots treated with 100 mM and 300 mM of NaCl, and from untreated control plants. The libraries were sequenced using an Illumina Genome Analyzer (sRNAseq), resulting in 14.5, 14.8 and 13.8 million clean reads respectively. A number of miRNA families, which are well-conserved in plant species, were identified from the banana roots. Sequence analysis revealed that some of these conserved miRNA families, with known roles in regulation of stress responses, are also differentially expressed in banana root tissue in varying stress magnitudes. Several putative novel miRNAs (not found in other species), including some that are differentially expressed in salt-stressed banana roots, were identified. Using our transcriptome data (Illumina RNAseq) and the recently published banana genome sequence, the potential targets of the conserved and novel miRNA in banana were also identified, focusing on those differentially expressed during abiotic stress and, thus, of interest for elucidating the underlying biology of stress responses in banana.
DNA Fingerprinting of Popular Indian Banana Varieties Using SSR and ISSR Markers

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India, being one of the centers of origin for Musa spp., has a large and varied Musa diversity with almost 120 varieties in cultivation across the country. A total of 10 Inter-Simple Sequence Repeat (ISSR) and 20 Simple Sequence Repeat (SSR) markers were tested for DNA fingerprinting of 14 ruling commercial varieties of Musa representing AAA, AAB, ABB and AB genome. Out of 10 ISSR markers tested, 9 amplified products resulting in discrete, repeatable amplicons and a total of 105 alleles were identified with a mean of 11.7 alleles per primer based on the presence (1) and absence (0) of alleles. The maximum of 20 alleles were observed in UBC 811 and a minimum of 7 alleles were produced by primer UBC 836. Out of 20 SSR markers tested, a total of 17 primer pairs generated unique alleles for all the commercial varieties except Dwarf Cavendish and 14 microsatellite primers produced alleles that were commonly shared by different varieties of the same genomic group (AAA, AAB and ABB). Genetic identity in terms of DNA fingerprints developed in the present study would have greater applications in aiding variety registration, distinctness, uniformity and stability (DUS) characterization and in detecting infringement of breeders’ rights and biopiracy.
Species of Banana Streak Virus (BSV) in the Philippines and Its Activation by Tissue Culture Processes and Gamma Irradiation

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Banana streak virus (BSV) causes banana streak disease (BSD) in many tropical and subtropical banana-producing countries. Interests to study BSV have increased in the past year because of the virus’ behaviour as an integrant (endogenous and non-pathogenic) in the Musa genome that when activated becomes pathogenic (episomal). The activation was attributed to many host and environmental stress factors including, but not limited to, the association of A and B genome groupings, tissue culture processes and gamma irradiation. In this study, national and germplasm collections of Musa spp. were indexed using standard and Immunocapture PCR to detect BSV, identify species and determine its relationship with various genome groups. Tissue culture (TC) processes and gamma irradiation (GR) studies were also initiated to determine their effects on the frequency and distribution of both endogenous and episomal BSVs. Results showed the existence of three known BSV species in the collection namely, Mysore, Goldfinger and Imove that appear as integrant but were not detected as episomal BSVs. These species were strongly associated to cultivars with B and AB genomes. Although endogenous sequences were detected, no episomal BSVs were detected in tissue cultured and gamma irradiated materials. These suggest that the first proliferation stage of tissue culture and different gamma ray dosages (as low as 5 and as high as 50 Gy) bear no effect on the activation of the virus to its pathogenic state.
Identification of Genome Composition of Bananas Using Flow Cytometry and A Combination of Molecular Markers

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Bananas (Musa spp. sect. Eumusa) originated from intra- and interspecific hybridization between two wild diploid species, M. acuminata Colla. and M. balbisiana Colla., which contributed the A and B genomes, respectively. The traditional method for determining the genome composition of Musa cultivars is based on the Simmonds-Shepherd scoring system which relies primarily on morphological characters. Several studies have differentiated the four genomes (A, B, S, T) involved in banana cultivars using genomic in situ hybridization (GISH), which could also be used to determine genome structure of banana cultivars containing A and/or B genomes. However, the method of GISH is time-consuming and requires a high level of experimental skill. Previous investigators have found that molecular makers including PCR-RFLP of the rDNA ITS region, RAPD and IRAP, could be suitable for identifying genome composition, and have several advantages over morphological scoring system and molecular cytogenetics methods like GISH. However, those methods of differentiating triploid AAB and ABB types mostly relied on the band intensity of PCR-amplification products, regardless of the molecular maker tools they used. Many factors could strongly affect the band intensity during DNA extraction, PCR-amplification, gel electrophoresis and stain process, which inconsequently influences the accuracy of genome identification in bananas. This study presents a more reliable identification strategy, based on a combination of molecular markers to differentiate A and B genomes, together with ploidy selection by flow cytometry. Flow cytometric analysis of nuclear DNA content was firstly used to estimate ploidy levels of bananas. Secondly, the digested DNA fragments of rDNA ITS region amplified by ITS L and ITS 4 primers and digested by RsaI, were separated and in which 530-bp fragment was diagnostic for the presence of ‘A’ genome while the 350- and 180-bp fragments were diagnostic for the presence of the ‘B’ genome. If the ploidy level of the samples is diploid, their genome compositions are AA, BB, or AB, depending on the presence of different fragments tagging ‘A’ and/or ‘B’ genomes. If the ploidy level of the samples is triploid or tetraploid, their genome compositions are AAA, AAAA, or BBB, BBBB, depending on the presence of the only fragments
tagging ‘A’ or ‘B’ genomes, respectively. However, if the digested ITS fragments show the presence of both ‘A’ and ‘B’ genomes, the next step of molecular identification using IRAP is required to identify the number of ‘B’ genome complements. Thus, multiple polymorphic bands were firstly amplified with the gypsy-IRAP primer from genomic DNA of those triploid samples, in which ~350-bp fragment was tagged for the ‘B’ genome. After that, a second PCR with Musa copia-IRAP primer pair (BFor plus BRev) from ‘B’ specific bands was designed with AluI. The restriction pattern showing one or two fragments around 200 bp was linked to one or two ‘B’ within the genome composition of those triploid samples, viz. AAB or ABB. For tetraploid bananas, one 200-bp fragment could be indentified as AAAB type, but if two 200-bp fragments were observed, it remains hard to distinguish the AABB and ABBB types in them. Choosing PCR-RFLP of ITS as the first step to identify the genome composition, is the less fragments amplified, giving clear and distinguishable fragments linked with ‘A’ and ‘B’ genomes. The presented identification strategy provides a simple, fast and more accurate method to large-scale throughput demands in determining the genome constitution of mostly Musa accessions and hybrid populations generated in breeding programmes.

Identification and Development of Molecular Markers Specific to Eumusae Leaf Spot Disease

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Among the three major Mycosphaerella spp., M. eumusae has been identified as the pathogen causing the leaf spot disease in India. The pathogen affects almost all banana cultivars grown in India, which results in severe yield and quality loss. As India does not have the black leaf streak (M. fijiensis), which is the severe form of leaf spot pathogen worldwide, nor the yellow Sigatoka leaf spot disease (M. musicola), the differentiation of these two pathogens from M. eumusae is very important, especially for quarantine management strategies. Hence, this study on molecular markers, particularly the Sequenced Characterized Amplified Region (SCAR) marker specific to M. eumusae was developed, based on the DNA fingerprints obtained from Random Amplified Polymorphic DNA (RAPD) analysis. A total of 40 primers were screened and the specific unique bands that were able to differentiate three species of Mycosphaerella were eluted and sequenced. From these sequences, 10 different sets of primers were designed and validated using the DNA samples of major Mycosphaerella spp. from different banana regions (M. fijiensis, M. musicola and
M. eumusae), and six other leaf spot causing fungi (M. marksii, Cladosporium spp., Corynespora cassicola, Nigaspora spp. and Phomopsis spp.). The primer set 4f and 5r only reacted with M. eumusae DNA generating the expected PCR product. No reaction was observed from any other of the samples analyzed. Further, the primer set has also been validated using the leaf spot samples collected from different banana growing regions of India. The diagnostic tool developed would be useful for both early and easy detection of M. eumusae pathogen and efficient management of the Eumusa leaf spot disease in banana.

**Poster Presentations**

**Differential Gene Expression in Banana in Response to Mycosphaerella eumusae**

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Among the three Mycosphaerella species, M. eumusae (Eumusae leaf spot) is the most important banana pathogen in the Indian context, causing crop losses of up to 60%, especially in Cavendish varieties. Knowledge on host-pathogen interaction is a basic requirement for creating strategies in developing resistant varieties. In this context, a functional genomics approach had been used for the identification of differentially expressed gene(s) between the contrasting parents with the same genomic background (AAA), namely cv. Manoranjitham (resistant) and cv. Robusta (susceptible). Based on real-time polymerase chain reaction (PCR) analysis of peroxidase, polyphenol oxidase and catalase genes, the optimum time for sample collection for functional genomics studies, after pathogen inoculation under controlled conditions, was determined to be from 6-36 hours. A cDNA-SSH library was constructed with about 1100 positive clones of which 851 positives clones were randomly selected, sequenced and submitted in National Center for Biotechnology Information (NCBI) genebank. Expressed Sequence Tags (ESTs) were assembled using CAP3. The study revealed a total of 498 unigenes, which consist of 78 contigs and 420 singletons. Top BLAST hits of BLAST2GO analysis discovered
resistance/defense related genes such as genes for TIR-NBS-LRR resistance protein, cytochrome oxidase, lipoxygenase, ethylene response factor, serine-glyoxylate aminotransferase, aleurin-like protease, flavin-containing monooxygenase, zinc finger protein, senescence-associated protein, and catalase, etc. Probes were synthesized for eight randomly-selected ESTs from top BLAST hits and subjected to preliminary gene expression studies on resistant and susceptible cultivars which had been challenged with *M. eumusae*. About six ESTs revealed a high-intensity of spots (up-regulated) in resistant when compared to susceptible cultivar. Isolation and characterization of full length of these up-regulated genes are in progress.

**Germplasm Collection and Evaluation of Banana Cultivars (‘Saba’ Sub group) in the Philippines**

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The Philippine banana chips industry has become one of the country’s emerging export winners. One of the major problems besetting the industry is lack of raw materials for processing into banana chips. The current cultivars used (namely ‘Saba’ and ‘Cardaba’) are tall and bear first fruits after almost two years. Cultivars with short stature may result to earlier fruit production as well as less time exposure to pests and diseases, and natural disasters such as typhoons. Conventional breeding strategies are difficult to implement in edible banana because of sterility and polyploidy of edible bananas. One strategy is to use the naturally occurring clonal variability to select short stature cultivars that maybe growing in the country. One hundred sixteen (116) accessions of ‘Cardaba’/‘Saba’ and other cultivars were collected from twenty six (26) banana growing areas of the country during the period. Of these, 77 accessions were considered putative dwarf, with pseudostem height below 4 meters. These accessions are currently maintained in the field for evaluation and confirmation. From these collections, 32 bunches have already been harvested, characterized and evaluated. Three promising cultivars have been selected based on short stature, early fruiting and high yield. These
Molecular Detection, Cloning and Partial Characterization of Banana Streak Virus from Sri Lanka

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Banana streak virus (BSV) is a member of the Badnavirus genus in the Caulimoviridae family with circular double-standard DNA genome. BSV has emerged as an important pathogen affecting the productivity of bananas and plantains in Sri Lanka. Total plant and viral genomic DNA was extracted from young leaf tissues of BSV-infected banana using a modified cetyltrimethylammonium bromide (CTAB) method. The expected size of 770-bp fragment of the RT/RNase H region located on ORF III in the genome of BSV was strongly and consistently amplified with BSV infected plants using specific primers (sense primer BSV 5466 5’-AGA GTG GGT TTC ATC AAG TAG-3’ and anti-sense primer BSV 6196 5’-GAA TTT CCC GCT CGC ATA AG -3’) designed on the sequence data of the Onne of isolate BSV (GenBank Accession No. AJ 002234). The polymerase chain reaction (PCR) assays developed in this study allowed for the specific detection of BSV-infected plants and its discrimination from healthy ones. The purified PCR fragments obtained were cloned into the plasmid vector pTZ57R/T using InstAcloneTM PCR Cloning Kit (Fermentas Life Sciences, Germany) and inserts were sequenced. The clones were found containing a part of open reading-frame III of BSV. The sequences were compared

include: 09-063 (‘Luyluy’/‘Dippig’), 09-064 (‘Cardaba’), and 10-009 (‘Saba’). Sensory evaluation was conducted using 16 different accessions of ‘Saba’ and ‘Cardaba’ for both cooked and uncooked type. For the uncooked type, ‘Dippig’ appeared to be mostly liked by the respondent while 09-011 (‘Cardaba’) and ‘Dippig’ were more preferred for the boiled banana. On the other hand, 7 accessions were used for banana chips evaluation. Based from the sensory, 09-044 (‘Cardaba’) was preferred most while 09-010 (‘Dalian’) was the least preferred by the respondents. Morphological characterization and photo documentation of all the collections were also conducted. Disease evaluation for BBTV, BBrMV, and CMV was done using ELISA. None of the accessions were found to have BBTV while 2 accessions namely: 09-041 (‘Dalian’) and 09-058 (‘Dippig’) were positive to BBrMV.
Isolation and Characterization of Major Anthocyanins and Phytosterols in Banana Male Buds

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Banana (Musa spp.) is one of the commercially important tropical fruits in Taiwan. The banana male bud is a component of the inflourescence of the banana plant. In some countries, banana male buds are used as a culinary ingredient but in Taiwan they are discarded in banana orchards. Studies on banana male buds are limited, especially in the analysis of bioactive components. Anthocyanins are water-soluble phenolic pigments with antioxidant properties and widely distributed in plants. Phytosterols are also found in plants, and can be used to lower cholesterol and blood sugar. The purposes of our study are to isolate and characterize the major anthocyanins and phytosterols from banana male buds. Anthocyanins in banana bracts were extracted with acidic methanol, purified using Sep-Pak C18, and then characterized by UV-visible spectroscopy and high-performance liquid chromatography (HPLC). Cyanidin (68.89% of total anthocyanins) was found to be the major anthocyanidin in banana bracts and delephinid (17.67%) was the second. Minor anthocyanidins in banana bracts were petunidin, mavidin and peonidin. Phytosterols in banana male flowers (BMF) were extracted with petroleum ether at room temperature. The extracts were isolated and purified repeatedly by column chromatography. The fraction was then measured by HPLC method and compared with the standard of known phytosterols. At present, two major sterols, stigmasterol and β-sitosterol, from the BMF’s petroleum ether extract have been isolated and identified, and quantitative investigations of these steroids are in progress.
Screening of *Musa* Germplasm Against Banana Thrips

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More than 15 insect pests have been reported as pests of banana and plantains. Six species of thrips belonging to the *Thripinae* and *Heliothripinae* families were found associated with bananas and plantains. These inflict damage on fruits, which adversely affects the fruit marketability and commands lower market-prices. *Musa* germplasm available at the National Research Centre for Banana (NRCB) in Tiruchirappalli, India was evaluated against finger thrips between 2005-2010. Observations were recorded on 223 accessions, of which 54 accessions indicated rust thrips and 46 accessions revealed silver thrips, with the single cultivar Nendran indicating flower thrips infestation. One hundred twenty-two (122) accessions were found free from any thrips infestation. The rust thrips infestation was higher in banana germplasm belonging to the ABB genomic group followed by 37% in ABB. The silver thrips infestation was recorded more in AB (59%), followed by 17% in AAB interesting genomic group belonging to ABB (39%), ABB (33%) and AB (15%) were found free from thrips infestation. Flower thrips, (*Thrips hawaiiensis*) infestation was very severe in the plantain cultivar, Nendran. Among the genomic groups, the leaf thrip— *Helionothrips kadaliphilus* (R&M) infestation was least observed at 4% in Nandan (AB) and most recorded at 58% in Nendran (AB). Among the AA diploids 8% infestation was reported on Hatidat and 42% in Amrit sagar, whereas among AB diploid infestation the percentage was 4% in Nandan and a maximum of 58% in Norman. Bhimikol, showed a minimum percentage of 7% and maximum in *Musa balbisiana* (BB). Among the triploids (AAA) Thellackackrakele showed a minimum infestation of 5% and a maximum of 54% by Galanamulu; whereas for ABB, Chandan showed 4% and Rasthali 42%. In ABB, a minimum of 4% by Ennabenian and 32% by Bersain was observed. Among ABBB tetraploids 6% was maximum (Klueteparod) and 36% (Hybrid sawai) was the maximum infestation.
Comparison of Aroma Compounds in Cavendish Banana (*Musa* spp. AAA) Grown From Organic and Traditional Cultivation

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The aroma profile from ripened fruits of Dwarf Cavendish banana cultivars grown under traditional (Tr) and organic cultivation (Or) was studied in order to determine aroma differences. Aroma compounds were extracted with dichloromethane, and analyzed by gas chromatography (GC), flame ionization detection and GC–mass spectrometry. According to sensory analysis, the aromatic extract of banana was representative of banana odour. A total of 66 components were identified and quantified in Tr-banana and 76 in Or-banana. Or-banana contained more aroma compounds both qualitatively and quantitatively. Of all aroma compounds measured, esters were present in the highest amounts, followed by aldehydes. The main esters were 2-Pentanol acetate, isoamyl butanoate, 3-Methylbutyl 3-methylbutanoate and n-Butyl acetate. The total amount of esters in Tr-banana was 19.93 mg/kg and in Or-banana 27.74 mg/kg. Based on the sensory analysis, Or-banana was preferred over bananas produced in traditional cultivation, because of their aroma quality.

Potential of *Musa* EST-SSR Markers in Improving Members of the Order Zingiberales

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The Expressed Sequence Tag-Simple Sequence Repeats (EST-SSRs) are located in well-conserved regions across phylogenetically-related species, making them the markers of choice for comparative mapping and relevant functional and positional candidate trait specific genes. EST databases of 11 *Musa* cDNA libraries were retrieved from National Centre for Biotechnology Information (NCBI) and used for mining SSRs. Out of 21056 unique ESTs, SSR regions were found only in 5158 ESTs. A gene ontology search was carried out in *Musa* ESTs containing di, tri, tetra, penta and hexa repeat SSR regions, by using the Blast2GO (www.blast2go.org) tool and the results revealed that nearly 29% of ESTs are grouped
under unknown/predicted/hypothetical categories. The remaining ESTs were categorized according to molecular functions. In silico comparative analysis indicated that when DNA sequence identity was at ≥ 80 %, *Musa* SSR containing ESTs sequences showed 23% and 10% homology to EST sequences of *Oryzae* and *Arabidopsis*, respectively. This poor homology with monocot and dicot model-crops suggested that these are not ideal for comparing the *Musa* genomes. To extend the application of information generated, its transferability across the other members of *Zingiberales* was studied, where EST databases are limited. For this, SSR primers were synthesized for 24 ESTs having putative functions, and tested across different genomic groups of *Musa, Ensete superbum, E. glaucum* (Musaceae) and *Zingiber officinale, Elettaria cardomomum* and *Curcuma longa* (Zingiberaceae). The results showed that 88% of primers used were functional primers and 43% showed polymorphism among the *Musa* accessions. Transferability studies of *Musa* EST-SSRs among the genera of the order *Zingiberales* exhibited 100% and 58% transferability in Musaceae and Zingiberaceae, respectively. This suggests that *Musa* EST-SSR markers can be a valuable resource for such comparative mapping, through developing COS-markers for evolutionary studies and in improvement programmes of the members of Zingiberaceae and Musaceae.
Genetic Diversity of *Fusarium oxysporum* f. sp. *cubense* in East and Central Africa Based on Vegetative Compatibility, Ribosomal DNA Polymorphism and Phylogenetic Analysis

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The pathogen *Fusarium oxysporum* f. sp. *cubense* (Foc) is a major constraint to banana production globally due to a lack of reliable and/or efficient control options, and threatens the income and livelihoods of millions of people in east and central Africa (ECA). Sustainable management of the pathogen depends on a proper understanding of its diversity and population dynamics. The current study investigated the diversity and dissemination of Foc in ECA. Based on vegetative compatibility group (VCG) analysis, PCR-RFLPs of the IGS region, as well as phylogenetic analyses of the elongation factor-1α gene, we found that five VCGs, all belonging to Lineage VII, were widely distributed throughout the region. These included VCGs 0124, 0125, 0128, 01212 and 01220, and complexes thereof. VCGs 0128 and 01220 are reported for the first time in Rwanda, Burundi, the Democratic Republic of Congo (DRC), Tanzania and Uganda. Furthermore, VCG 01212 isolates were identified in the DRC, Tanzania and Uganda, and isolates potentially belonging to VCG 01214 (lineage VIII) were identified in Tanzania. This makes ECA the second most diverse centre for Foc after Southeast Asia. The VCGs were disseminated relatively equally throughout the region, except for VCGs 01212 and putative VCG 01214 isolates, which were mainly found in Tanzania, suggesting that the pathogen was probably introduced into ECA via Tanzania with planting materials from Asia. This information is important for the implementation of disease management practices in the region, such as the restricted movement of infected planting material and the selective planting of resistant banana varieties.
The Development and Impact of In Vitro Induction in Organogenesis and Somatic Embryogenesis of Bananas by Professor Ma.


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The plant tissue culture suffers a lot of stresses during serial culture period, also feasibly to offer diverse stress pressure and to select desirable mutants. The application of in vitro technology is based on the regeneration system that is divided into two major pathways as organogenesis and somatic embryogenesis. Professor Ma has great contribution on both regeneration pathways mediated somatic (shoot apex), reproductive (inflorescence) and endosperm tissue cultures. He published the first paper of decapitated shoot apex culture to induce adventitious but on modified mediums supplemented with 340 mg/L NaH2PO4, 100mg/L tyrosine, 160mg/L adenine sulfate and 2 mg/L of both IAA and kinetin. Repated subculture of small shoot cluster on BA (5mg/L) containing medium resulted in multiple shoot proliferation. And indicated that the decreased agar concentration (0.5%) or in liquid medium is effectively to stimulate shoot sprouting and rooting. Additionally, demonstrating young inflorescence section culture exhibited high caulogenic competence, the condition for adventitious bud induction and serial proliferation is resemble to decapitated shoot culture. Professor Ma is also the first to establish inflorescence tip section or young male flower cultures for qualitative somatic embryos formation via callusing, cell suspension culture, cell plating and embling conversion procedures with four different formulated media respectively. The longest growth cycle of embryogenic cell suspension culture can be divided into five phases and 15 stages. It was found that the apolar PEDCs and polar EDCs are interreversible via extracellular pH controlling. Subsequently, the
Some systemic virus diseases have been causing great losses on fruit yield and quality, and have become one of the serious constraints of the banana industry in Taiwan. The virus diseases can be well controlled through integrated disease management. Of particular importance is to cultivate virus-free (VF) banana seedlings through tissue culture with cultivars of VF banana foundation. The precise and rapid virus-indexing techniques are indispensable for the disease management. The molecular diagnostic probes including monoclonal antibodies based enzyme-linked immunosorbent assay (ELISA) and diagnostic strips, and primer pairs for polymerase chain reaction (PCR) and reverse transcription PCR (RT-PCR), have been developed for formulating indexing techniques, and characterization of the viruses and their strains. The banana bunchy-top disease (BBTV) has been the common and destructive virus disease of banana since the beginning of the 20th century in Asian and Pacific regions. Several occurrence of outbreak became the limiting factor for
banana industry in Taiwan during the past decades. The BBTV strains were differentiated into such four symptom-types including severe (S), intermediate (I), mild (M) and latent (L) strains, and characterized by PCR amplification patterns with three primer pairs into the six PCR genotypes. Banana mosaic (CMV) caused by cucumber mosaic cucumovirus (CMV) was first reported in New South Wales in 1929. This disease had become prominent in Taiwan in 1974, and severe outbreaks occurred recently after common cultivation of tissue-culture plantlets. Three strains of CMV were found to induce three leaf symptom types including necrotic sever mosaic, severe mosaic with distortion and mild chlorotic stripe. Banana streak disease (BSV) was first described from Ivory Coast in 1974. The disease has been found world-wide. Leaf-stripping symptoms in Mysore (AAB) in Trinidad, have been found associated with banana streak badnavirus (BSV). The virus infection was found in exotic Mysore banana in Taiwan in 1994. The BSV-infected Mysore plants and germplasm had been destroyed soon after the first discovery. The BSV infected banana cultivars in episomal and integrate forms. Three strains of episomal form including Obino l’Ewai, Mysore and Goldfinger were detected in 11 exotic cultivars including AA, AAA, AAAA, AAB and ABB genotypes of germplasm from 225 cultivars. The all exocotic cultivars under quarantine condition were indexed by PCR and RT-PCR with 3 strain-specific primer pairs. The 11 cultivars showing positive detection of episomal form of transmissible BSV, had been destroyed soon after indexing. The cultivars of banana foundation free from BBTV, CVM and episomal BSV have been used for production of TC-plantlets.

Key Banana Pest and Disease Challenges and Their Mitigation in Africa

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Africa enjoys a wide range of production and agroecological systems in which a diversity of banana types is thriving. The systems support a wide range of pests and diseases that attack the plant and curtail its ability to grow and function. Yield losses of 5-100% pose livelihood challenges as smallholder yields of 6-15 t/ha are far below the potential of 40-60 t/ha. The composition of banana pests and diseases—weevils, nematodes, viruses, fungal and bacterial diseases—has not changed much over the last 50 years.
though their importance has varied with production and agroecological systems. Weevils, burrowing nematodes and black sigatoka occupy regions below 1400 masl in East and West Africa, while yellow sigatoka and lesion nematodes occupy regions above 1400 masl in Africa. Banana bunchy top disease (BBTD), originally confined to hot lowlands (<1000 masl), probably due the vector ecology, has invaded higher grounds. Similarly, the banana Xanthomonas wilt (BXW) confined to the Ethiopian highlands for more than half a century, has moved out to the rest of East Africa in the last decade. Other diseases appear to be more cosmopolitan, regardless of the agroecology (BXW and BSV) while others are limited to specific production systems (Fusarium wilt). A combination of climate change and weak quarantine support has been cited to explain the changes in distribution of most diseases in Africa. Management strategies, including breeding for resistance, micro- and macro-propagation, cleaning infected material, pest trapping, biological control and host of cultural controls linked to field sanitation have been tried singly and in combination. Here the level of management is a function of production systems, farming objectives and government policies for the banana sub-sector. Resource-poor farmers may not readily adopt expensive options such as chemical control or quality seed. Conversely, commercial farmers will adopt new technologies given their know-how and resources to invest. Increased yield loss assessment studies, coordinated quarantine, strengthened human and infrastructure capacity and improved investment in the banana sub-sector will alleviate pest and disease pressure for smallholder farmers in Africa. The paper reviews pest and disease management strategies applied in Africa, discusses their strengths and suggests aspects that require urgent attention.

**Bananas in Latin America and the Caribbean: Major Pest and Disease Challenges and Perspectives for Sustainable Management**

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Although neither the center of origin of bananas nor a centre of domestication or secondary diversity, Latin America and the Caribbean (LAC) grow 28% of the global production and 7 countries of the region are
in the top 10 banana exporting nations. In spite of considerable technical 
change in recent decades, bananas in LAC continue to face important 
challenges for sustainable pest and disease management. While some 
problems such as Fusarium wilt (*Fusarium oxysporum* f. sp. *cubense*), banana 
rust thrips (*Chaetanaphothrips signipennis*), Erwinia soft rot (*Dickeya* spp.) and 
moko (*Ralstonia solanacearum*) are specific to certain production systems, 
Black Leaf Streak Disease (BLSD) or Black Sigatoka (*Mycosphaerella fijienis*) 
is still the major phytosanitary challenge for banana production in LAC. 
BLSD was officially reported in the region in Honduras in 1972. Forty years 
later, BLS has caused severe economic and environmental impacts and 
reached the only tropical countries that had remained BLSD-free. There is 
a common understanding among experts that chemical control alone is no 
longer sustainable, due to fungicide resistance, increasing legal limitations 
and environmental issues, but control measures for BLSD still rely heavily 
on fungicide applications. Significant knowledge has been accumulated 
in different components of the integrated management, such as reduction 
of the inoculum pressure in the field through sanitation, forecasting-
guided fungicide application, fungicide sequence management, as well as 
timing and quality of the chemical applications, which can contribute to 
fewer fungicide applications. Furthermore, promising alternatives such as 
biological control and enhance natural plant defenses are under validation 
in some research institutes in the region. In this work, we will present the 
state-of-the-art of major pest and disease problems in LAC emphasizing 
novel developments for integrated disease management and giving a 
detailed overview of BLS impact including the breakdown of resistance 
in FHIA cultivars and the recent spread of BLS to the Caribbean Islands St 
Vincent, Sta Lucia, Martinique, Guadeloupe and Dominique.
A Novel Technique for Mass Indexing of Tissue-Cultured Banana Plants for Banana Bunchy Top Virus (BBTV)

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Among the four major viral diseases infecting banana, banana bunchy top virus (BBTV) is the most devastating as it can cause heavy yield losses if planting materials have been pre-infected. Banana viral diseases continue to be a serious problem in banana cultivations, due to their systemic, invasive nature. These are transmitted through vegetatively-propagated infected planting materials. One of the disadvantages of tissue-cultured plants is the possibility of viral infection when sensitive, rapid and reliable indexing procedures are not followed to eliminate infected plants at any stage of the tissue-culture protocol. Thus, indexing mother plants and planting materials for freeness from viruses becomes more important to assure the availability of healthy planting materials to growers. Theoretically, it is ideal to test and index all or a large proportion of mother plants and plantlets before releasing to farmers. However, from a practical point of view, it is rather difficult and costly to index a large number of samples with the techniques currently available. Therefore, a novel technique has been standardized to address this problem and provide results in a short period at a low cost. Testing of each sample using polymer chain reactions (PCRs) is laborious and costly, hence, emphasizing the need for more feasible mass detection techniques. A large number of samples could be assayed with a relatively small number of PCR reactions by using combinatorial screening in which 144 samples are arranged in 12 X 12 spatial format. Equal amounts of banana tissue (50 mg from each sample) from 12 samples arranged in a row were pooled (composite sample) for DNA extraction using a modified CTAB method and subjected to row PCR with BBTV specific primers. This would identify the rows that accommodated BBTV infected sample(s). Similarly, equal amounts of banana tissue (50 mg from each sample) from 12 samples arranged as a column were pooled (composite sample) for DNA extraction and subsequent PCR amplification in which columns accommodating infected samples could be easily traced. Considering the results of both row and column PCR, possible samples suspected to be infected with BBTV were recognized. These samples were individually subjected to PCR for exact
identification of the infected samples. The technique developed by us for mass-indexing of banana samples for BBTV is the first such technique in the world and has a number of advantages over the conventional PCR techniques currently used.

Rapid Mass Micropropagation of *Musa acuminata* cv Berangan (AAA): From Lab to Field

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Embryogenic cell suspension, which consists mostly of groups and of single cells which are totipotent, clonal with rapid cell proliferation, is not only an ideal system for genetic transformation, but is also suitable for protoplast culture and somatic hybridization purposes. Furthermore, somatic embryos are important for *in vitro* preservation of germplasm and trait improvement via mutation breeding. The current protocols for banana somatic embryogenesis are limited by low embryo germination, low plant regeneration rates and a long culture period. Thus, the downstream processes (multiplication, development and regeneration) need to be optimized to improve the number of plantlets recovered from somatic embryos. In this present paper, the optimum factors effecting Berangan somatic embryo development was studied. Two amino acids (L-glutamine and L-proline) of different concentrations were tested in different phases of developmental media (liquid and solid). Results obtained favoured the addition of glutamine to the culture media which supported the embryo formation and plant regeneration. Although proline was shown to help embryogenesis in some plants, the effect was contradictory for Berangan cell suspension cultures. Regenerants were acclimatized and transferred to the field successfully. The plants performances were assessed both grown in the open field and grown between oil palm trees. When compared to the controls, the occurrence of somaclonal variation was not significant. The fruit bunch was also comparable to the controls. Some plants were observed to flower earlier than the conventional 10 months period stipulated.
Improvement and Application of Banana Micropropagation in Taiwan

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The banana micropropagation system at Taiwan Banana Research Institute (TBRI) was established in 1983 to produce healthy plantlets to control the spread of Fusarium wilt (Foc TR4) through traditional planting materials. In the past 30 years, over 60 million plantlets have been propagated for commercial planting. Continuous efforts for improvement are made to overcome the increase in demand and rocketing production costs. A review of the improvement in culture medium formulation utilizing a mixture of Thidiazuron (TDZ) and Paclobutrazol (PP333) in Cavendish cultivars (AAA) and cultivars consisting of (AA), (AAB) and (ABB) genome will be presented. The investigation of different combinations of TDZ + PP333 in the culture medium resulted in the establishment of an efficient protocol for cauliflower-like bud clumps (also known as multiple bud clumps). The stepwise increase in TDZ concentration in the culture medium containing PP333 gives rise to the various sizes and shapes of clusters of tiny buds and naked meristems. These multiple bud clumps are useful materials for in vitro selection. In the past few years, this system has produced bud clumps which can survive high concentrations of Fusaric acid (0.15mM to 0.2mM). Upon regeneration of plantlets and screening for disease resistance in the net house, several somaclones with increased resistance to Foc TR4 and superior horticultural traits are identified in Fusarium wilt-susceptible Cavendish cultivars ‘Pei-Chiao’, ‘Tai Chiao No. 2’ and ‘Tai Chiao No.6’. Multiple bud clumps have also been applied in callus-induction, using Picloram in a semi-solid medium, and the subsequent regeneration of plantlets has shown normal and vigorous growth in the nursery. This callus-induction system is now applied in the in vitro selection for resistance to Fusarium wilt using Fusaric acid and to drought resistance using Polyethylene glycol.
Effects of TDZ on Morphological and Biochemical Changes of Banana Plantlets (Musa spp.) Cultivar Mas Cultured in Temporary Immersion Bioreactor System

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Banana is the second most important fruit crop in Malaysia covering 15% of the fruit acreage. Due to the high market demand the areas for banana planting are increasing, however, there is a shortage of quality planting materials to support the plantation industry. Banana cv Mas is a popular dessert banana, but displays a low multiplication rate especially in a solid media system. The application of a temporary immersion bioreactor (TIB) system to propagate banana plantlets offers a potential approach in mass producing planting materials. Our preliminary study has shown that TDZ could be used to efficiently micropropagate banana plantlets. The study was carried out to investigate the effects of different concentrations of TDZ on morphological and biochemical changes in banana plantlets cultured in a TIB system. Banana shoot tips were cultured for 28 days in Murashige and Skoog (MS) + B5 vitamins+ 30 g/l sucrose media supplemented with various concentrations of TDZ (0, 0.2, 0.4, 0.6, 0.8 and 1.0 mg/l). At the end of the experiment the following parameters were measured: the number of shootlets produced, the number of leaves formed and their respective fresh and dry weights, the total chlorophyll, protein and soluble sugar content. The results showed that TDZ at 0.4 mg/l produced a maximum number of shootlets (3.2±0.45) as compared to 1±0, 2±0, 2.4±0.55 and 2.2±0.45 in other TDZ treatments (0, 0.2, 0.6, 0.8 and 1.0 mg/l, respectively). However, no specific trend was observed in the chlorophyll, protein and sugar content for all treatments examined. Significant differences in these biochemical components may be observed if the experiment was conducted for a longer period of time.
Farmers’ knowledge of Banana Crop Management As Related to the Control of Banana Diseases in Burundi

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Banana is a major staple crop for the livelihoods of the people in all agro-ecological zones in Burundi. Unfortunately, this crop is threatened by different constraints that limit its production potential. In previous studies, Fusarium wilt, banana bunchy top disease (BBTD), sigatoka, weevils and nematodes were reported as the main constraints in banana plantations. Additionally, in November 2010, banana Xanthomonas wilt (BXW) had been reported in Cankuzo and Bubanza provinces. Hence, a baseline survey was conducted in August 2011 in all 16 banana-growing provinces in Burundi. A total of 6240 mats in 208 farms were assessed, consisting of 30 mats randomly sampled per farm. The status of diseases and pests, banana plantations, socio-economic aspects and farmers’ knowledge on disease management were evaluated. Interviewed farmers reported the major constraints of banana production to be pests and diseases (48%), low soil fertility (41%), limited land (30%) and lack of clean planting material (23%). The predominant diseases were black sigatoka (54%), Fusarium wilt (45%); BXW (25%), BBTD (16%), weevils (14%) and Armillaria corm rot (10%). The BXW attacks all banana cultivars and causes yield loss from 65 up to 95% at farm level and banana sales dropped by 35% in Burundi. This poses socio-economic and biological implications that require further investigations. In addition to these constraints facing the banana crop, lower farmer education level (around three years) and low awareness about disease symptoms and spread mechanisms could be the factors which negatively affect banana production in Burundi. Thus, raising farmer awareness about integrated crop management approach should contribute to sustain banana diseases control in Burundi.
Fine-tuning Xanthomonas Wilt Control Options Over the Past Decade in East and Central Africa

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Xanthomonas wilt, caused by Xanthomonas campestris pv. musacearum (Xcm) has, since 2001, become the most important and widespread disease of Musa in east and central Africa. Over the past decade, new research findings and especially feedback from small-scale farmers have helped in fine-tuning Xanthomonas wilt control options. During the initial years of the Xanthomonas wilt epidemic in East Africa, the complete uprooting of diseased mats and the burning or burying of plant debris was advocated as part of a control package which included the use of clean garden tools and the early removal of male buds to prevent insect vector transmission. Uprooting a complete mat (i.e. the mother plant and a varying number of lateral shoots) is understandably time-consuming and labor intensive. This strategy becomes very cumbersome when a large number of diseased mats have to be removed. Burning fresh banana plant tissue also requires a large amount of fuel wood, while digging a deep and large pit to bury plant debris is understandably very labor intensive. Heaping of plant debris at the edge of a diseased field was subsequently advocated as Xcm bacteria do not survive long in decaying banana plant tissue. Splitting pseudostems was advocated to enhance the decay of the plant tissue, while the herbicide 2,4-D was reported as very efficient in killing banana mats though the applicability is limited by high cost and the presence of roaming farm animals that could ingest some of the treated plant tissues. Recent research findings suggest that Xcm bacteria do not colonize all lateral shoots (i.e. incomplete systemicity occurs). This led to a new control method whereby only the visibly diseased plants within a mat are removed/cut at soil level. The underlying idea is that the continued removal of only the diseased plants in a field will reduce the inoculum level and will bring down disease incidence to an acceptable level. This method is less labor intensive and takes a short time compared to the removal of a complete mat. Single diseased stem removal needs to go hand in hand with prevention of new infections that can occur through the use of contaminated garden tools or through insect vector transmission. It is postulated that this method will work in fields were the initial incidence level is below 20%. Fields with
over 20% incidence levels need to be completely removed, i.e. cut all pseudostems of all mats at soil level and split the stems, and continuously remove all re-sprouts until all corm tissue is totally decayed. This corm rotting process may however take up to one year, during which annual crops can be planted.

The Study of Pisang Barangan Resistance to Banana Blood Disease Bacterium (*Ralstonia Solanacearum* Phylotype IV) By Use of Indigenous Arbuscular Micorrhizal Fungi

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Blood disease caused by *Ralstonia solanacearum* Phylotype IV is a major cause of production loss of banana in Indonesia. The disease is particularly severe in North Sumatera Utarahas. There is currently a lack of information about the application of indigenous Arbuscular Micorrhizal Fungi (AMF) to increase the resistance to *R. solanacearum* Phylotype IV in ‘Pisang Barangan’ banana. The purpose of this study was to investigate the effectiveness of increasing ‘P. Barangan’ resistance against *R. solanacearum* Phylotype IV. It was conducted in a completely randomized design comprising 3 types of AMF treatments Glomus type-1; Acaulospora type-4 and *Glomus fasciculatum*. The results indicate that Glomus type-1 and *G. fasciculatum* increase banana resistance to BBD by 100% while Acaulospora type-4 does only 20%.
Comparison of Liquid Culture Methods and Effect of A Temporary Immersion Bioreactor on Multiplication of Banana (Musa cv. GCTCV)

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Four different liquids, as well as solid culture methods used in shoot propagation of banana were compared. Treatments studied were solid medium (A), liquid medium with immersion of plants (B), liquid medium with span support (C), liquid medium aerated by bubbling (D), and liquid medium with a temporary immersion bioreactor system (TIB) for 15 minutes every 4 hours (E). After 4 weeks of culture, shoots in liquid medium with immersion and liquid medium aerated by bubbling showed none too little proliferation. Shoots in the solid medium and those cultured in liquid medium containing span culture supported played multiplication rates of 2.7 to 3.5 with the highest multiplication rate (> 7.00) observed in the explants that were subjected to the TIB in the medium. Three treated groups differed in the accumulation of dry matter; the lowest weight (around 0.6 g) was observed in treatments B and D, while 2 to 4 times greater accumulation was observed in the explants in the solid medium and those cultured in the liquid medium with a cotton culture support. The highest multiplication rates and weight gains were observed in the liquid medium with a TIB (E).
Production of Tissue-Cultured Banana Seedlings and Farm Improvement in Sri Lanka

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Lack of disease-free and uniform planting material and updated knowledge are major problems among banana farmers in Sri Lanka. In order to solve these problems, the University of Colombo set up a tissue culture laboratory at the Magampura Agro-technology and Community Service Center in 1998. The community service centre grew to become a legal body called The Institute for Agro technology and Rural Sciences, University of Colombo. The Institute has introduced tissue-cultured banana production methods to farmers. Currently, 19 village girls are employed at the tissue-culture unit, which produces 15,000 banana seedlings per month. The seedlings are sold at Rs 50 (US$ 0.50) per plant. It conducts farmer trainings on banana cultivation and guidance programmes up to marketing level. These new technologies are easily adopted by farmers resulting to improved income usually by 8-10 folds as compared to their previous typical rice-based cropping system. A farmer down south of Sri Lanka obtained Rs 1.6 million (US$ 12,400) from a 1-ha tissue-cultured banana field with a single harvest in 2011. The Institute carries out regular monitoring and evaluation to guide farmers with updated knowledge. The farmers’ purchasing power and availability of farm machineries have also substantially increased. The Institute has developed digital content and published in Wiki Educator for banana farmers with the collaboration of Lifelong Learning for Farmers (L3 farmers) project of the Common Wealth of Learning (COL) in both Sinhala and English media to improve farm income and livelihoods. The eco-friendly farming system that had been implemented in the southern part of the country is now expanded to the northern and eastern provinces of Sri Lanka. More than 5,000 farmers have been involved with the Institute and benefitted from the new banana-based technologies and learning system.
Evaluation of Cavendish Somaclone Variants and Local Cultivars Against Fusarium Wilt (TR4) in the Philippines

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The recent epidemics of Panama wilt (Fusarium wilt) caused by the virulent Tropical Race 4 (TR4) of Fusarium oxysporum f.sp. cubense (Foc) is a serious threat to the Philippines’ banana industry. To mitigate the disease, selected varieties from the Bioversity’s International Transit Centre (ITC) in Belgium, and local cultivars were evaluated for their reactions to Foc in two commercial fields (Lapuy and Callawa in Davao City, Philippines) heavily infested by TR4. Eight varieties, including one commercially grown Cavendish, 4 Cavendish somaclone variants from Taiwan (GCTCV 105, 119, 218, 219) and 3 important local cultivars were evaluated. Experimental plot comprised of 10 tissue-culture derived seedlings, replicated 10 times, and arranged in completely randomized design. Disease incidence was assessed weekly by monitoring the appearance of the early symptom of yellowing of older leaves and/or other symptoms such as pseudostem splitting. To confirm the strain of the Foc pathogen, sample of the infected vascular tissues were analyzed for Vegetative Compatibility Group (VCG). The commercially grown Cavendish, Grand Naine, showed susceptible reactions with incidence of 97% incidence before shooting in the primary crop in Lapuy and 17% in Callawa. Lakatan, a popular local cultivar for the local market was most susceptible with 100% incidence in Lapuy and 42% in Callawa area. The GCTCV 105 and 218 from Taiwan did not show any infected plants in the first crop, and GCTCV 119 and 219 showed 1% incidence in Lapuy. While in the Callawa area, GCTCV 105 and 119 did not show any fusarium wilt incidence, while GCTCV 218 and 219 showed 6% and 1% incidence, respectively. Saba, an important cooking banana showed very high resistance with zero incidence observed until the ratoon crop. VCG analyses confirmed that Foc VCG 01213/16 was associated with the infections. Fruit yield and quality were also determined. The resistant Cavendish somaclones have comparable yield and fruit quality, even as these were relatively taller and matured slightly longer than the commercial varieties. The fruits of the resistant varieties were sweeter and are potentially acceptable in the export market.
Green Technologies to Enhance the Banana Industry in Sri Lanka: A Review

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Banana is the major fruit crop grown in Sri Lanka, covering 60,000 ha with an annual production of 110,000 MT per year. The banana industry in Sri Lanka has made significant progress in implementing more sustainable production. With objectives of introducing environmentally friendly techniques for fast propagation, pest and disease management, and improvement of product quality, as well as for development of banana-based products much work has been completed. The objective of this paper is to present a summary of findings made in respective disciplines in recent years. The availability of quality planting materials has been a major obstacle to expanding cultivation and introducing a high-density planting system. A farmer-friendly technology has been developed in this regard, thus improving access to suitable planting materials. Mechanical disturbance of the apical bud of developing plants of the crop activates the dormant buds to be grown into suckers providing a fast, user-friendly propagation technique as an option for tissue culture. A six-month old sucker produces 5 – 7 suckers, depending on the variety which reach transplanting maturity after three months. The spread of corm weevil via conventional suckers has restricted their usage and also increased infestation in new areas. Instead of using agrochemicals to treat the suckers, immersion of the corm in boiling water for 30 seconds successfully eradicated corm weevils, nematodes and certain other pathogens. In addition, heat treatment suppresses the development of virus symptoms after planting, possibly either due to the deactivation or stoppage of multiplication of virus particles. Results revealed that only 6 % of heat-treated plants showed disease symptoms in the latter part of the crop under an annual planting system and 94% showed no symptoms, though they possibly contained viruses. Generally in annual planting systems, herbicides or kerosene oil are used for de-suckering. However, careful detachment of plantlets from the mother corm inside the soil itself encourage the plantlets to produce roots within three weeks thus conferring independence from the mother plant. After three weeks these plantlets can be pulled from soil and uses as planting materials with well-developed root systems. This technique is preferable to chemical de-suckering with kerosene oil since it generates additional income for the growers and avoids using chemicals for sucker management.
In expanding cultivation, farmers tend to cultivate more lucrative banana cultivars such as Kolikattu (Silk) under irrigation, which unfortunately are also highly susceptible to Panama disease. Planting a Fusarium wilt-tolerant cultivar such as Embul (Mysoor) with wilt-susceptible banana cultivars such as Kolikattu (Silk), Anamalu (Grossmichel) has successfully reduced the damage caused by the fungi by preventing the disease spread. In an annual high-density planting system, planting susceptible cultivars with alternate barrier-rows of Mysoor completely prevents lateral spread of Fusarium wilt. In such a system, group planting with inclusion of a mysoor variety in a three plant cluster reduces the chances of infection of Fusarium wilt by 90%. The standard chemical fertilizer application has been altered by substituting inorganic phosphates with bio-charcoal in the late crop stages. In the specific management package developed for rain-fed banana, trimming of older leaves has been identified as a more-effective non-chemical means of controlling leaf spot diseases which easily invade the lower leaves. It is recommended to trim 3 – 4 lower leaves to control the disease especially in rainy periods. Technology has been developed to replace the commonly used polythene food wrappers using banana leaves. Banana leaves can be used to produce cured bio food wrappers which can be stored for three weeks in refrigerator without affecting the quality. Using all forms of banana leaves can be fabricated into bio plates with a cost of production of US $ 0.012 per plate. Since this creates an unprecedented demand for banana leaves ultra dense planting system has been introduced for leaf-oriented banana cultivation. De-belling of bunches before completion of the hand separation in ultra high-density planted banana improved bunch quality, producing alluring bunches potentially commanding a higher price. Presently three separate management-packages have been developed for cultivating banana which are for fruits; fruits and leaves, and leaves only. Accordingly, the Sri Lankan banana industry has been rendered more sustainable.
‘Pei Chiao’ Fruit and Pseudostem Replacements for the Mainly Carbon Source of Trametes Versicolor and Antrodia Camphorate Liquid Culture Medium

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Banana is one of the popular fruits in Taiwan. Among the banana cultivars, ‘Pei Chiao’ is most profitable. White-rot and brown rot fungi are considerably effective in decomposition of lignocellulose. ‘Pei Chiao’ pseudostems were dried and crushed into 5 mm powder to replace the mainly carbon resource of Trametes versicolor, or Yunzhi, (white rot fungi) Sabouraud dextrose broth (SDB) liquid culture medium. Trametes versicolor would effectively decompose lignocellulose of banana pseudostem after a 12-day culture, degrading 18% of crude fiber content, exciting cellulose and hemi-cellulose which could serve as material for the fast conversion to green energy. Furthermore, unripe ‘Pei Chiao’ fruit was dried and crushed to 5 mm power to substitute Antrodia camphorata (brown-rot fungus) yeast extract liquid medium (YM) as the mainly carbon source. It was significant that the lipase activity of Antrodia camphorata reached up to 5.613 Um.L-1 and exopolysaccharide (EPS) content increased by 3.577 gm.L-1. Compared with the conventional YM medium, the ‘Pei Chiao’ fruit and pseudostem could effectively replace traditional chemical media as carbon source as it helps reduce cost and address the problem of banana surpluses in Taiwan.
Understanding of Plant-Soil Health for Sustainable Banana Production

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Banana production commercially has a narrow genetic foundation, meaning that management decisions have a major impact on the viability of production systems. Soil management, particularly the recognition of soil constraints, is the first step to developing more resilient systems. This requires assessment of physical, chemical and biological indicators, which can be related to important soil functions, like soil structural stability, nutrient and water capacity, toxin degradation and diseases suppression. Recognition of production and sustainability constraints allows management systems to be targeted to overcome problems, enhancing soil functions. For banana growers to adopt management practices that enhance soil health it is important to provide information where they can perceive the benefits to their business. This requires the delivery of information in a format which they can relate to and which overcomes their production problems. The importance of the different soil functions depends on the situation of individuals, differing between regions, farms and cultivars. Therefore, a general framework where banana growers can assess production constraints and implement management practices to enhance soil functions, can improve production and sustainability of bananas. For example, soils infested Fusarium oxysporum f. sp. cubense, suppression of the disease is required to sustain production of susceptible cultivars. The recognition of soil factors constraining suppression, such as low biological activity and diversity allow adjustments to management
practices to increase Fusarium antagonistic organisms. Maintaining vegetated ground cover around the base of banana plants was found to overcome low biological activity and diversity, increasing antagonistic organisms, resulting in suppression of the disease. This system is currently being trialled as part of an integrated Fusarium wilt management system to suppress the disease in Australia. Furthermore, observations from farmer’s fields suggest where soil health has improved, Fusarium wilt progresses slowly, due to an increase in biological activity and diversity. For banana growers to adopt management practices that enhance soil health it is important to provide information where they can perceive the benefits to their business. This requires the delivery of information in a format which they can relate to and which overcomes their production problems. The importance of the different soil functions depends on the situation of individuals, differing between regions, farms and cultivars. Therefore, a general framework where banana growers can assess production constraints and implement management practices to enhance soil functions, can improve production and sustainability of bananas.

Potential of Multipurpose Intercrops for the Management of *Radopholus similis*, Arbuscular Mycorrhizal Fungi and Root-nodulating Rhizobacteria in Banana-based Cropping Systems

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Plant-parasitic nematodes, especially the burrowing nematode *Radopholus similis*, continue to be a serious problem in banana-based cropping systems due inter alia to the lack of resistant banana cultivars and the limited availability of registrated nematicides. Up to 87% of the banana production worldwide takes place in subsistence cropping systems with mixed stand plants. In these low-input systems, the use of biological control organisms (BCO’s), which are sensitive to the use of agro-chemicals and heavy tillage, seems a promising alternative for integrated nematode management. Potential BCO’s are arbuscular mycorrhizal fungi (AMF) and root-nodulating rhizobacteria. In the study presented here, the interactions of five different biotic components in a mixed banana-based cropping system (banana and intercrops, AMF, root-nodulating bacteria and nematodes) were studied to develop a more
efficient nematode management strategy. Non-leguminous multipurpose banana intercrops included in the study were cotton, sesame, sorghum, sweet potato, marigold, sorgho-Sudangrass and wormseed. Leguminous multipurpose intercrop species included in the study were cowpea, Grant’s rattlesnake, hairy indigo, pigeon pea, sunn hemp, common bean and soybean. The results of the study and perspectives for the future will be presented and discussed.

Status of Distribution, Damage and Mitigation of Bacterial Wilt in Malaysia

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In Malaysia, banana is the second most widely cultivated fruit. However, in 2007, the banana industry was threatened by a bacterial wilt disease causing significant yield losses. After the disease outbreak, the Department of Agriculture conducted a survey covering an area of 3,212 ha from a total area of 8,200 ha planted with banana. Survey results showed that 60.7% of the banana plants were infected by the disease. To date, the disease has spread to other states namely, Kedah, Perak, Negeri Sembilan, Malacca, Pahang and Kelantan. The survey also showed that the cooking banana type viz. Pisang Abu, Pisang Nipah and Pisang Raja were badly infected with incidences of 100, 85 and 77%, respectively. Dessert bananas such as Pisang Rastali and Pisang Berangan were also heavily infected with an incidence of 64%. Generally, incidence of the disease in cooking bananas ranges from 70-100% while in dessert types it is between 30-50%. Banana plants infected with the bacterial disease display wilting and leaves become chlorotic at a very early stage of disease development. The internal portions of the fruits from infected plants show brown discolouration and premature necrosis. Recommendation for mitigation of the disease includes: 1) bagging the inflorescence; 2) removal of male flowers; 3) field sanitation; 4) sterilization of farm tools; 5) restriction of planting materials movement from infected areas to other areas; and 6) extensive campaigns for farmers on the recognition of disease symptoms, and preventive and control measures. Research initiatives are intensified to combat this disease especially in breeding for resistance, biological control and induced acquired resistance.
Suppressing Fusarium Wilt of Bananas With Ground Covers

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Widespread losses to banana production worldwide are attributed to Panama disease (Fusarium wilt) of bananas, caused by Fusarium oxysporum f.sp. cubense (Foc). Increasing soil biological diversity is a suggested strategy to manage soil-borne diseases, and ground covers are known to support different soil organisms. In a pot experiment, banana plantlets were grown with three different ground cover species, including broad leaf carpet grass, green leaf desmodium and pinto peanut, as well as with a combination of all three covers. The pots containing all three covers consistently showed higher microbial activity (Fluorescein Diacetate Activity, FDA), higher cellulose degradation (β-Glucosidase, BG) and better nematode indices than pots with individual covers, or those with pasteurized soil. This suggests that different ground covers support microbial diversity in the soil, and that multiple ground covers grown simultaneously increase soil biological activity the most. The outcome of the pot trial was further tested in a field trial in North Queensland to assess whether a naturally occurring ground cover established in Ducasse (Musa ABB) banana plantings suppresses Foc race 1 (VCG 0125). This ground cover was compared with a conventional practice of regular herbicide treatments with banana residues left on the soil surface. It was found that the ground cover reduced external and internal disease symptoms compared to those with bare soil and banana trash left on the soil surface. These plants also produced a greater proportion of harvestable bunches. The soil with a ground cover also significantly increased the activity of FDA and BG, as well as improved nematode indices in the field. Although the presence of a ground cover did not eliminate Foc, it demonstrated that healthier soil and plants suppress the effects of Panama disease.
Increased Soil Suppressiveness to Banana Fusarium Wilt Disease Through Banana Intercropping with *Allium* spp.

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Fusarium wilt (*Fusarium oxysporum* f.sp. *cubense* or Foc) is one of the most destructive diseases of banana and has spread in many local plantations in Indonesia. Until now, the effective ways to control banana Fusarium wilt disease have not been found yet. *Allium* spp. is one of many horticultural crops generally cultivated in Indonesia. Research conducted in China showed that the banana crop rotation systems planted with chinese leek (*Allium tuberosum*) in soil infested with Foc were able to suppress the development of banana Fusarium wilt disease effectively. This research was conducted to determine the effect of several species of *Allium* sp. planted with banana intercropping to improve soil suppressiveness to banana Fusarium wilt disease. The results showed that up to 12 months after planting, of four species of *Allium* spp. (*A. tuberosum*, *A. fistulosum*, *A. cepa* and *A. wakegi*) intercropping planted with banana Ambon Kuning (AAA) cultivar, only *A. tuberosum* and *A. cepa* were able to suppress the incidence of banana Fusarium wilt disease by 46% and 33% respectively, when compared to the control treatment. We suspect that the bulb extract of *Allium* spp. have different ability to suppress the growth and spore germination of Foc.
Isolation and Evaluation of Biocontrol Agents From the Phylloplane and Soil Rhizosphere of Banana Plants for Suppressing the Growth of *Fusarium oxysporum* f. sp. *cubense*

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Fusarium wilt of banana also known as Panama disease is caused by *Fusarium oxysporum* f. sp. *cubense* (Foc). The disease is considered fatal to bananas and is now found in most banana-producing regions except islands in the South Pacific, the Mediterranean, Melanesia, and Somalia. There are three known Foc races- Race 1, Race 2 and Tropical Race 4 (TR4), displaying different levels of virulence, with TR4 being the most virulent. Each Race has a range of strains categorized into vegetative compatibility groups (VCGs) These VC groupings help characterize the pathogenic virulence. As the disease contaminates the soil, production of susceptible banana varieties are reduced (such as Cavendish bananas for TR4). Chemical control of Fusarium wilt in bananas has proven ineffective against the pathogen’s thick-walled and long-lived chlamydospires. Moreover, chemical fungicides are potentially hazardous to the environment. Difficulty in controlling Foc without excessive use of fungicides has stimulated interest in biological control. As an environmentally-sound alternative control measure, biological control offers an effective and sustainable method against Fusarium wilt of banana. The objectives of this research were to: (i) isolate and identify potential biocontrol agents (BCA) against Foc and (ii) evaluate the efficacy of the BCAs isolated against Foc under laboratory conditions. The antagonists were isolated from the phylloplane and soil of banana rhizosphere in the field. Isolates were tested for antagonism against Foc on a PDA medium by the dual-culture plate method. The width of the antagonist growth was the only parameter measured. Seventy-one (71) isolates of BCAs isolated from the phylloplane and soil rhizosphere of banana roots were screened. Among these isolates, 5 isolates were found to be effective in inhibiting Foc. The BCAs were able to suppress the Foc up to 10 days. The isolates that had the most effective inhibition were further studied using an in planta assay.
Cultivation Management on Organic Banana Production at TBRI Farm

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Organic farming is becoming increasingly popular as an alternative to conventional agricultural production worldwide. Among many fruit crops grown organically, banana is one that can be produced with greater success. Banana remains an important fruit for export in Taiwan. In the organically operated banana plantation at TBRI, banana plants are either ratooned or re-planted using suckers. To prevent the plants from toppling during the typhoon and rainy season, 2-4 suckers are retained around the mother plant in each mat. Decayed plant residuum is considered as the primary source of nutrition supply. Castor seed-meal, palm bunch-ash and powdered oyster-shell are also applied as supplements. Manual weeding, mechanical weeding and mulching with plant debris are used as means of weed management. The plantation is completely infested with native weeds. Disease and pest incidences usually occur to a slight extent in the well-managed organic banana plantation. Freckle disease and flower thrips are the two most annoying problems in the management. Deleafing to reduce source of pathogen is the predominant way to control leaf Freckle disease. In addition, several materials that are effective and permitted in organic farming are recommended. Early bagging benefits fruit bunch protection against Freckle disease and flower thrips. Other bunch management operations include removal of flower remnants, dehanding, and debudding. In banana hand management, an EVA pad is inserted into the space between the upper hand and the lower hand to avoid the scarrings and blemishes caused by finger tips of the lower hand. Banana bunches are harvested according to a reference chart designed uniquely on the basis of banana maturity.
Influence of Long-Term Organic Farming on Banana Plantation Soil: From Microbial Aspect

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Organic farming, a promising agricultural approach which doesn’t rely on chemical fertilizers or pesticides, has gained much attention in recent years. The benefits from organic farming include the improvement of soil fertility, soil quality and food safety, which embrace a more sustainable agriculture. The present study aims to demonstrate the influence of long-term organic and conventional farming on soil microbial diversity. The carbon source utilization patterns regarding bacterial functional diversity as demonstrated by using different Biolog systems were validated. By analyzing the general characteristics of soil, bacterial numbers and functional diversity under different farming systems, we are able to recognize the response of microbial populations and their functional diversity in banana plantation soils. Additionally, the spatial and temporal variations of microorganisms were also assessed. The results demonstrated that bacterial numbers of heterotrophs, nitrogen-fixing bacteria and phosphate-solubilizing bacteria increased after organic amendments. The levels of enhanced richness, AWCD and H index which reflected the functional diversity were also recorded in soils after long-term organic fertilization. Certain kinds of carbon sources were only utilized by bacteria presented in organic-farming soils, which might serve as markers to trace unique populations. Although there were spatial variations in the soil systems under different treatments, the present study provided preliminary information on the benefits of bacterial diversity gained from organic farming.
The Effect of Cropping Systems in the Management of Fusarium Wilt to Increase the Livelihoods of Smallholder Banana Farmers


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Pilot studies through a livelihood approach of managing banana wilts and improving farm productivity to increase income of small scale farmers were carried out among small scale banana growers in Sarampad village – Cugenang – Cianjur – West Java – Indonesia. Different levels of disease and crop management practices developed from previous studies and experiences were adapted by farmer cooperators. Crop management options included land preparation, clean planting materials, plant density management, nutrient management, soil water moisture management, crop diversity (i.e intercropping, crop rotation). Disease management options included variety selections, clean planting materials, early detection and eradication, weed control, and vector management. Farmer cooperators chose to adapt various combinations of the above management options depending on their resources, capabilities, needs and interest, which was determined through a participatory rapid appraisal before the study was implemented. An assessment of 20 farmer cooperators and 11 non-cooperators were carried out to determine farmers engagements with the various options and what outcome in terms income has these options or combinations of options had brought to the household. Farmers owned grew bananas as single crop or in a mixed cropping system. Both cooperators and non-cooperators grow bananas in as a single crop or a mixed crop in land areas ranging from .3 to 3 hectares. Most of the small scale farmers who used mix-cropping systems with land preparation and population management had higher income. Farmer cooperators who used mixed cropping and clean banana planting materials and other disease management options such as early detection and eradication had their banana crops suffered less banana wilts (Panama Disease or Blood Disease), thus having generally more income contributed by the banana crop. This study is still work in progress, but preliminary results show that small scale banana growers who use cropping diversity with some cultural management such as land preparation, plant density management, nutrient management and certain disease management tactic generally are having higher income.
Field Evaluation of Pseudostem Injected Vydate L against Banana Nematode under Tropical Lowland Conditions in Mindanao, Philippines


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In order to reduce the negative environmental impacts of soil applied nematicides a new mode of application of Vydate L through the pseudostem was tested. The systemic active ingredient is basipetal, known to accumulate more in the root tips, within zones of elongation and points of lateral root formation. This study was conducted in collaboration with Dupont Far East Incorporated in a Cavendish plantation in Igpit, Digos City, Philippines. The trial area is typical of humid tropical lowland conditions. The trial was initiated in March 2010 and terminated in April 2012. The experiment included two treatments (Vydate L applied at four cycles/year, Vydate L applied at three cycles/year) and untreated control plots in a randomized complete block design (RCBD) replicated six times. Vydate L was applied through pseudostem injection accordingly to the plant development at rates of 10, 7.5 and 5ml/plant for the non bearing, follower and sucker stage, respectively. Vydate L considerably reduced Radopholus similis population below an economic threshold (10,000/100 g roots) within one year after of application and maintained a low population in the second year. The population of the Helicotylenchus sp. was also reduced within two years in the treatment using four cycles/year. The reduction in Radopholus similis and Helicotylenchus sp. population per 100 g roots improved root quality but did not influence the amount of marketable fruit after one year. However, a 3 to 5 kg/bunch increase occurred in Vydate L towards the second year indicating good root uptake of soil nutrients. The application method of Vydate L was not sufficient to cause a reduction of corm weevil, Cosmopolites sordidus Germar and aphids, Pentalonia negronervosa Coq. This was also manifested in the number of infested and eradicated plants attributed to these two pests. The fruit from Vydate L treated plants were submitted for residue test, which yielded results below the minimum residue level (MRL) imposed by the Japan Ministry of Health for exports of Cavendish banana.
Poster Presentations

Novel Approaches for the Management of Major Nematodes Infesting Banana in India

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Banana is known to adopt very quickly and produce high yields under favourable conditions. It is however, prone to attack by different pathogens like fungi, viruses, bacteria and nematodes. Among the production constraints, plant parasitic nematodes are recognized as major constraints in banana production and are responsible for serious yield losses. Crop losses caused by nematodes to bananas are very high, with an average annual yield losses estimated at about 20% worldwide. A total of 151 species of nematodes belonging to 54 genera are reported to be associated with the rhizosphere of banana worldwide. Out of these, 71 species of nematodes belonging to 33 genera are recorded from banana in various parts of India. The most destructive and widely distributed nematode is the burrowing nematode, *Radopholus similis* which caused an annual yield loss up to 41%. This nematode was reported from banana in almost all the banana growing States in the country including the isolated areas like Andaman and Lakshadweep Islands. The nematode-infested banana plants exhibit general decline, stunting, premature defoliation, unthriftiness and carry small bunches and fruits. They topple over easily during wet and windy weather because of inadequate anchorage. The root-lesion nematode, *Pratylenchus coffeae* is considered to be an important nematode pest next only to the burrowing nematode. The crop losses caused due to root-lesion nematode in banana cv. Nendran was reported to be 44.4%. The symptom produced by this nematode was similar to that of *R. similis* and often its damage is attributed to *R. similis*. The other economically important nematode pests of banana which have some regional differences are the spiral nematode, *Helicotylenchus multicinctus*, *H. dihystera*, root-knot nematode, *Meloidogyne incognita*, *M. javanica*, cyst nematode, *Heteroderma oryzicola* and reniform nematode, *Rotylenchulus reniformis*. Since all the commercial cultivars are found susceptible to either one or more nematodes, it is rather difficult to manage the nematodes with single method. Therefore, an integrated approach is suggested for the effective implementation of control measures for the economically
important nematode diseases of banana. Accordingly various methods like uses of non-chemical methods viz., botanicals, biocontrol agents, organic amendments, and resistant/ tolerant varieties have been developed at NRCB for the management of nematodes in banana are highlighted in this paper.

**Field Evaluation of Antagonistic Microbes for the Suppression of Fusarium Wilt Disease of Banana**

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Fusarium wilt, caused by *Fusarium oxysporum* f.sp. *cubense* (Foc), is one of the most destructive banana diseases worldwide. Disease management practices developed so far, including biocontrol, have not been effective in controlling the disease. Therefore, fungi and bacteria from the rhizosphere and inside roots were isolated and characterized as potential biocontrol (mycelial inhibition, spore germination, volatile and non-volatile production, HCN production) and plant growth-promoting (IAA production and Phosphate solubilization) organisms. Internal Transcribed Spacer (ITS) and 16S rRNA gene sequencing of fungal and bacterial isolates, respectively, indicated the presence of *Trichoderma* spp., *Penicillium* spp., *Lysinibacillus* spp., *Pseudomonas* spp., *Bacillus* spp., *Acromobacter* spp., *Burkholderia* spp. and *Sinorhizobium* spp. Additional fungal biocontrol agents which have previously been mutated for fungicide resistance and improved biocontrol and plant growth-promoting abilities were also included in this study. Microbes that suppressed Foc race 1 completely under laboratory and greenhouse conditions were further evaluated in the field. Two field trials, one with potential fungal and bacterial bioagents and another with fungicide-resistant fungal mutants with and without fungicides, were conducted, and treatments applied to Grand Naine banana plants by using four different methods. These included application (i) at the time of planting (ATP) (ii) 2nd month after planting (iii) 4th month after planting and (iv) ATP + 2nd month after planting + 4th month after planting. The application of biocontrol agents significantly decreased Fusarium wilt incidence and severity (10%-67%) in the field, and also increased the number of hands (6%-29%) and bunch weight (15%-67%) compared to untreated control plants. Among the treatments, the application of endophytic *Penicillium pinophilum* + rhizospheric *Trichoderma asperellum*, endophytic *Bacillus* sp.+ rhizospheric *Bacillus* sp., mutant of endophytic *T. harzianum* + mutant of
rhizospheric *T. harzianum* and mutant of endophytic *P. pinophilum* + mutant of *T. asperellum* + difenconazole 0.1% applied three times (ATP +2nd month after planting + 4th month after planting) have reduced Fusarium wilt severity by 64% to 67%. It also increased the number of plants harvested from 85% to 95%, number of hands from 9% to 29% and bunch weight from 48% to 67% compared to untreated control plants. These findings suggest that Fusarium wilt disease can be managed effectively under field conditions.

**Production of Beauvericin and Fusaric Acid by *Fusarium oxysporum* f. sp. *cubense*, Causal Agent of Fusarium Wilt in Banana**

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Fusarium wilt, caused by the fungal pathogen *Fusarium oxysporum* f. sp. *cubense* (Foc), is one of the most destructive diseases of banana. Twenty strains of Foc Races 1 and 4 were isolated from Guangdong, Hainan, Guangxi, Fujian and Yunnan Provinces in China. Their secondary metabolites were analyzed and some characteristic fingerprinting signals were captured by high performance liquid chromatography - electrospray ionization ion trap mass-spectrometry (HPLC-ESI-MS). Two primary phytotoxins were detected, including fusaric acid (FA) (179 Daltons) and a compound with a molecular weight of 783 Daltons. This compound was subsequently purified and identified as beauvericin (BEA) by ¹H-nuclear magnetic resonance chromatography (¹H-NMR). In vitro experiments showed that both beauvericin and fusaric acid can result in pseudostem rot and wilting of banana plantlets. The 20 Foc strains were then inoculated in banana plantlets and the concentration of the two toxins determined in plant roots, pseudostems and leaves. It was found that the more virulent Foc strains produced more toxin in the host plant. These results suggest that fungal toxins contribute to the pathogenicity of Foc in banana.
Biomanagement of *Pratylenchus coffeae* Using Fungal and Bacterial Endophytes in Banana

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Plant parasitic nematodes are posing serious economic loss to banana and plantain in almost all production systems. Among the nematode pests, the root-lesion nematode, *Pratylenchus coffeae* plays a key role in limiting banana production due to heavy damage produced on the root system. Though, the chemical nematicides are giving sharp decline of nematode populations, but their residual effects on environment health require serious attention in looking for alternate methods to tackle nematode menace and to increase the economic return. In order to overcome the deleterious effects of climate change as well as by the application of chemical nematicides, alternative method of using endophytes for the management of nematodes in banana has been identified. Accordingly soil, corm and root samples collected from different varieties of banana conserved in the *Musa* germplasm experimental field at National Research Centre for Banana, Tiruchirapalli, were isolated and identified 14 endophytic fungi strains based on the morphological characterization and 11 endophytic bacterial strains by using the semi selective medium. Among the 14 endophytic fungal strains, the effective four strains viz. *Alternaria tenuis*, *Curvularia geniculata*, *C.lunata* and *Trichosporium nigricans* were used for testing their effect on the mortality of root-lesion nematode, *Pratylenchus coffeae* under *in vitro* condition. The results of the study revealed that the endophytic fungi viz. *A. tenuis*, and *C.geniculata* exhibit 100% mortality at 100% concentration when exposed for 72 hrs, whereas the other two fungi viz. *C.lunata* and *T. nigricans* exhibited 75% mortality at 100% concentration when exposed for 72 hrs. These four isolates were further tested at two levels of concentration under pot culture against *P. coffeae* in cv. Poovan banana. The results revealed that higher level of concentration of 30g/plant of *A. tenuis*, and *C. geniculata* exhibits maximum plant height (40cm and 39 cm), pseudostem girth (12 cm each), number of leaves (8 each) and reduction in nematode populations (90%) respectively. Among the 11 endophytic bacterial strains, the effective eight strains viz. *Marinococcus* sp., *Lactococcus* sp., (NRCB-EB 3), *Leuconostoc* sp., *Bacillus* sp., (NRCB-EB 1) *Sporolacto bacillus*, *Lactococcus* sp., (NRCB-EB 4), *Clostridium* sp., and *Bacillus* sp., (NRCB-EB 2) were used for testing their effect on the mortality of root-lesion nematode, *Pratylenchus coffeae* under *in vitro* condition. The isolates of *Bacillus* sp. (NRCB-EB1), *Marinococcus* sp.,
Actinomycetes are the next most abundant after bacteria found in the soil. They grow slower than most bacteria and slower compared to Foc. This research is conducted to analyze an actinomycete communities in the infected vs uninfected rhizosphere of banana planted in different cultural practices (location). A Starch Nitrate Agar medium was used to recover Actinomycetes from rhizosphere soil samples obtained from three different types of banana cultivation: traditional farms in Central Java and Yogyakarta; banana industry in Lampung, Sumatera, and a new setting of banana with different cultural practices in Cianjur West Java. A Foc antagonistic assay was conducted by paper disc techniques for secondary metabolites of actinomycetes isolates. There is no clear relationship between Foc infection and actinomycete abundance since some actinomycete populations were found both in Foc-infected and healthy soil samples. However one isolate obtained from a healthy soil sample in Yogyakarta was found to produce a secondary metabolite suppressing Foc. Further research is in progress for the possibility of using Foc antagonist actinomycetes for biological control of banana fusarium wilt.

Lactococcus sp., (NRCB-EB3) Leuconostoc sp., showed 100% mortality of P. coffeae at 100% concentration when exposed for 48 hrs. These eight isolates were further tested at two levels of concentration under pot culture against P. coffeae in cv. Ney Poovan banana. The results revealed that higher level of concentration of 40g/plant of Clostridium sp, Bacillus sp.,(NRCB- EB1) Sporolactobacillus., and Lactococcus sp.,(NRCB-EB3) exhibits maximum plant height (35cm to 40 cm), pseudostem girth (10 to 12 cm each) and number of leaves (6 to 8 each) and reduction in nematode populations (85%). Hence, the present study elevates a high scope for using fungal and bacterial bio-inoculants against nematodes thereby avoiding the hazardous nature of chemical control as well as huge potential to isolate these effective native strains and mass multiply the same as successful commercial product for the management of nematodes in banana.
Aspects of soil health related to Panama disease in sub-tropical Australia

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Panama disease (Fusarium wilt) caused by pathogen *Fusarium oxysporum f.sp. cubense* (Foc) is the main constraint for farmers growing the Lady finger variety in the sub-tropical banana producing region of northern New South Wales. Two farms from this area were selected for in-depth soil health studies after a survey of four candidate farms. The two properties were chosen on the basis of anecdotal evidence of Panama disease suppression and results from the initial soil health screening of the four farms. At the selected farms two sites were sampled; one where the disease had progressed rapidly (“rapid”) and one where the progression was slower (“slow”). Soil samples from each site were subjected to a suite of chemical, physical and biological tests and factors such as disease incidence and drainage were assessed and rated in the field. Indicators of biological activity such as Fluorescein diacetate hydrolysis and beta-glucosidase levels were greater (in some cases double) at the potentially suppressive sites when compared to the sites with rapid disease progression. The results of these soil enzyme analyses indicate that the soil microbial community was more active at the “slow” sites. Drop plates and the most probable number technique were used to assess the *Fusarium oxysporum* population at each site and the proportion of Foc within this population is also being determined by vegetative compatibility group (VCG) testing. Early indications from these analyses show genuine suppression may be occurring at one of the farms, where pathogen levels are equivalent at both the “slow” and “rapid” sites, whereas the difference at the other property may be due to differences in pathogen population at the two sampling sites. Previous studies have determined that physicochemical characteristics (such as clay content, pH, nitrogen, potassium, calcium or iron levels) are in some cases associated with suppression of Fusarium wilt diseases. Analysis of these soils reveal no major differences in such characteristics between the “slow” and “rapid” soils which could account for the disease suppression. Assays are being performed on the soils in order to gather more evidence for the putative biological nature of this suppression.
Studies on controlling Basilepta balyi Harold on banana in Vietnam

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Basilepta balyi Harold is a common pest in many banana production areas in Vietnam, severely damaging Cavendish group cultivars. There are many banana-skin blemishes on affected fruits, that discourage consumption, and reduce selling-price. This pest seriously damages banana orchards, occurring in continuous plantations on slightly porous soil. B. balyi Harold has several life cycles per year, and adults cause damage from March to October. that the best results were provided from spraying Etofenprox (Trebon 10 EC) 0.20% combined with a pesticide sticker HPC 0.15% 10-days after flowering, then bagging the banana bunch by polyethylene light blue pipes gave the best results. Application of IPM techniques for B. balyi Harold has reduced the pest damage, thereby increasing income for banana growers by 9 million VND/ha.
Fusarium Wilt of Banana: A Global Perspective

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Fusarium wilt of banana, caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *cubense* (Foc), is considered the most destructive disease of bananas globally. Since its discovery in Australia in 1876, the disease has resulted in two severe epidemics; one caused by Foc race 1 in Central America, and another caused by Foc race 4 in tropical Asia. Throughout history, researchers have employed a diverse array of methods to control the disease, often exaggerating their triumphant achievements after early accomplishments. Most disturbing are the promises made by people in the agro-industry and even scientists, often without substance or feasibility, that new products and technologies will end the dissemination and annihilation caused by the Fusarium wilt pathogen. In Central America, the induction of good agronomic practices and flood fallowing previously claimed an end to the disease. Yet, it was only the replacement of Gros Michel with Cavendish bananas that eventually brought Fusarium wilt under control. Since the disease became of international concern following rampant outbreaks in seedless Cavendish cultivars, new and opportunistic claims and promises are rife about opportunities and technologies that will bring an end to Fusarium wilt in all cultivated bananas. These promises include the use of biological control products, disease suppression in soils, and biotechnology. In the current presentation, reasons for outbreaks and the rapid spread of Fusarium wilt, and strategies to manage the disease, will be critically assessed. Past and current disease management practices will be deliberated, and the future of Fusarium wilt as a global epidemic will be contemplated.
Non-conventional Banana Breeding Through Somaclonal Variation Selection in Taiwan

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It was found that about 3% of the plantlets derived from tissue culture of Giant Cavendish were mutants, offering a wide range of genetic variation useful for varietal improvement. An unconventional, innovative banana breeding through somaclonal variation selection was undertaken by TBRI, beginning in 1984. The breeding programme was targeted at obtaining a Cavendish resistant to *Fusarium oxysporum* f. sp. *cubense* Race 4 which has caused considerable losses of banana production in Taiwan since 1967. The selection was conducted in two ways. First, plantlets of Giant Cavendish were planted in a screening nursery which was heavily infested with Fusarium Race 4 in soil, and survivors were selected and resistance was confirmed in the field test. Second, TBRI has produced more than 3 million tissue-cultured plantlets annually since 1983 for distribution to thousands of small-scale farmers. Suckers of surviving plants were collected from disease hotspots of diseased farms, also helped by farmers, and resistance was confirmed in the field test. As of 2002, the programme has obtained a total of 13 resistant clones through this procedure, of which 7 were highly resistant, while the other 6 were moderately resistant. Among them, the clone GCTCV215-1 was formally registered as cv. Tai Chiao No. 1 for commercially planting in 1992. Another clone GCTCV-218, which is superior to GCTCV-215-1 in both the level of wilt resistance and in bunch weight, was registered as cv. Formosana for commercial planting in 2002. With the release of these resistant clones, many farmers are able to grow bananas continuously on the diseased farms, saving Taiwan banana industry from the destruction by the Fusarium wilt. *In vitro* propagation produces banana clones that are very diverse. For Giant Cavendish, in addition to resistance to Fusarium wilt, the tissue culture method also generated clones with increased resistance to strong wind, heavier fruit bunch, and sweeter fruit. The commercial value of these selected clone are now being explored. In this study, we have demonstrated the feasibility of using tissue culture to generate variation for selection of commercially acceptable wilt resistant cultivars of Giant Cavendish. The technique is simple and quick for obtaining a desired trait. The first wilt resistant cultivar acceptable for commercial planting was obtained within only six years of research. The selected trait is very stable, as the level of resistance of both Tai Chiao No. 1 and Formosana against Fusarium wilt has not changed in more than 10 years under various environmental conditions.
Fusarium Wilt Disease in Asia-Pacific: Update on Its Distribution and Associated Damage and Disease Management Approaches

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This paper reviews the geographic occurrence of *Fusarium oxyporum f.sp cubense* (Foc) in Asia, with special attention to Foc Tropical Race 4 (TR4). It also summarizes some R&D highlights towards mitigation in TR4-affected countries in the region. In a survey and characterization studies conducted by Bioversity and BAPNET partners, VCG1213/16, the strain associated with Foc TR4, was confirmed to be present in Australia, Indonesia, Malaysia, Philippines, Taiwan and China. The TR4 in Australia however is only confined in the Northern Territory. TR4 is found in all islands of Indonesia. TR4 isolates were only found in the southern island of the Philippines where export Cavendish is grown. In China, it has been reported in provinces of Guangdong, Guangxi, Fujian and the Hainan island. Ten other VCGs known to be associated to Race 1 were found in other countries. The outbreak of Foc epidemics in Cavendish in China and the Philippines has renewed serious concerns regarding its destructive potential in the tropics, where most bananas for export and local consumption are produced. Mitigation measures are being developed. Disease management studies include cultural practices such as rotation of non-host crops, biological control-soil suppression, cropping systems approach, and development and use of resistant cultivars. This paper highlights the adaption of Foc resistant Cavendish developed through somaclonal variant selection. Foc resistant GCTCVs developed from Taiwan were evaluated, and further selected for improved phenotypes. Some successes were achieved in Australia, Indonesia, China, Philippines and Taiwan. Improved resistant Cavendish resistant cultivars are now adapted in farmers’ fields in these countries. In China, two resistant clones, Kangku No. 1 and Kangku No. 5 were selected from GCTCVs from Taiwan, while Zhongjiao No. 3 was selected from the commercial variety
Baxijiao. In Australia, a Cavendish tolerant DPM25 was selected following tissue culture/gamma irradiation of a Subtropical Race 4 resistant, extra-dwarf Cavendish cultivar ‘Dwarf Parfitt’. It is now grown by farmers in the Northern Territory where TR4 has devastated Williams. Resistant GCTCVs are part of an integrated disease management approach being implemented in Taiwan. In the Philippines, an improved selection from GCTCV 119 and Formosana are performing well on severely affected farms. Further adaption trials are in place.

Integrated Use of Resistant Somaclones in the Management of Fusarium Wilt in Taiwan

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Cavendish banana, which is characterized by its superior eating quality, has been the number one export fruit crop in Taiwan since 1960s, and ‘Pei-Chiao’ in the subgroup of Giant Cavendish is the major cultivated variety. A record high of 40 million cartons (12.5 kg/carton) of banana was shifted to Japan in 1965. Affected by the epidemic of Fusarium wilt, caused by Fusarium oxysporium f. sp cubense Race 4 (Foc Race 4) aside from other limiting factors such as high labour cost, typhoon damage, and problems associated with unstable supply and quality control, volume available annually for export declined drastically, and an average of only 1 million cartons in the last 5 years was observed. Currently, 25% of 5,000 ha of banana growing areas for export were affected mainly by Foc TR4 (VCG 1213/1216). To sustain the export market for Taiwan banana, the deployment of integrated management to curb the spread of Fusarium wilt is necessary. The implemented field managements include land selection, healthy seedling, suitable variety, crop rotation with aquatic crop, and other appropriate culture practice such as good drainage, careful desuckering, regular field sanitation, optimized use of fertilizer and herbicide, and prevention of floating mat for root health. Among these managements, the annual supply of banana growers with germ-free tissue culture seedlings and the release of new commercial somaclone varieties derived from ‘Pei-Chiao’, play very important roles for the export industry in Taiwan. To ensure the bright future of Taiwan banana industry, recurrent selection of superior Cavenish somaclone variety is essential, and an improved somaclone, GCTCV-2163, selected from GCTCV-105 with high resistance to Foc Race 4, has been recently identified with high potential as a new commercial variety in 2013.
Integrated Disease Management of Fusarium Wilt in China

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Fusarium wilt, caused by the fungal pathogen *Fusarium oxysporum* f. sp. *cubense* (Foc), is one of the most destructive diseases of banana in China, and the disease can be managed in the field by planting resistant plants and adopting proper cultural measures. However, little information is available on the genetic basis of plant resistance to Foc, the diversity or evolution of the pathogen etc. In this presentation, we discussed the development of the measures in China, and also incorporate our own research results. To better understand the defense response of resistant banana plants to the Fusarium wilt pathogen, the transcriptome profiles in roots of resistant and susceptible Cavendish banana challenged with Foc TR4 were compared with the method of RNA-seq. This study generated a substantial amount of banana transcript sequences and compared their defense responses against the pathogen. More than 100 Foc isolates from China were characterized to lineage level and VCG identity was determined by pairing with an international VCG tester set. The results showed that Foc in China was highly diverse, and included 4 of the 8 lineages and 11 of the 24 known VCGs. We also investigated the whole invasion process with the GFP-taged Foc TR4 and found a new mycotoxin --- beauvericin (BEA). The current study provides the first investigation of toxins produced by Foc in banana. Their levels of banana contamination, however, were too low to be of concern to human and animal health. Rather, these toxins appear to contribute to the pathogenicity of the fungus during infection of banana plants. With the above results, we developed and adopted some effective measures. We developed a highly efficient banana transformation method and some resistant genes had been introduced into traditional cultivars. Traditional and non-traditional breeding were carried out, like crossing, polyploidy breeding, physical and chemical mutation breeding etc. Banana germplasm was also collected and evaluated. Some resistant cultivars had been screened and applied in the production. We also found the inhibitory effects of Chinese leek (*Allium tuberosum*) on Foc, its rotation with banana had been used in the production widely. We also developed biology control and fermented the pseudostem to produce the fungicide-fertilizer dual purpose bio-organic manure using endophytic fungi with high activity of cellulase, and gained good results in greenhouse and field.
The Status of Banana Fusarium Wilt Research in India

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In India, Fusarium wilt disease caused by Fusarium oxysporum f. sp. cubense (Foc) is considered as the major constraint in the production and productivity of banana. The disease is widespread in almost all the banana-growing states of India, and up to 95.5% of disease incidence was noticed particularly in Tamil Nadu where a greater number of susceptible varieties are grown. The disease was recorded in ‘Silk’ (AAB), ‘Neypoovan’ (AB), ‘Pisang Awak’ (ABB), ‘Pome’ (AAB), ‘Bluggoe’ (ABB) and ‘Monthan’ (ABB) banana groups. Furthermore, the Cavendish and Mysore groups of banana, which were considered as resistant, have recently succumbed to Fusarium wilt. Diversity analysis carried out in more than 200 Foc isolates, collected from different banana growing regions of India indicated the presence of 10 known VCGs viz. 0124, 0125, 0124/0125, 0128, 01212, 01217, 01218, 01220, 01221, which belong to Race 1 and Race 2. VCG 0124 was found as the most virulent form of Foc, as it infects all the commercial cultivars except Red Banana. During the VCG studies, cross-reaction among Race 1 and Race 2 isolates was observed, which was confirmed under pot culture studies. In addition, molecular characterization was also carried out and ISSR analysis was found to be the best method, which has differentiated all the Foc isolates based on races/VCGs and distinguished the newly emerged Foc strain of Cavendish and Poovan, and also the non-pathogenic Foc isolates from other Foc isolates. For diagnosing the Fusarium wilt pathogen, a SCAR marker was developed, which can specifically detect Foc Race 1 and 2 and be validated. For the effective management of the disease, biopriming of banana plants with endophytic and rhizospheric Trichoderma, Pseudomonas and Bacillus isolates with or without botanicals has been developed and tested under both greenhouse and field conditions. Use of Mycorrhizae and its helper-bacteria and other associated bacteria for the management of Fusarium wilt disease have also been studied. Also, cheaper mass production and storage methods for the effective biological control agents have been developed for the effective management of the disease. These research topics on Fusarium wilt disease in India are discussed in fuller detail.
An Early Diagnostic of Fusarium Wilt of Banana: Recent Advances and the Implication for Disease Management


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An early diagnostic of plant diseases is a critical step for preventing pathogen dissemination, precluding incursions into areas where the disease has not been observed, and for reducing the inoculum pressure. This is especially true for the tropical race 4 (TR4) of Fusarium oxysporum f. sp. cubense (Foc), a virulent race of the causal agent of Fusarium wilt of bananas. Foc TR4 is a quarantine pathogen in many bananas producing regions of the world and considered a major threat to the banana industry. Trading of symptomless, but infected banana planting material, movement of machinery with adhering infested soil and contaminated irrigation water all facilitate the spread of Foc. A PCR-based detection tool for TR4 has been developed and subsequently improved (Nested and qPRCs) enabling detection at different levels, including symptomatic and symptomless banana tissues, soil and water. While the main use of this diagnostic tools supports National Plant Health Organizations in detecting incursions, it also has a tremendous potential for implementing regional/local quarantine measures and enables disease management in areas where TR4 is established. Here, we present recent advances of the Foc TR4 diagnostic in relation to these applications.
Using Arbuscular Mycorrhizal Fungus and Other Microorganisms for Control of Fusarium Wilt of Banana

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Fusarium wilt of banana (Musa spp.), caused by Fusarium oxysporum f. sp. cubense (Foc), is one of the important factors limiting the development of banana industry in Taiwan. The objective of this study was to conduct a field experiment on the control of Fusarium wilt of banana by microbial agents. Three microbial agents were used in this study including one mycorrhizal fungus Glomus clarum, developed at Taiwan Agricultural Research Institute and two commercial products, Pseudomonas putida and Trichoderma asperellum. Banana tissue culture plantlets obtained from the Taiwan Banana Research Institute (TBRI) were acclimated at the Taiwan Agricultural Research Institute in September 2009. After 34 days acclimation, the tissue cultured plantlets were inoculated with G. clarum, 200 spores per plant, and after a further 92 days transplanted to the trial-field at TBRI, located in Pintong County. On the same day as transplanting, the seedlings were each inoculated with Pseudomonas putida (1 × 108 cfu per plant) and Trichoderma asperellum (1 × 106 cfu per plant). At 158 days after transplanting banana to the field, plants infected by Foc were recorded and data on disease incidence and severity were collected and analyzed. Compared to the untreated control, banana plants treated with G. clarum resulted in 12.6% increase (or 16 cm increase) in plant height and 36.9% increase (or increase of 2.4 leaves) in number of leaves. Also, treatment with G. clarum resulted in a significant (P < 0.05) reduction in incidence of Fusarium wilt of banana (67%), compared to in untreated control (88%). However, banana plants pretreated with G. clarum, and then post-inoculated with the commercial product (Pseudomonas and Trichoderma) did not cause a significant difference (P > 0.05) in the incidence and severity of Fusarium wilt of banana, compared to the untreated control. This study indicates that the arbuscular mycorrhizal fungus G. clarum could be an effective agent for reducing incidence and severity of Fusarium wilt of banana and could be integrated with other management strategies to reduce the disease. Further studies on other control measures are needed for achieving effective protection of this devastating disease of banana under field conditions.
Characteristics and Applications of Plant Endophytic Bacterium, Burkholderia cenocepacia 869T2, on Biocontrol of Fusarium Wilt In Planta

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Fusarium wilt (Panama disease) of bananas caused by Fusarium oxysporum f. sp. cubense tropical race 4 (Foc TR4) is a soil-borne vascular disease. Foc could invade the root and block the vascular system, causing the banana to wilt and die. Now no effective chemical method could control it. So, the use of endophytes as biocontrol agents will be an alternative strategy for this disease. Endophytic bacteria are bacteria living intercellular in plants but won’t be harmful to plants obviously. Recently, endophytic bacteria are widely studied on biocontrol and plant growth promotion. Therefore, in this study, we tried to use endophytic bacteria inoculating in banana tissue culture for biocontrol of Fusarium wilt in planta. Previously, we isolated the endophytic bacterium, Burkholderia cenocepacia 869T2, from roots of vetivers. B. cenocepacia 869T2 inhibited the growth of Foc TR4 100% on media for at least 10 days. After inoculating on bananas (Musa sapientum cv. Cavendish, Pei-chiao, AAA), B. cenocepacia 869T2 decreased the disease incidence of Fusarium wilt and promoted the growth of bananas effectively both in green houses and fields. The height, girth, and healthy leaves of inoculated bananas were increased significantly about 20-40%. We can also re-isolate this strain 869T2 from banana after 3-4 months in green house and field tests. Results suggested that endophytic bacterium, B. cenocepacia 869T2, had good potential for biocontrol of Fusarium wilt and plant growth promotion of bananas.
An Efficient and Reliable Molecular Method for Detection of *Fusarium oxysporum f. sp. cubense* Race 4 Using Real Time PCR

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*Fusarium oxysporum* f. sp. *cubense* (Foc) is one of the most serious pathogens of bananas (*Musa* spp.), and causes a devastating fungal wilt disease. Globally, fusarium wilt is considered a major threat to the billion-dollar banana industry. Disease monitoring is vital in managing this fatal banana disease. Prevention of pathogens from contaminating uninfected plantations, avoidance of crops being planted in infected fields, and preventing serious pathogens from being disseminated from diseased to healthy plants, are the top priorities in disease management. This study describes an efficient and reliable real-time PCR method for the specific detection of Foc race 4 in planta. The developed method is highly reproducible and very sensitive to detecting Foc genomic DNA (gDNA). It can detect low amounts of gDNA and conidia of Foc race 4, and can quantify Foc gDNA in pseudostems and banana leaves, with the detection data conforming to the corresponding symptomatic characteristics of infected plants. This research was supported in part by the Council of Agriculture, National Science Council, Ministry of Education under the ATU plan, and by the National Chung Hsing University of Taiwan, R.O.C.
Deep-Sequencing-based Banana Rot Transcriptome Profiling Analysis of the Resistant Mutant to *Fusarium oxysporum* f. sp. *cubense* Tropical Race 4 and Its Wild-Type

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Fusarium wilt (*Fusarium oxysporum* f. sp. *cubense*, Foc) is the most important banana disease and is potentially lethal. Of the four races described for bananas, tropical race 4 (TR4) is by far the most damaging biotype. Although some resistant somaclonal mutants of Cavendish have been discovered, little has been understood of the mechanisms underlying the resistance. In this study, the root transcriptome profiling of Foc TR4-resistant mutant of banana and its susceptible wild-type was developed. RNA-seq analysis generated more than 103 million 75-bp clean pair end (PE) reads, which were assembled into 88,161 unigenes (mean size=554bp). Based on sequence similarity searches, 61,706 (69.99%) genes were identified, among which, 21,273 and 50,410 unigenes were assigned to gene ontology (GO) and clusters of orthologous groups (COG), respectively. Analysis in the Kyoto Encyclopedia of Genes and Genomes Pathway database (KEGG) mapped 33,243 (37.71%) unigenes to 119 KEGG pathways. A total of 5,008 genes were assigned to plant-pathogen interaction, including disease defense and signal transduction. Digital gene expression (DGE) analysis revealed large differences in the transcriptome profiles between the Foc-TR4 resistant mutant and the susceptible wild-type. Expression-analysis of genes involved in pathogen-associated molecular pattern (PAMP) indicated that the basal defense mechanisms involved the recognition of PAMPs and the high accumulated levels of defense-related transcripts may contribute to Foc TR4 resistance in banana. This study generated a substantial amount of banana transcript sequences and compared the defense responses against Foc TR4 between the resistant mutant and wild-type bananas. The results contribute to the in-depth study of candidate-genes for innate immunity in the non-model organism, banana, and help to improve current understanding of Foc-banana interactions.
Ultrastructural Differences Between Banana Cultivars Resistant and Susceptible to Fusarium oxysporum f. sp. cubense

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Fusarium wilt, caused by the fungal pathogen Fusarium oxysporum f. sp. cubense (Foc), is one of the most destructive diseases to banana production worldwide. In the present study, ultra-structural differences between banana cultivars resistant and susceptible to Foc were investigated to understand the mechanism of disease resistance. The resistant banana cultivar GCTV-119 (Musa AAA) and the susceptible cultivar BAXI (Cavendish, Musa AAA) were first inoculated by dipping their roots in a cell suspension of Foc. Changes in the cell structure of the pseudostem were then observed by electron microscopy. Hyphal invasion of the spaces between parenchyma cells was observed in the susceptible cultivar but not in the resistant one. This suggests resistance to infection through the root epidermal layer. Plasmolysis and the decomposition and rupture of cell walls and membranes of cytoplasmic organoids were also observed in the susceptible cultivar, while the damage in the resistant one was much less. Tylose and browning of xylem vessels were observed in both resistant and susceptible cultivars, but thicker cuticles and suberification, and tubercles in cell walls, were only found in the resistant cultivar. These results indicate that differences exist in the cell structure of banana plants resistant and susceptible to Foc which should be considered for the genetic improvement of the crop.
Development of Disease Management Strategies for Lakatan, Latundan and Saba Against BBTV, Sigatoka, Fusarium Wilt and Bugtok/Moko

F.M. Dolojan

The two project-studies aimed to enhance the productivity and sustainability of banana production for smallholder farmers by developing IPM programs for ‘Lakatan’, ‘Latundan and ‘Saba’ against BBTV, Sigatoka, Fusarium Wilt and Bugtok/Moko. Cropping system and the use of cultivar diversity were the elements used in managing these diseases on banana. In cropping system using tissue culture plantlets and suckers as planting materials in a banana disease management strategy,, two diseases of key concern were studied: banana bunchy top virus (BBTV) and sigatoka, which were observed in the experimental areas. The use of tissue-cultured planting material is better than the suckers as they are guaranteed to be free from the virus. For Sigatoka infections, Lakatan plants derived from sucker and tissue culture materials were infected with the pathogen both in the annual and ratoon contexts. Statistical analysis in the combined results showed that occurrence of BBTV and sigatoka were not significantly affected by the cropping system or by the type of planting material. The yield, however, was affected by the cropping system, where annual plants produced heavier bunches than ratoon plants. In considering cultivar diversity, BBTV disease was observed on Lakatan and senorita plants only. The BBTV incidence in Lakatan was lower in the mixed-cultivar set-up than in the mono-cultivar set-up, proving that resistant cultivars such as FHIA 17 and saba served as barriers to the transmission of the virus by aphids. Sigatoka was observed in all the cultivars used whether in the mixed-cultivar set-up or in the mono-cultivar set-up. Bugtok/moko was not observed in all the experimental areas confirming the absence of the disease in the province.
The Influence of Arbuscular Mycorrhizal Fungi and Their Mycorrhizae Helper Bacterial Isolates on the Management of Panama Disease of Banana

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Biological control is considered an effective management practice for controlling Fusarium wilt disease, although it has not achieved complete control. The disease is still causing severe yield losses in different banana growing regions of the world. Among different biocontrol agents, endomycorrhizae particularly *Glomus* spp. are known to suppress pathogenic fungi and also promote plant growth. It has also been proved that the efficiency of *Glomus* isolates will be enhanced in the presence of mycorrhizal helper-bacteria. Therefore in the present study an attempt has been made to isolate and evaluate different native Arbuscular Mycorrhizal Fungi (AMF) and also the associated Mycorrhizae Helper Bacterial (MHB) for the management Fusarium wilt disease of banana. Altogether, four out of 25 isolates of AMF, and nine out of 29 isolates of MHB were evaluated individually and in combinations, for the suppression of Fusarium wilt disease (Foc -VCG 0124) in cv. Grand Naine under pot culture conditions. Furthermore, a VAM isolate obtained from the market (commercial formulation) and necessary positive and negative controls were also maintained for comparison. 6 months after planting, plant growth parameters, root characters and Fusarium wilt disease severity were recorded and analyzed statistically. The results indicated that all the AMF isolates, both individually and in combination with respective MHB isolates, significantly reduced Fusarium wilt disease and significantly increased plant growth and root characters compared to Foc alone inoculated plants. However, complete control of Fusarium wilt disease (100% reduction) was recorded only in the plants treated with AMF *Glomus mossae* KPV + MHB bacteria *Enterobacter* sp. + *Azotobacter* sp. and *Glomus* spp. TPV+ MHB bacterium *Pseudomonas* sp.
Enhancing the Control of BBTV in Smallholder Farms in Cagayan Valley Through Public-Private Partnership

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This project aims to improve the productivity of smallhold banana growers in selected areas in Cagayan Valley through the development, identification, validation and upscaling of appropriate technologies in banana production supported by public-private sectors’ complementation. These technologies revolved around one major production constraint, the Banana Bunchy Top Disease. The project was collaboratively implemented by Isabela State University (ISU), Department of Agrarian Reform-Isabela Provincial Office (DAR-IPO), Cooperative for Rural Development (CORDEV) and selected Local Government Units (LGUs) in partnership with PCARRD, INIBAP (now BIOVERSITY International) and the Department of Agriculture. Package of technologies (POTs) were developed. Various activities were conducted to upscale the adoption of recommended POTs. As a result, an aggregate area of 102 hectares was already established where majority of the farmer-cooperators adopted the different component technologies on the production of quality banana planting materials, detection and eradication, and prevention of the spread of Banana Bunchy Top Virus. A system of delivering affordable clean planting materials through the use of tissue culture to village nurseries for small scale farmers was developed. Using production improved production practices, there was a marked increase in the level of banana production with 37% and income at 24% among farmer cooperators. Nursery establishment was also shown as a profitable venture with a return on investment (ROI) of 189%. The project demonstrated strong collaboration of stakeholders and willingness of farmer-cooperators to adopt recommended technologies that contribute to the strengthening and improving the level of productivity and income of smallhold banana growers.
Agronomic Evaluation of Putative Fusarium Wilt (*Fusarium oxysporum* f. sp. *cubense* Tropical Race 4) Tolerant Cavendish Clones, Bukidnon, Philippines

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Selection and development of tolerant/resistant Cavendish clones and their adaption by the industry is believed to be an effective mean of overcoming Banana Fusarium Wilt caused by *Fusarium oxysporum* f. sp. *cubense* Tropical Race 4 (Foc TR4). This trial was initiated to evaluate Three Foc TR4 resistant somaclonal variant selections from the Taiwan Banana Research Institute provided by Bioversity International through the Bureau of Plant Industry, Davao-Philippines. The trial area at Valencia, Bukidnon, Philippines (412 m a.s.l., 2,593 mm annual average rainfall, average min/max temperature 20.2°C and 31.6°C) was previously cropped with ‘Williams’ and quarantined after positive occurrence of Foc TR4. The soil is classified as silty clay with a pH of 5.7. Three clones, GCTCV 106 (T2), GCTCV 109 (T3) and GCTCV 247 (T4) were compared to ‘Williams’ (T1) as commercial standard. In total 178 tissue cultured plantlets (28-50 data plants per clone) were planted April 14, 2011 with a planting density of 2,000 plants/ha in a CRD layout. Data collection during plant crop and first ratoon comprised agronomic and harvest parameter following the INIBAP Technical Guidelines (1998). Disease incidences were monitored weekly and symptomatic Foc TR4 cases verified by PCR analysis using the primer for VCG1213/16 that was developed by Dita et al. (2010). Until first harvest T2 showed with 16.0% the highest Foc TR4 incidence rate, followed by T4 with 7.1% while T1 and T3 had only 6.0% and 4.0% cases, respectively. Disease incidences for T1 and T2 increased to 28.0% and 34.0% until 75 weeks after planting, whereas no additional cases were observed for T3 and T5. The clones differed considerably for plant height at shooting (T1: 252 cm, T2: 282 cm, T3: 358 cm, T4: 295 cm), days from planting to harvest (T1: 265, T2: 284, T3: 376, T4: 329) and bunch weight (T1: 27.3 kg, T2: 28.4 kg, T3: 27.1 kg, T4: 22.5 kg). Blow down damages were frequent in T3 accounting for 34% plant losses. Other agronomic and harvest parameters are presented.
Survey of the Distribution of Vegetative Compatibility Groups of Fusarium oxysporum f. sp. cubense in West Java Province, Indonesia

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A survey was conducted in West Java province, Indonesia in 2006 to 2008 to determine the occurrence and distribution of the various strains of Fusarium oxysporum f. sp. cubense and what varieties do they infect in the field. Samples from the infected plants were collected and were analyzed for vegetative compatibility group (VCG) using the technique described by Puhalla (1985). Isolation and purification of the pathogen through single spore technique was done at the Protection Laboratory of the Indonesian Tropical Fruit Research Institute (ITFRI), Solok in January to March 2006 and July to September 2008. VCG analyses were done at the Department of Primary Industry, Plant Pathology Section, Australia from July 2007 to December 2007, and at the Protection Laboratory of ITFRI in July 2009 to December 2010. Seventeen VCG testers from Australia were used. A total of 47 Foc isolates were isolated from 10 banana cultivars that were collected from all locations. These were six varieties of dessert banana i.e., Pulo, Muli (AA), Ambon kuning/putih (AAA), Gros michel), Ambon hijau (AAA, Cav. group), Raja sere and Raja bulu (AAB) and four varieties of cooking bananas i.e., Kepok, Siem/Awak (ABB), Nangka and Tanduk (AAB). Results of VCG test showed that 30 Foc isolates belonged to 11 VCGs, while 17 isolates were unidentified by the testers used. Nine isolates representing 19% were VCG 01213/16 (TR4) and were isolated from four banana varieties. VCG 120 and VCG 123 had similarly found 8.6% of the samples. The other isolates comprised four isolates of VCG 0123 in two banana varieties, three isolates of VCG 01218 in two banana varieties, two isolates of VCG 0120/15 in two banana varieties, two isolates of VCG 0124/5/8 in one banana variety, two isolates of VCG 01219 in two banana varieties, four isolates were VCG 0121, 0126, 0124/5 and 0124/5/20, each attacking one banana variety. Fusarium wilt was found in all observed locations in West Java, VCG 01213/16 (TR4) was the most prevalent, therefore management and preventive measures should be a concern.
Mechanism of Resistance to Banana Bunchy Top Virus

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One of the practical yet effective measures against banana bunchy top disease (BBTD) is the use of varieties that confer resistance against the Banana bunchy top virus (BBTV). Some banana cultivars with resistance to the virus have been identified in previous studies. The mechanism of resistance against the virus needs to be elucidated, hence this study. This paper reports the mechanism of resistance of four (4) banana cultivars representing different genomes (AAB, BBB and AA) based on host-preference of a viruliferous aphid vector (Pentalonia negronervosa) as well as virus replication, transport and distribution. Among the four, Pisang Lingi (unknown genome) is the most preferred cultivar followed by Latundan (AAB) and Lakatan (AA) with mean aphid populations of 120, 148.9, and 81.2, respectively. The least preferred cultivar is Cardaba (BBB) with 54.7 mean aphid population. An increase in aphid colony count was noted from 2 to 3 weeks after inoculation (WAI) and decreases at 4 WAI. Typical symptoms of marginal chlorosis and rosetting were observed at 4 to 7 WAI and progresses into bunchy top until 3 months after inoculation. Highest incidence was observed on Lakatan (70%) and the lowest was noted on Pisang Lingi (10%). Results showed that aphid preference varied depending on banana cultivar. Cardaba (BBB) gave the lowest aphid population (54.7) and lower BBTV incidence (30%) indicating that it was not preferred by the aphid as host and resistance to the virus can be attributed to non-preference of aphid for colonization. In contrast, Pisang Lingi had the highest number of aphids and the lowest BBTV incidence. Although most preferred by aphids, there could be host derived mechanism that limits virus multiplication in this cultivar. The virus transport and distribution are being assessed using PCR-based method.
Occurrence of Various Vegetative Compatibility Groups (VCG) of *Fusarium oxysporum* f. sp. *cubense* in Asia

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Recent epidemics of Panama disease (Fusarium wilt) in China and the Philippines caused by the virulent Tropical Race 4 (TR4) of *Fusarium oxysporum* f. sp. *cubense* (Foc) have posed a serious threat to the banana industry in Asia, and beyond. This race, belonging to the Vegetative Compatibility Group (VCG) 1213/16, is extremely important because it attacks the widely grown and traded Cavendish varieties, and many local cultivars grown by smallholder farmers. A study to determine the geographic distribution of the various pathogenic VCGs of Foc in Asia was carried out as a key step towards designing policies and measures to prevent further spread of TR4. Samples were collected from diseased banana plants between the period of 2006-2009 from 12 countries in tropical Asia. Foc was isolated from these samples, single-spored, and nit-1 and nit-M mutants generated in laboratories in Australia and South Africa. These mutants were then paired with an international VCG-tester set for Foc using the technique described by Puhalla in 1985. Nine VCGs (1213/16, 0120/15, 0121, 0123, 0124/5, 0126, 0128, 01218, 01220) were identified in Asia. VCG1213/16 (TR4), was the dominant VCG from samples collected in China, Indonesia, Malaysia, Philippines, and Taiwan but not found in samples from the other countries. VCG 0124/5, a VCG associated to Foc Race 1, was the dominant VCG in samples from India, Bangladesh,
Cambodia, Sri Lanka, Vietnam, and Thailand. No Foc infection of banana was found in Papua New Guinea. These results are relevant in preventing the movement of TR4 in areas that are not yet affected through effective quarantine measures.

Cavendish R&D: Addressing Fusarium Wilt Incidence in the Philippines

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The Philippines is the third largest producer of banana in terms of production volume (FAOStat 2010) and the third top exporter of banana in terms of volume in 2009 (FAOStat). The ‘Cavendish’ variety accounts for 51% of the total banana production in the Philippines and is mainly grown by big multinational companies in Mindanao for export. In 2009, bananas exported by the Philippines amounted to 1.74M mt generating US$ 360M. Currently the Cavendish industry is being threatened by Fusarium wilt particularly Tropical Race 4, which was reported to be present in the country. Considering the nature of the pathogen, the infection could easily spread if it is not suppressed. To address the concern on Fusarium wilt, a program entitled, “S&T Management Approaches against Fusarium wilt [Fusarium oxysporum f. sp. cubense (Foc)] on Cavendish in Mindanao” has been funded and monitored by the Department of Science and Technology-Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (DOST-PCAARRD). The program is composed of three projects which aim to assess the adaptability of seven promising GCTCV somaclones from TBRI against Fusarium Wilt, which were made available by Bioversity International to the Philippines; apply commercially available biological control agents and develop strategies to effectively deliver these agents to the soil; and assess the distribution of Fusarium Wilt incidence in Mindanao and identify the races. The results of the program will eventually become the basis for strict quarantine implementation in the future. Two projects will involve farm-cooperators from independent growers who are willing to share the cost of implementing the trials in their farms. The participation of private growers aims to enhance public-private collaboration for a more sustainable project implementation.
Risk Assessment of Eastern African Highland Bananas and Plantains against *Fusarium oxysporum* f. sp. *cubense* (Foc) Tropical Race 4 (TR4)

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Fusarium wilt of banana has widely been considered as one of the most devastating diseases in agricultural history, until resistant banana cultivars replaced susceptible ones in Central America. New outbreaks of the disease in Asia, caused by Foc TR4, have raised concerns that the disease is, once again, threatening banana production in the world. Of particular concern is the threat to food security in Africa, where the East African Highland bananas (EAHB) and plantains form the staple diet and only source of income to millions of Africans. To assess this risk, 10 of the most important cultivars in Africa were evaluated in the Philippines where TR4 is found. Ten tissue culture-derived seedlings were planted in experimental unit replicated 10 times in a Completely Randomized layout. Disease incidence data were recorded by determining the number of infected plant showing the typical yellowing of leaves starting from older leaves and/or pseudostem splitting. Data on agronomic traits were also collected. More than 12 months after planting, 9 of the 10 African cultivars showed relatively low infection incidence ranging from 1 to 5 percent. Only one cultivar, Ibwi, showed infection of 29%. A local susceptible check, Lakatan, showed 90% incidence. TR4 was verified by isolating the pathogen and tested against the primer of VCG 01213/16 developed by Dita et al (2000). This study is a pro-active effort to prepare Africa against the potential introduction of Foc TR4 into the continent, and to select or develop material with resistance to the pathogen.
Crown Rot Disease of Banana cv. Hom Thong and Its Control by GRAS

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Crown rot disease caused by Lasiodiplodia theobromae, Fusarium sp., Colletotrichum musae, Pestalotiopsis sp. and Phomopsis sp. is the major problem for postharvest quality in banana. This research was conducted to study the effect of generally recognized as safe (GRAS) viz. potassium sorbate, oxalic acid and salicylic acid at concentrations of 100, 250, 500 and 1,000 mg/L on controlling of crown rot disease in banana cv. Hom Thong. The experimental design was completely randomized design (CRD) with 16 treatments. The results showed significant difference in percentage of mycelial inhibition. Salicylic acid at 1,000 mg/L had the efficiency for inhibiting the mycelial growth of Fusarium sp., C. musae, Pestalotiopsis sp., Phomopsis sp. and L. theobromae to 100.00, 100.00, 82.35, 79.45 and 45.67% respectively. Efficacy of GRAS compounds to control L. theobromae crown rot of pre-inoculation treatment keeping at room temperature for 5 days was salicylic acid 250 mg/l with 57.16% disease severity, however in post-inoculation treatment oxalic acid 100 mg/l showed the best result followed by salicylic acid 250 mg/l causing disease severity 44.68 and 46.87 % respectively. From this study, salicylic acid 250 mg/l was effective to control crown rot disease of L. theobromae inoculated banana.
Status of Fusarium wilt Management in the Philippines

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Fusarium wilt of banana is causing an alarming threat to the banana industry in the Philippines. In Southern Mindanao, where majority of banana for export are found, Fusarium wilt begins to devastate a considerable hectarage of banana plantations. The threat brought about by Fusarium oxysporum f. sp. cubense (Foc) created a widespread media mileage in Southern Mindanao that led the Department of Agriculture to create a Fusarium Wilt Taskforce in all banana growing areas in Mindanao. Several management strategies were initially implemented like the mapping out of incidences, installation of billboards, quarantine points and capacity building of all banana growers and agricultural technicians. Eradications of infected mats were also done and the constructions of mini-laboratories for Trichoderma sp. -a biological agent for Foc, were installed in strategic municipalities in Davao region.
Banana Production, Consumption and Trade in Asia: Situation and Challenges

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Asia is the continent with the world’s highest banana production and consumption. Based on production data averaged over five years (FAOSTAT, 2006-2010), Asia’s share on the 4.84 million ha world banana area is about 2.00 million ha, where India, the Philippines, China, Thailand and Indonesia together account already for 1.72 million ha. The same countries represent with an aggregated production of 49.46 million tones already 52.9% of the total world banana production. The total food supply from bananas in Asia is estimated to be 57.8% of the world banana food supply of 70.71 million tones. The net export of bananas, essentially Cavendish, from Asian countries is rather small. Only the Philippines with a share of 13.7% enters as worldwide second ranked banana exporting country in the group of the 15 largest net exporting countries, accounting together for 97.2% of the global net exports. On the other hand, in terms of imports the five Asian countries Japan, Iran, China, Republic of Korea and Saudi Arabia are in the group of the 15 largest banana importing countries, representing together 18.5% of the global net imported volume. The regional pattern with regard to production and consumption are presented in the context of the prevailing socioeconomic, biological and climatic conditions. The banana trade patterns within Asia are illustrated based on exports by countries of destination and imports by countries of origin. An attempt is made to identify the actual constrains for Asia’s banana production and trade by region and to give an outlook of possible impacts on the evolution and prospects of banana trade in Asia.
The banana industry is one of the most important sources of income for farmers, generating more profit than other agricultural crops. Thus, bananas are one of the main crops grown on small- and large-scale plantations in tropical countries. As a crop exported to different parts of the world, various challenges arise. Fluctuations in quality, volume and market value prove to be main challenges. Worldwide competition throughout the years has made it increasingly difficult to sustain the industry’s profitability, not only for farmers, but for wholesale and retail vendors as well. Moreover, plant diseases that can cause the death or stunt the growth of crops pose a threat to the quality of production. This presentation aims to provide a summary of the challenges met by the banana industry and explore a number of solutions provided from a marketing perspective. These recommendations aim to aid in the repositioning the product’s place in the market. Although the industry relies on research, other tactics can no longer be taken for granted. Putting emphases on branding, marketing strategy and customer service could create various opportunities for suppliers. In fact, they may be necessary tools to keep up with today’s market.
Consumer Perceptions and Purchase-Decisions Regarding Organic Banana: An Empirical Analysis Based on Multiple-Group Analysis of Structural Equation Model

C. Xinjian, Chen, D. Tao and G.J. Yi

Fruit Tree Research Institute of Guangdong Academy of Agricultural Sciences, Guangzhou, P.R.C.

The global market for organic food has developed significantly in the past decade. In China, organic food production began in 1990 and has boomed since 2000 to become the third biggest organic-producer in terms of land acreage. The most important organic agricultural products in China are rice, vegetable and tea. Organic fruit production is insignificant. Apple, peach, orange, grape and strawberry are the main organic fruits in China. Organic banana production has begun in recent years and there are very few organic banana producers or companies operating in China. However, with the increasing demand in the market for safe organic fruit, organic banana supplies will rise rapidly and currently organic banana farms are more commonplace in Guangdong, Guangxi, Hainan and Yunnan province. More than 1000 hectares have been planted for organic banana farming. The organic fruit market in China is mainly in big cities like Beijing, Shanghai, Guangzhou and Shenzhen. The aim of this paper is to investigate urban consumers’ decision-making processes for organic banana in large Chinese cities. A structural equation modeling approach and multiple-group analysis based on demographics were used to analyse 1017 consumers data provided by a survey conducted in Beijing, Guangzhou, Shanghai and Shenzhen. The findings indicated that the organic banana concept cognitive, quality and externality cognition, supply of organic banana cognitive have significant positive influence toward organic banana. Results from Multiple-group analysis show that gender, age, family income, education and children as the adjustable variables between different groups which are significantly different between the effect. Consumers who have children and high income have the strongest desire to buy organic banana.
Development of A New Banana Processing Product: Banana Starch As A Health Food from Cavendish Banana in Taiwan

T.C. Huang¹, Y.T. Fu² and H.C. Chen²

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Banana (Musa spp.), including pulp, peel, flower and pseudostem is known to have health-beneficial effects. Unripe banana flour presented a high amount of total dietary fiber, which consisted of resistant starch and fructans. The colonic fermentation of the flours produce high amounts of short-chain fatty acids such as acetate, butyrate and propionate. The banana flower is a rich source of flavonoids (apigenin glycosides, myricetin glycoside, myricetin-3-O-rutinoside, naringenin glycosides, kaempferol-3-O-rutinoside and quercetin-3-O-rutinoside. Among them, naringenin which exhibits antidiabetic activity deserves special interest. Naringin also markedly lowered the activity of hepatic glucose-6-phosphatase and phosphoenolpyruvate carboxykinase. Banana has also been identified as containing the neurotransmitters norepinephrine, serotonin and dopamine. The banana is of great nutritional value and has a rare combination of energy value, tissue-building elements, protein, vitamins and phytochemicals.
High Value Products Derived From Banana Peduncles

M.A.T. Tavanlar¹, T.J. Ramirez¹, A.B. Sapin¹, S.A. Sedano¹, C.M. Bueno², D. Eusebio³, A.S. Torres³ and R.V. Valle³

¹National Institute of Molecular Biology and Biotechnology (BIOTECH), University of the Philippines Los Baños (UPLB), College, Laguna, Philippines 4031; ²Animal Science and Dairy Cluster, UPLB; ³Forest Products Research and Development Institute – Department of Science and Technology, College, Laguna, Philippines

Residual banana peduncles are normally thrown away or allowed to decompose in the field, after removing the fruit-bunches. About 2.3 million metric tons of banana peduncle are generated annually in the Philippines. As such, management of this waste is a challenge. Owing to the very few reports on the practical use of peduncle other than for compost, the feasibility of utilizing peduncle for value addition of mainstream products was investigated. Peduncle fiber was obtained either by pressing out the juice or by retting. The juice and fiber were characterized for physical and chemical properties prior to downstream applications. Despite the higher ash content of peduncle fiber as compared to pseudostem fiber, pulp was easily produced after mild soda treatment under atmospheric conditions. Peduncle pulp blended with old corrugated carton pulp yielded paper bags with better resistance to burst, endurance to folding, grammage, thickness and density than a commercial sample. Good adhesion of the fiber to resin or cement gave sturdy composite boards suited for construction purposes. Microcellulose fibers amenable for development into carbon whiskers, supplemental dietary fiber and moisture retention ingredients in meat products were attributed to the high water and oil holding capacity of the fiber. Being rich in potassium ions, peduncle juice was added into citrus energy drinks, hydroponics media and liquid fertilizer for banana and various crops. The products compared favorably with conventional counterparts. The lowly banana peduncle is therefore a lucrative source of additional income, innovative and eco-friendly products for pulp and paper, composites, construction materials, food, feed and organic agriculture.
Promoting Pacific Banana Diversity (Feʻi, Iholena and Maoli-Popoulu): Nutrient-Rich for Health and Wealth

V.S. Tuia and L.M. Waqainabete

Centre for Pacific Crops and Trees (CePaCT), Secretariat of the Pacific Community (SPC), Narere, Suva, Fiji

Over 100 accessions of unique banana diversity (fei, iholena and maoli-popoulu types) from the Pacific are conserved, virus tested and promoted by the Secretariat of the Pacific Community’s Center for Pacific Crops and Trees (CePaCT) based in Fiji, in collaboration with project and country partners. These accessions are used as cooking bananas, dessert and for value-added products. CePaCT also distributes non-Pacific banana diversity for building resilience of countries to climate variability and improved disease management through evaluation and adoption of climate ready and disease resistant varieties.
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