Bananas, genetics and appropriate biotechnology

Pat Heslop-Harrison www.molcyt.com

Generation
Cultivating Plant Diversity for the Resource-Poor

PROMUSA
A Global Programme for Musa Improvement

University of Leicester

What are bananas?

What is in banana DNA?

What is the future for banana?

What is the future for diet and farmers?

WINE
Luxembourg
79.5 litres
(17.5 gal)
By contrast, the smallest measurable wine consumer is Egypt, where the average yearly wine consumption amounts to about two tablespoons.

BREAKFAST CEREAL
Sweden
10.4 kg (22 lb 14 oz)

BAKED BEANS
United Kingdom
5.3 kg (11 lb 10 oz)
In contrast, the USA consumes just 1.3 kg (2 lb 13 oz) of baked beans per capita.

HONEY
Central African Republic
3 kg (6 lb 9.7 oz)

DID YOU KNOW?

The ***oldest cultivated plant for food*** *is the Abyssinian banana* (Ensete ventricosum). *Historians suggest that between 4,000 and 7,000 years ago, the hunter-gatherers of ancient Ethiopia learned to use this plant as food.*

ICE CREAM
Australia
16.6 litres
(3.6 gal)

TEA
Ireland
2.6 kg (5 lb 14 oz)
This equates to approximately 1,184 cups per person in one year.

CHOCOLATE
Switzerland
11.5 kg (25 lb 6 oz)
This is the equivalent of each person eating 230 bars weighing 50 g (1.75 oz) per year.

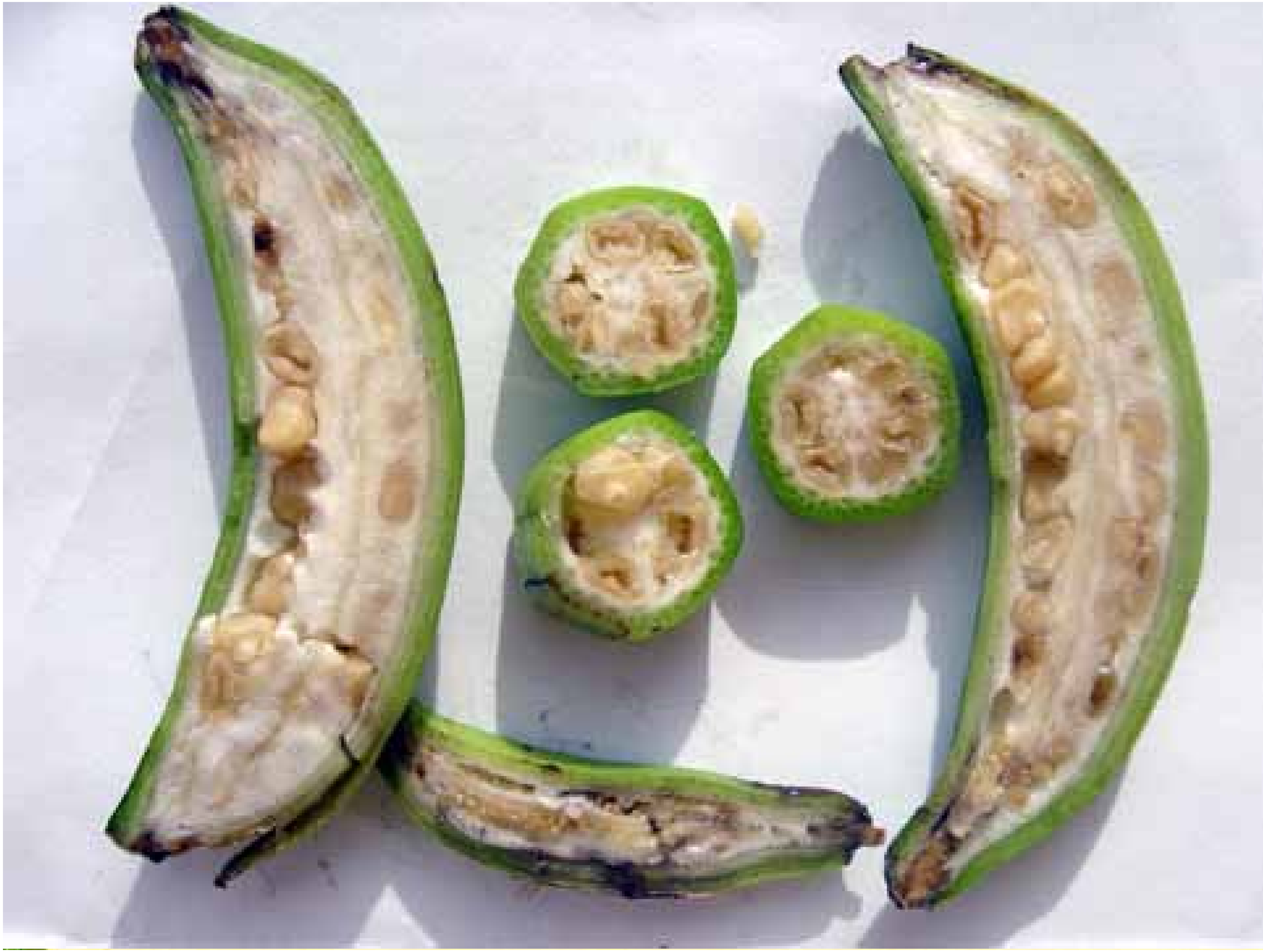
SPIRITS
Russia
6.2 litres
(1.3 gal)

the banana (musa sapientum) is the most consumed fruit in the world. It is the 4th most important staple food world wide and the fifth most important agricultural product after cereal, sugar, coffee and cocoa. The Brits eat 140million bananas every week!


Zingiberales Order Bed, National Botanic Garden of Wales, 2006

What is a banana?

Monocotyledon – giant herb not a tree!



Banana Evolution

- Cultivars: sterile, parthenocarpic clones
- In the wild, no fruits without a seed (and only in last decade for oranges & grapefruit)
- Introduced with farming and domesticated, along with all other major crops and animals, 8000-10000 years ago

Uganda

- 400 kg/person/year annual consumption
- Matoke of steamed bananas then mashed

From www.synesthete.com

Banana Plantains *Musa*

1-7 year plantation
Vegetatively propagated (exclusively)

85% used as local staple

20-30kg fruit bunch
>100Mt /yr

2n=3x=33

- Subsistence agriculture
- Smallholder farms
- Cash crop
- Commercial
- Year-round production
- Eaten by all ages of people

Cultivated banana

- Origin from two species in Asia:
- *Musa acuminata* (the A genome) and *Musa balbisiana* (B genome)



L to R:

Red - AAA

Palayam codan AAB (two bunch yellow, one green)

Peyan ABB (green cooking banana),

Njalipoovan AB (yellow)

Robusta AAA (green ripe)

Nendran AAB

Poovan AAB (one yellow bunch)

Red AAA

Peyan

Varkala, Kerala, India

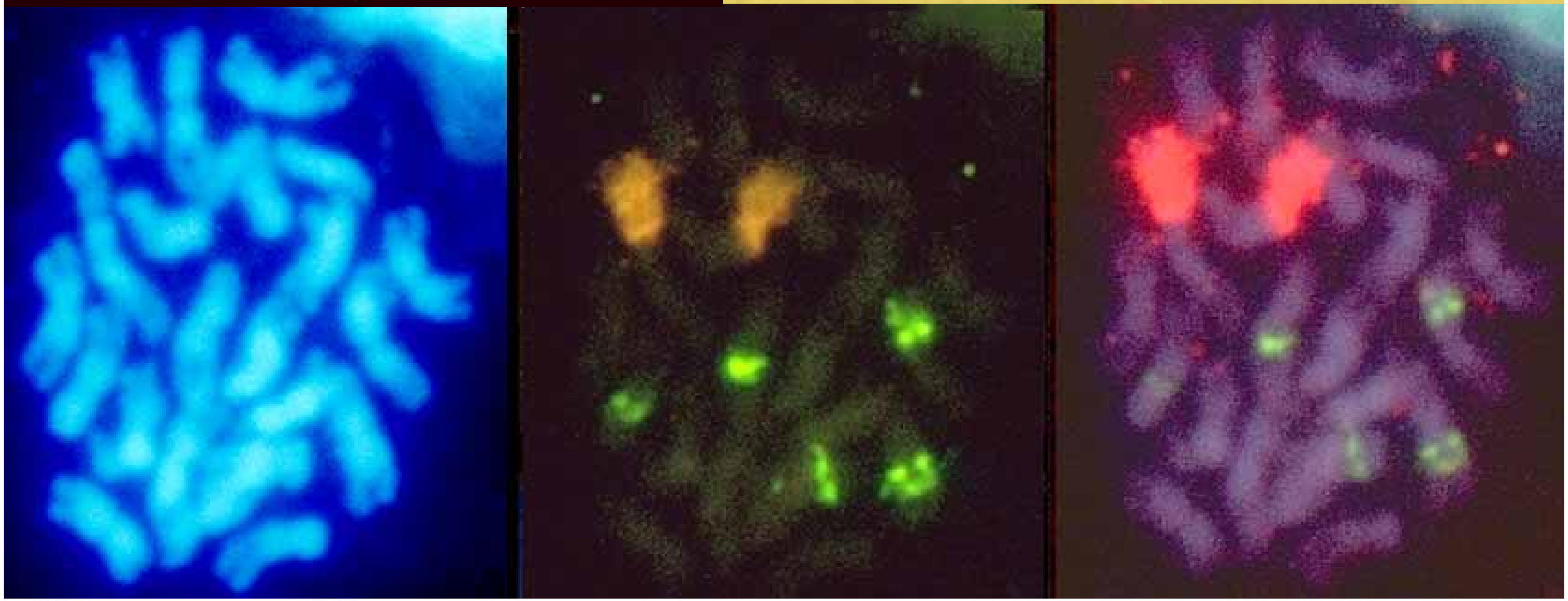
Wild banana

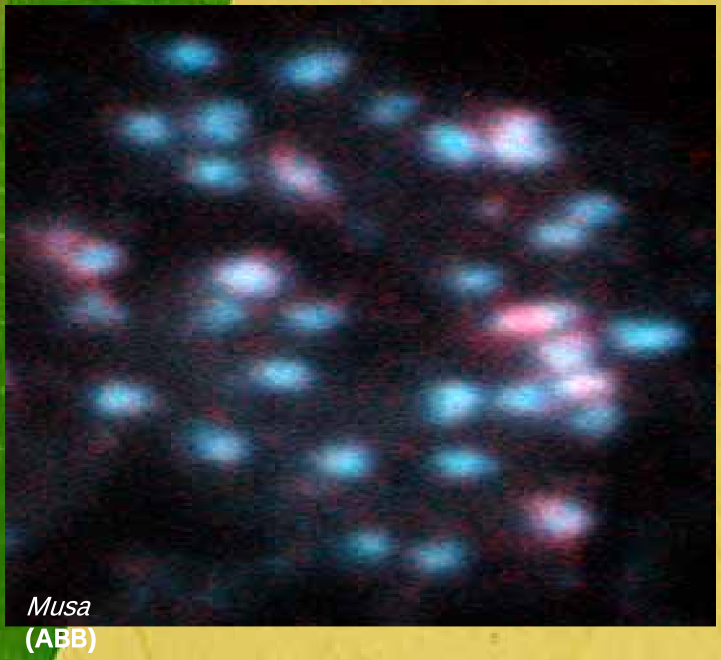
Musa acuminata ‘Calcutta 4’

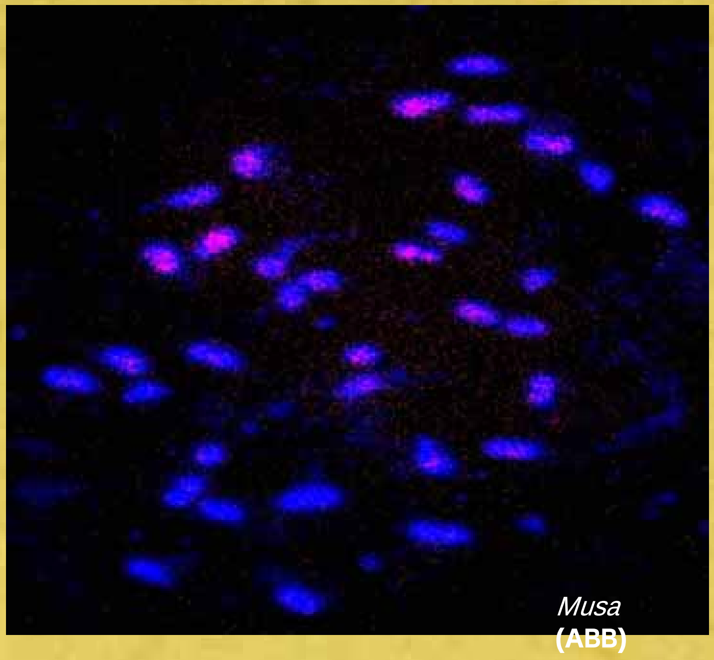
AA genomes, 2n=2x=22

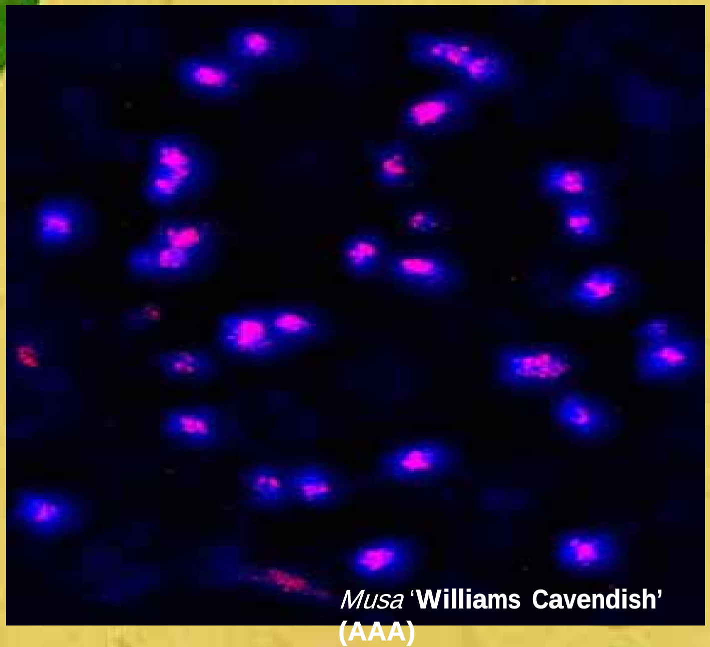
One genome and 11 chromosomes from mother

Other genome and 11 chromosomes from father







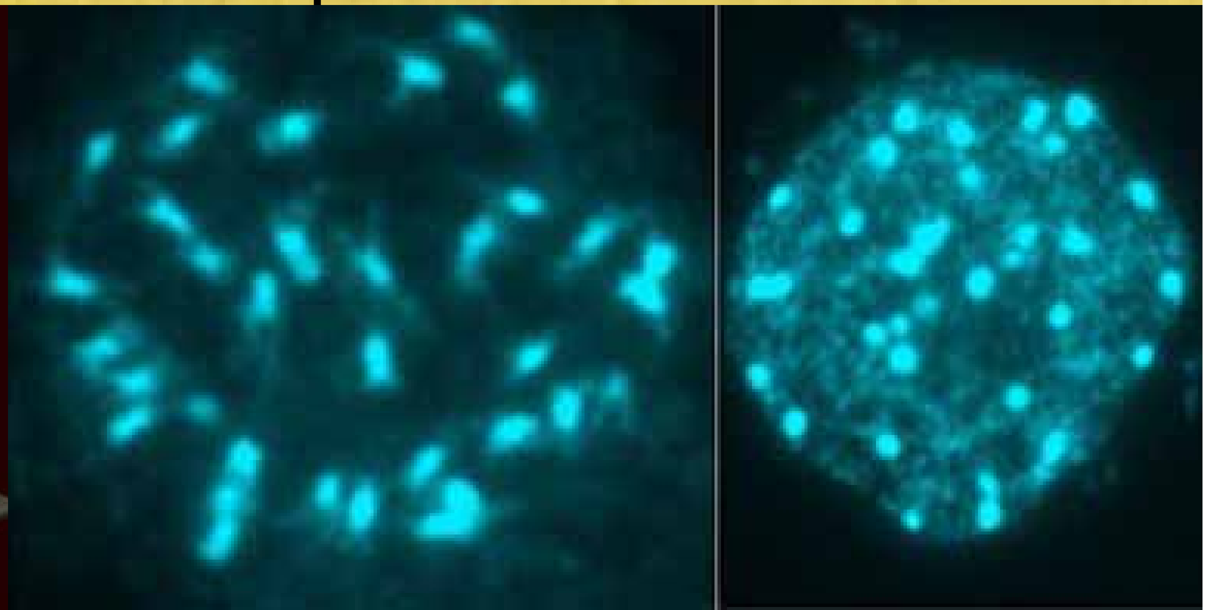


Florescent In-Situ hybridization: **An A-genome specific hAT in three *Musa* hybrids (2n=3x=33) located on A-genome chromosomes.**

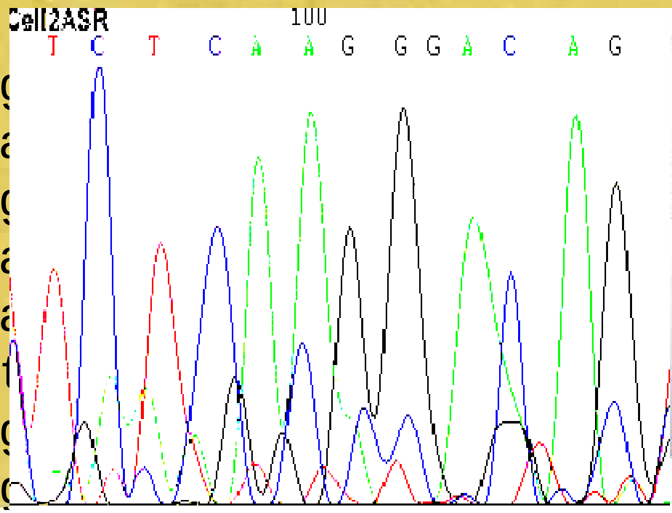
Measuring diversity

What is a genome?

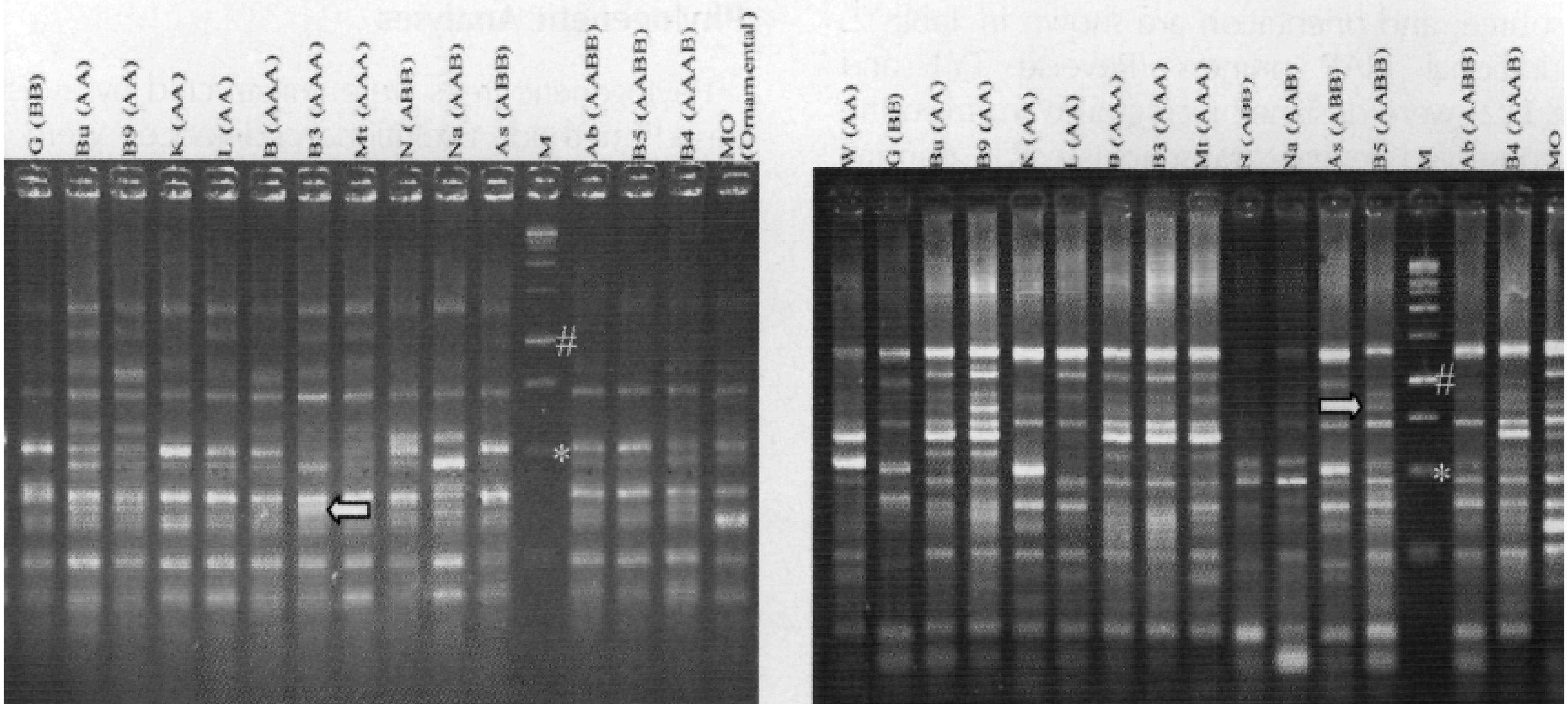
- In bananas and plantains, about 500 million base pairs of DNA



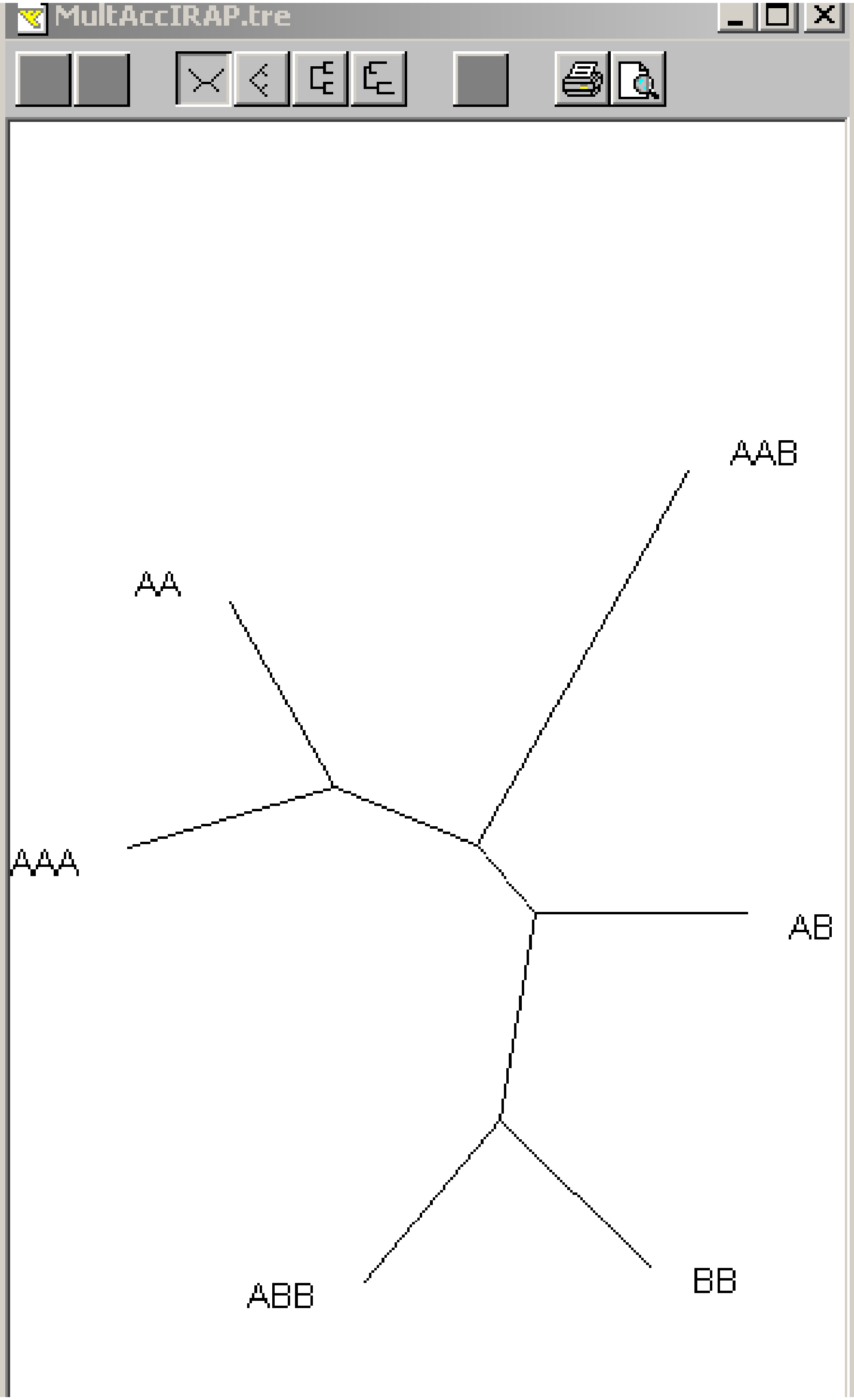
ta clone MuG9, genomic, 73268bp
aaatccaatcaatccagatcaatattgatcg
gacgaagcagtcaaactgatcactaaaattca
gagtgctgatttcagaaacttaatcccttct
caacttacactaattagtcttaaaactcatta
ataaatgtcatattacccttccaggtcataa
atgctgaagctattggcattacacttagtct
tttaacgatatgacaatcaataatgagatag
aaatgacatttttttgaactctgcagaatta



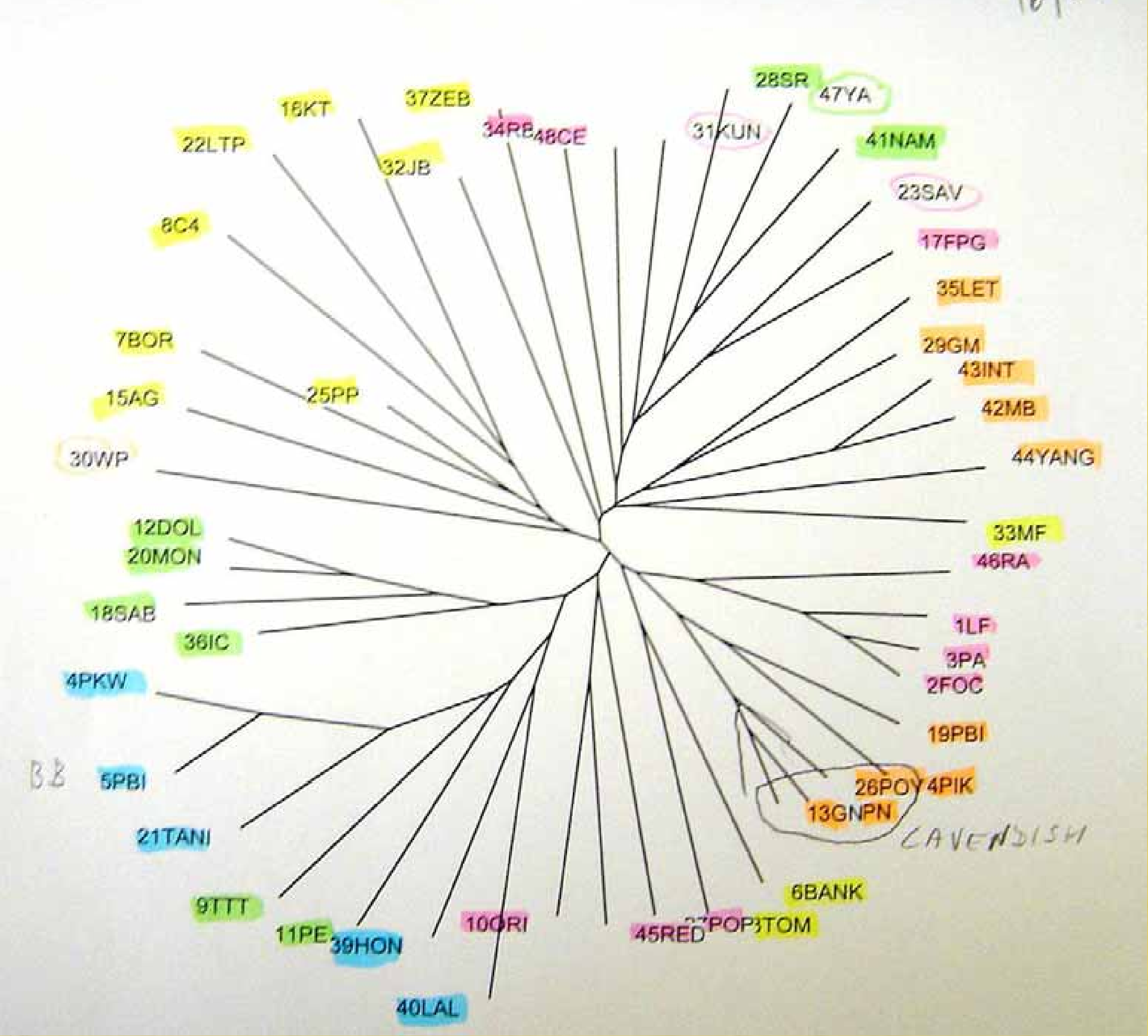
IRAP diversity in Musa



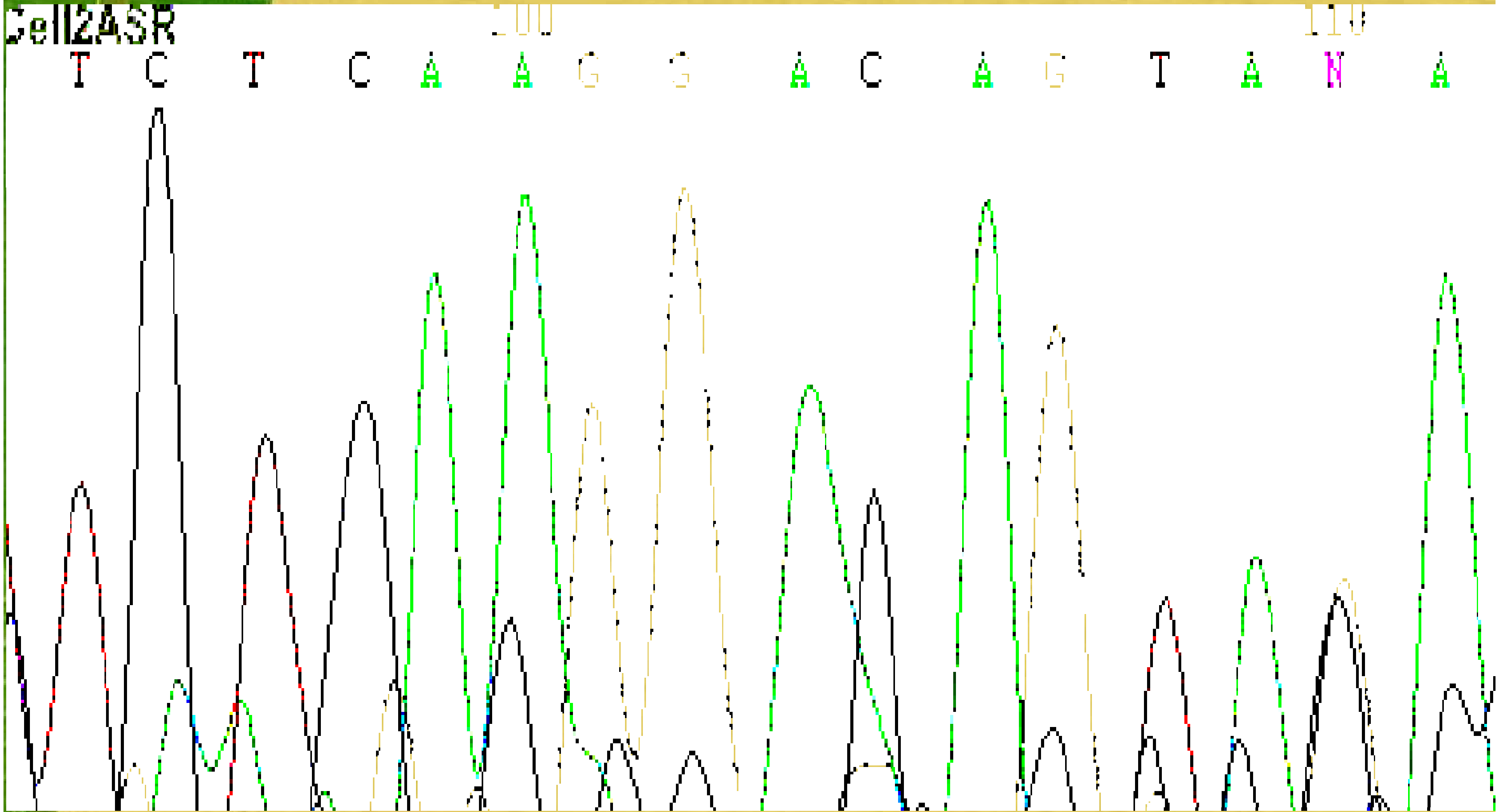
Teo, Tan, Ho, Faridah, Othman, HH, Kalendar, Schulman 2005 *J Plant Biol*
Nair, Teo, Schwarzacher, HH 2006 Euphytica
Desai, Maha..., HH et al. in prep.


MultAccIRAP.tre
AAB
AA
AAA
AB
ABB
BB

- Yellow AA; Green ABB; Blue BB; Pink AAB; Orange AAA



Cellulose Synthase
Single Nucleotide Polymorphism SNP



5 ACE consensus sequence alignments with reference BAC sequence

```
                         0
BAC Ref MA4_64C22         CCATAGGGTTGAAGCTCCTGTTTCTAATATGAAAGTACCGATTATAATTT
Calcutta4                 CCATAGGGTTGAAGCTCCTGTTTCTAATATGAAAGTACCGATTATAATTT
Mala Allele 1             CCATAGGGTTGAAGCTCCTGTTTCTAATATGAAAGTACCGATTATAATTT
Mala Allele 2             CCATAGGGTTGAAGCTCCTGTTTCTAATATGAAAGTACCGATTATAATTT
Pahang Allele 1           CCATAGGGTTGAAGCTCCTGTTTCTAATATGAAAGTACCAATTATAATTT
Pahang Allele 2           CCATAGGGTTGAAGCTCCTGTTTCTAATATGAAAGTACCGATTATAATTT
Pahang Doub Hap           CCATAGGGTTGAAGCTCCTGTTTCTAATATGAAAGTACCAATTATAATTT
                         51
MA4_64C22                 CAGCTGTACAATAATTAAAGAAGAGCCTACCAATTCCTAGACCTTTGTGT
C410TF                    CAGCTGTACAATAATTAAAGAAGAGCCTACCAATTCCTAGACCTTTGTGT
Mala05TF                  CAGCTGTACAATAATTAAAGAAGAGCCTACCAATTCCTAGACCTTTGTGG
Mala allele2              CAGCTGTACAATAATTAAAGAAGAGCCTACCAATTCCTAGACCTTTGTGT
Pah06TR                   CAGCTGTACAATAATTAAAGAAGAGCCAACCAATTCCTAGACCTTTGTGT
Pah19TR                   CAGCTGTACAATAATTAAAGAAGAGCCTACCAATTCCTAGACCTTTGTGT
PDH07TF                   CAGCTGTACAATAATTAAAGAAGAGCCAACCAATTCCTAGACCTTTGTGT
                        101
MA4_64C22                 ACAGGCCCTTGTTCTCATGTCAATGCACAAAGGATGCACCTCAACACACA
C410TF                    ACAGGCCCTTGTTCTCATGTCAATGCACAAAGGATGCACCTCAACACACA
Mala05TF                  ACAGGCCCTTGTTCTCATGTCAATGCACAAAGGATGCACCTCAACACACA
Mala allele2              ACAGGCCCTTGTTCTCATGTCAATGCACAAAGGATGCACCTCAACACACA
Pah06TR                   ACAGGCCCTTGTCCTCATGTCAATGCACAAAGGATGCACCTCAACACACA
Pah19TR                   ACAGGCCCTTGTTCTCATGTCAATGCACAAAGGATGCACCTCAACACACA
PDH07TF                   ACAGGCCCTTGTCCTCATGTCAATGCACAAAGGATGCACCTCAACACACA
                        151
MA4_64C22                 CCAAACTCCAGTTGACTCATCTATACTTGGCCTAAATTGGACGGACTTGG
C410TF                    CCAAACTCCAGTTGACTCATCTATACTTGGCCTAAATTGGACGGACTTGG
Mala05TF                  CCAAACTCCAGTTGACTCATCTATACTTGGCCTAAATTGGACGGACTTGG
Mala allele2              CCAAACTCCAGTTGACTCATCTATACTTGGCCTAAATTGGACGGACTTGG
Pah06TR                   CCAAACTCCAGTTGACTCAGCTATACTTGGCCTAAATTGGACAGACTTGG
Pah19TR                   CCAAACTCCAGTTGACTCATCTATACTTGGCCTAAATTGGACGGACTTGG
PDH07TF                   CCAAACTCCAGTTGACTCAGCTATACTTGGCCTAAATTGGACAGACTTGG
                        200
MA4_64C22                 TAGGACTTGACCTAATTTGGTCAAGCTGGGACAAATTGACCAATTCCAAC
C410TF                    TAGGACTTGACCTAATTTGGTCAAGCTGGGACAAATTGACCAATTCCAAC
Mala05TF                  TAGGACTTGACCTAATTTGGTCAAGCTGGGACAAATTGACCAATTCCAGC
```

Where does diversity come from?

- The DNA
- Single nucleotide changes
  - Cellulose synthase
- Deletions/insertions in genes
- Duplications
  - Modifies expression
  - Important as gives something for evolution to work on
- Regulatory elements


O
EV
LUT
ON

Variety Cavendish

- 15% of banana production worldwide
- The vast majority of export banana to temperate countries
- Controllable ripening but very sensitive to conditions
- First collected in China in 1826 (Telfair), Sold to Duke of Devonshire, Chatsworth
- Distributed worldwide from 1836
- Became dominant variety in 1960s, replacing Gros Michel
- Has various variants: Williams, Dwarf C, Giant C, Grand Naine, Robusta, Poyo …

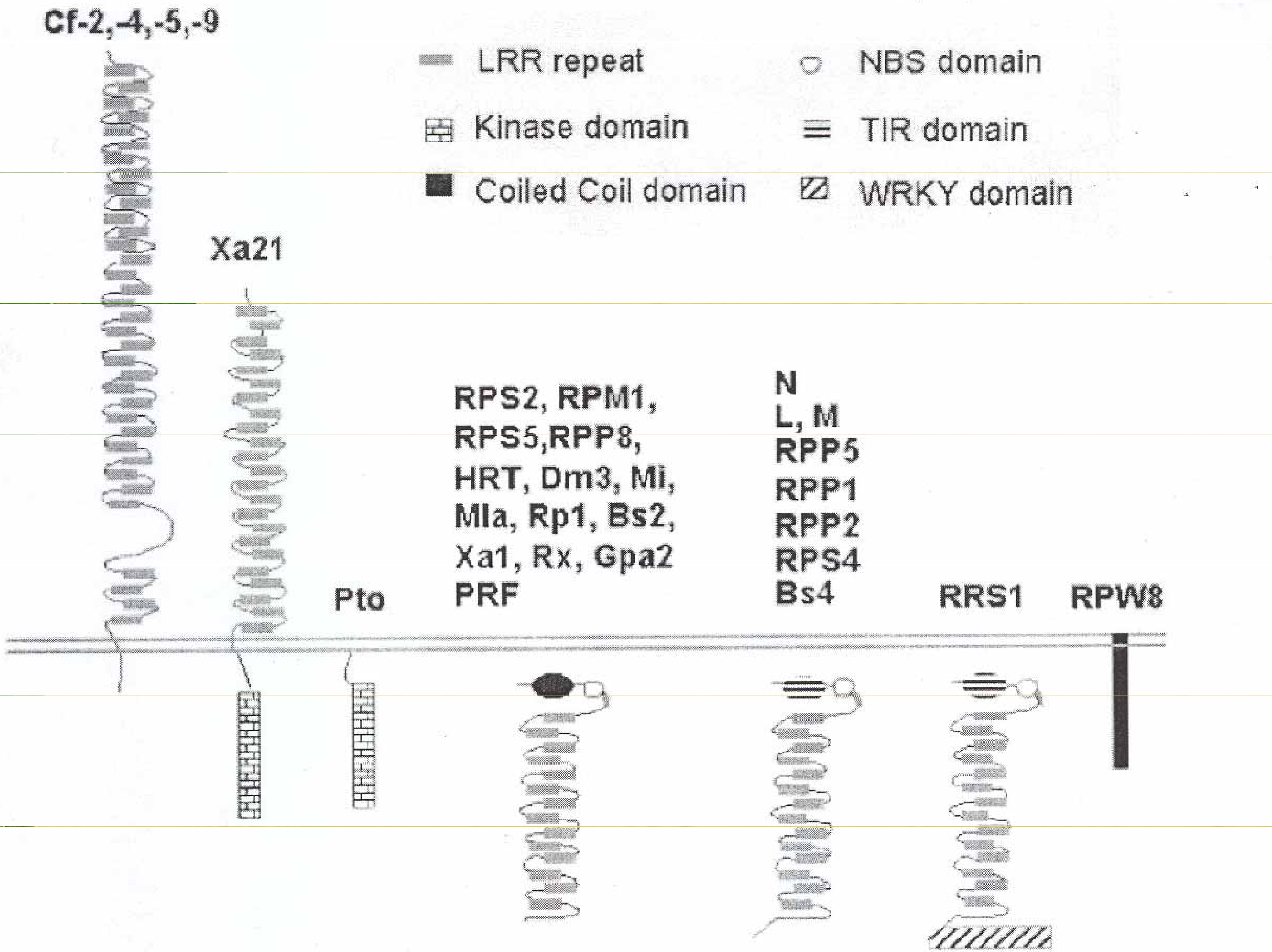
- Gros Michel in Fusarium (Panama disease) trial in Malaysia

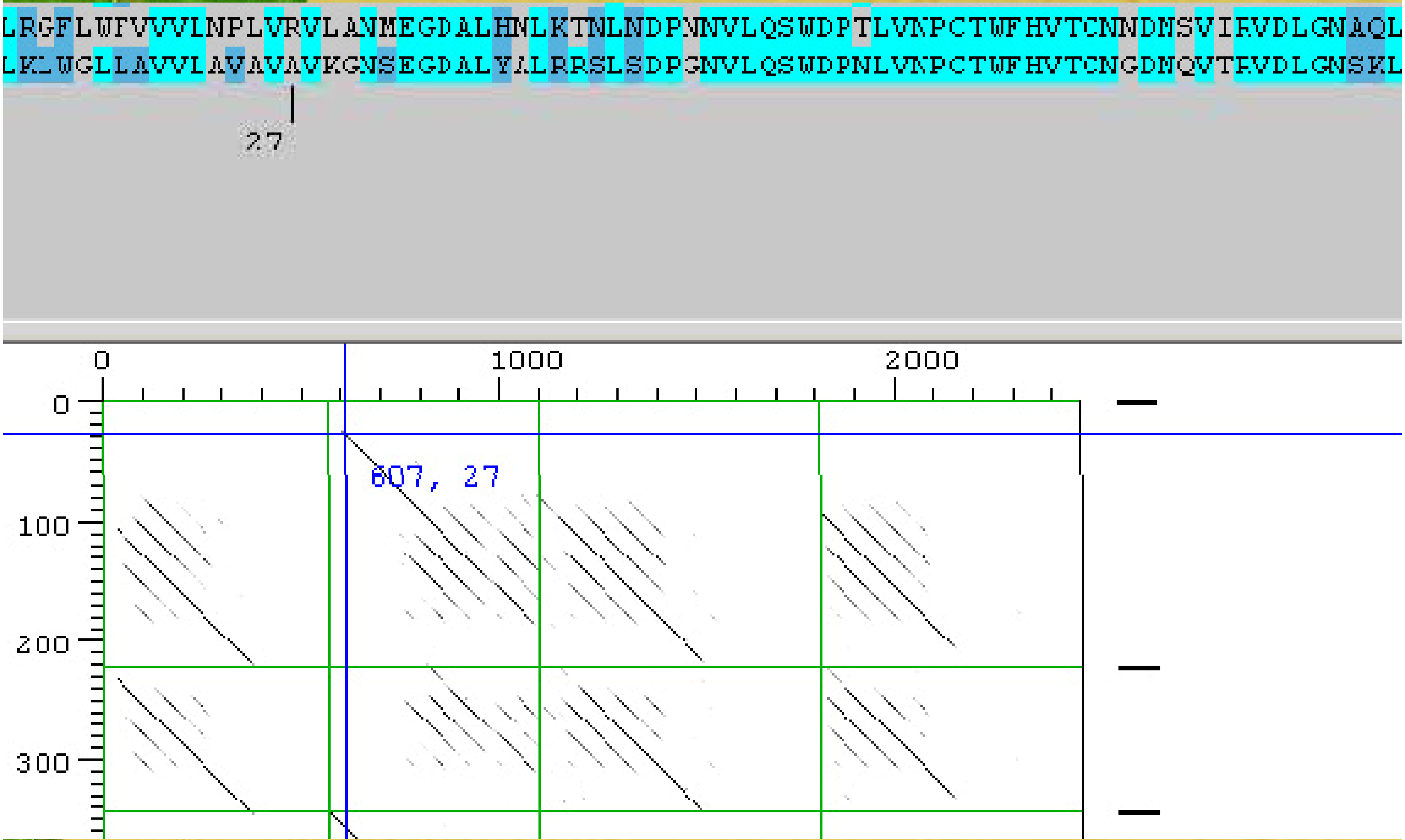
Daily Telegraph 23 May 2006

- **No 1 banana could face extinction**
  By Roger Highfield, Science Editor
- The most popular type of banana, the Cavendish, is under threat from disease. In the 1950s, Britons ate a different banana, the Gros Michel but it was wiped out by Panama disease.
- Now the Cavendish could follow suit as a new strain of the fungus to which it was supposed to be immune has begun to attack the plants. So far, the new, more aggressive variant of Panama disease - TR4 - has not reached the main exporting countries in Latin America or Africa but it is spreading widely through Cavendish plantations in Asia - Indonesia, Taiwan, southern provinces of China and Malaysia.
- In the humid conditions of traditional banana plantations in Central America, the black Sigatoka fungus which attacks leaves, also thrives and the plants must be protected by weekly sprays of fungicides. Although the Cavendish could disappear, experts are confident that a bunch of alternative bananas could fill the void. The caveat is that the taste and texture will be changed forever and there is likely to be a rise in price.

DSC4009 Maca FOC-R1.

RECOGNITION AND RESPONSE IN THE PLANT IMMUNE SYSTEM
Zachary et al.; Annu. Rev. Genet. 2003. 37:579–609





- LRRs in Musa compared to reference Rice

Cytogenet Genome Res 121:59–66 (2008)
DOI: 10.1159/000124383

Cytogenetic and Genome Research

Genomes, diversity and resistance gene analogues in *Musa* species

M. Azhar J.S. Heslop-Harrison

Abstract. Resistance genes (R genes) in plants are abundant and may represent more than 1% of all the genes. Their diversity is critical to the recognition and response to attack from diverse pathogens. Like many other crops, banana and plantain face attacks from potentially devastating fungal and bacterial diseases, increased by a combination of worldwide spread of pathogens, exploitation of a small number of varieties, new pathogen mutations, and the lack of effective, benign and cheap chemical control. The challenge for plant breeders is to identify and exploit genetic resistances to diseases, which is particularly difficult in banana and plantain where the valuable cultivars are sterile, parthenocarpic and mostly triploid so conventional genetic analysis and breeding is impossible. In this paper, we review the nature of R genes and the key motifs, particularly in the Nucleotide Binding Sites (NBS), Leucine Rich Repeat (LRR) gene class. We present data about identity, nature and evolutionary diversity of the NBS domains of *Musa* R genes in diploid wild species with the *Musa acuminata* (A), *M. balbisiana* (B), *M. schizocarpa* (S), *M. textilis* (T), *M. velutina* and *M. ornata* genomes, and from various cultivated hybrid and triploid accessions, using PCR primers to isolate the domains from genomic DNA. Of 135 new sequences, 75% of the sequenced clones had uninterrupted open reading frames (ORFs), and phylogenetic UPGMA tree construction showed four clusters, one from *Musa ornata*, one largely from the B and T genomes, one from A and *M. velutina*, and the largest with A, B, T and S genomes. Only genes of the coiled-coil (non-TIR) class were found, typical of the grasses and presumably monocotyledons. The analysis of R genes in cultivated banana and plantain, and their wild relatives, has implications for identification and selection of resistance genes within the genus which may be useful for plant selection and breeding and also for defining relationships and genome evolution patterns within the genus using the multi-copy and variable resistance genes.

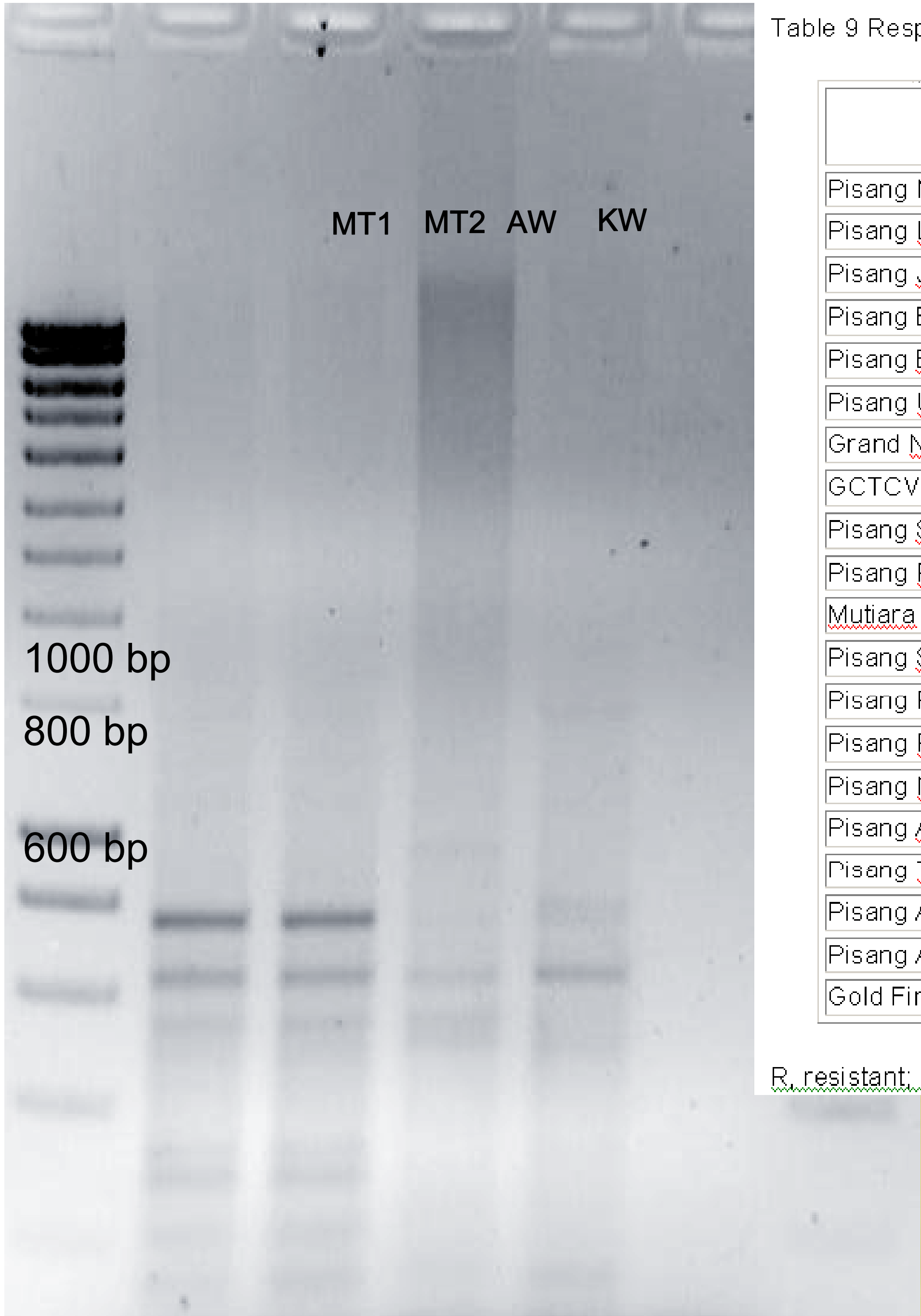


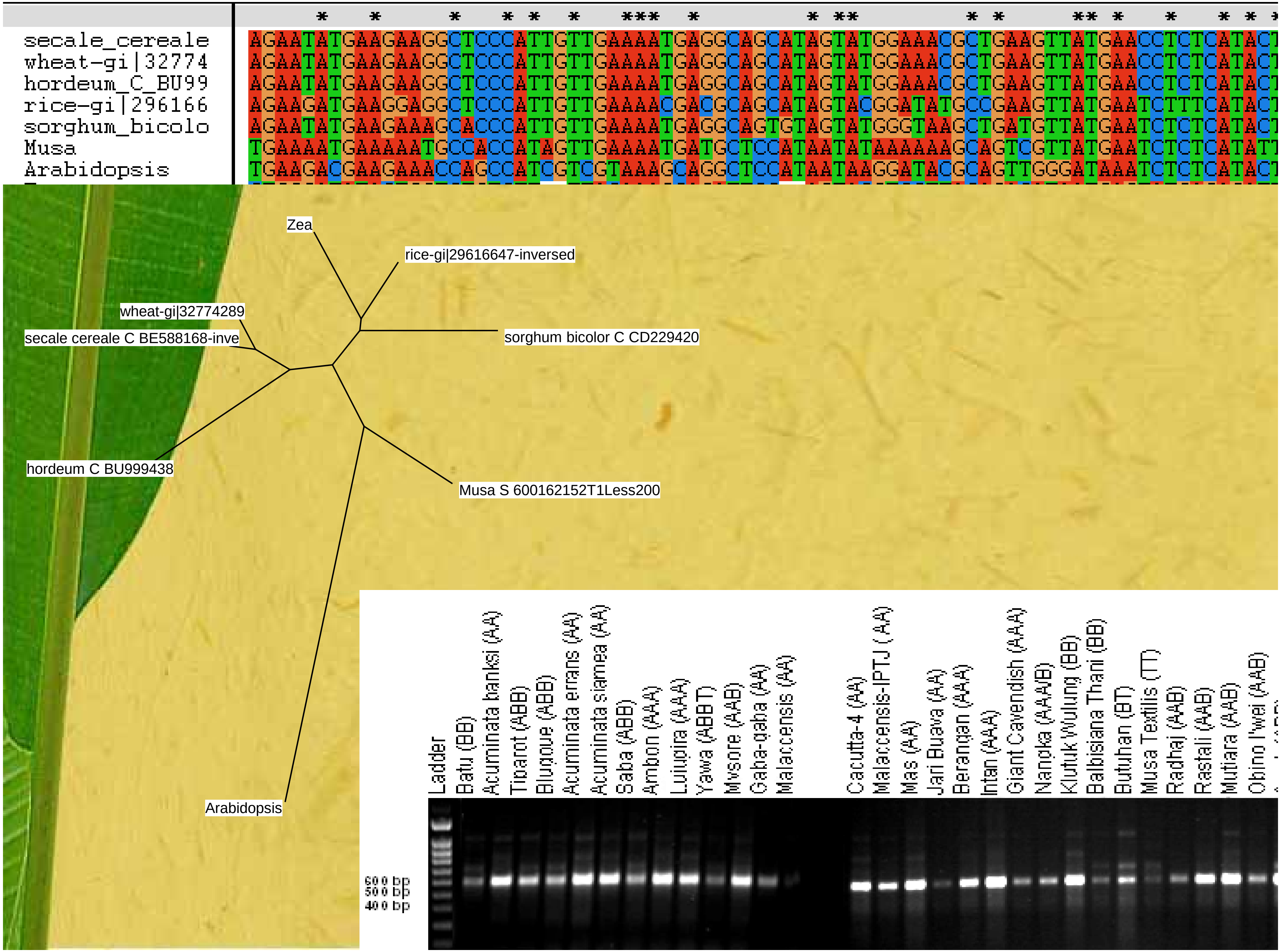
Table 9 Response of some banana cultivars to *Fusarium oxysporum* f. sp. *cubense* (FOC)

Cultivars	Genome	Disease Reaction	
		FOC Race 1	FOC Race 4
Pisang Mas	AA	T	S
Pisang Lemak Manis	AA	T	T
Pisang Jari Buaya	AA	R	R
Pisang Berangan	AAA	S	VS
Pisang Embun	AAA	VS	VS
Pisang Udang	AAA	S	S
Grand Naine	AAA	R	S
GCTCV215-1	AAA	R	T (?)
Pisang Serendah	AAA	R	T
Pisang Rastali	AAB	VS	VS
Mutiara (selected P. Rastali)	AAB	T	T
Pisang Seribu	AAB	S	S
Pisang Raja	AAB	S	S
Pisang Relong	AAB	S	S
Pisang Nangka	AAB	S	S
Pisang Awak	ABB	T	S
Pisang Tanduk	ABB	S	S
Pisang Abu Keling	ABB	T	T
Pisang Abu Nipah	ABBB	S	S
Gold Finger	AAAB	R	T

R, resistant; T, tolerant; S, susceptible; VS, very susceptible.

Primers : MLRR1-F and MLRR2-R

MT1 and MT2 – Mutiara tolerance to FOC
AW - Pisang Awak
KW – Klutuk Wulung



secale_cereale
wheat-gi|32774
hordeum_C_BU99
rice-gi|296166
sorghum_bicolo
Musa
Arabidopsis
Zea
rice-gi|29616647-inversed
wheat-gi|32774289
secale cereale C BE588168-inve
sorghum bicolor C CD229420
hordeum C BU999438
Musa S 600162152T1Less200
Arabidopsis
Ladder
Batu (BB)
Acuminata banksi (AA)
Tiparot (ABB)
Bluggoe (ABB)
Acuminata errans (AA)
Acuminata siamea (AA)
Saba (ABB)
Ambon (AAA)
Lulugira (AAA)
Yawa (ABBT)
Mysore (AAB)
Gaba-gaba (AA)
Malaccensis (AA)
Cacutta-4 (AA)
Malaccensis-IPTJ (AA)
Mas (AA)
Jari Buaya (AA)
Berangan (AAA)
Intan (AAA)
Giant Cavendish (AAA)
Nangka (AAA/B)
Klutuk Wulung (BB)
Balbisiana Thani (BB)
Butuhan (BT)
Musa Textilis (TT)
Radhaj (AAB)
Rastali (AAB)
Mutiara (AAB)
Obino l'wei (AAB)
600 bp
500 bp
400 bp

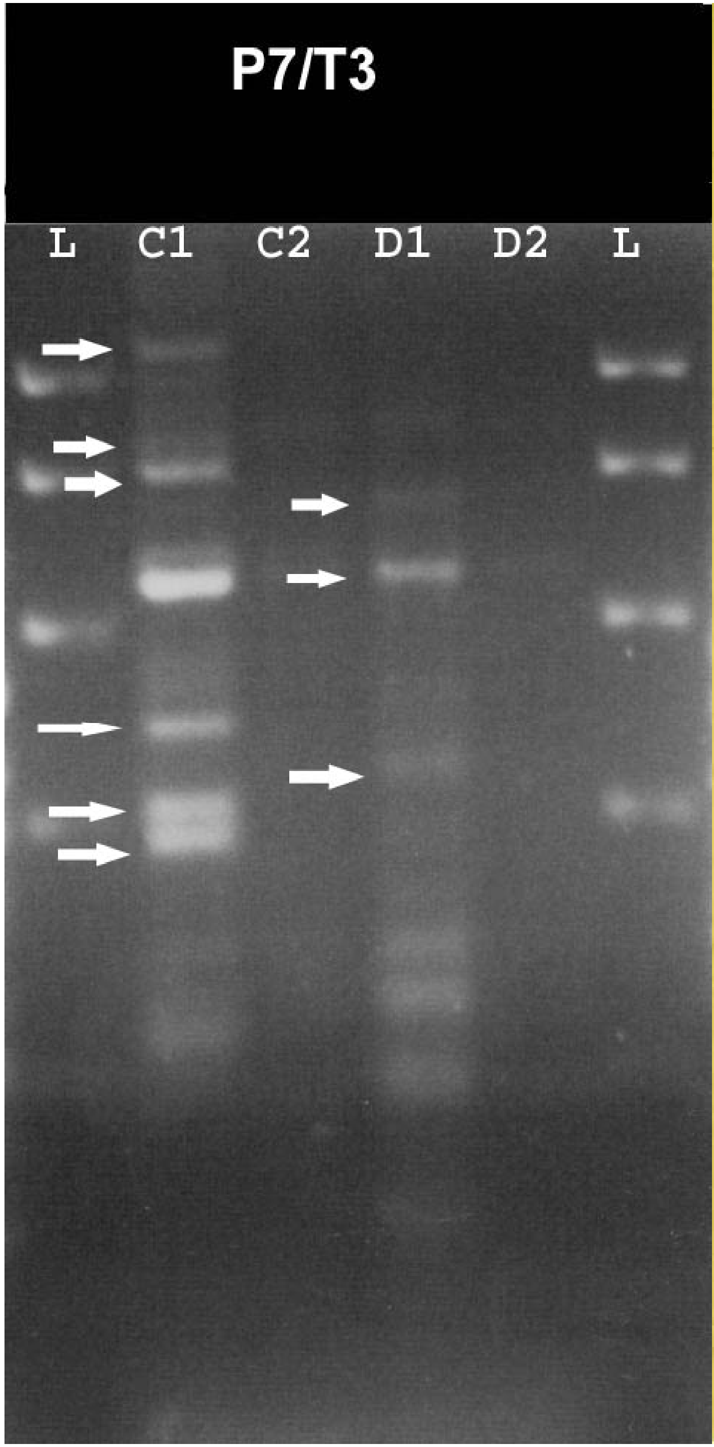
Plant breeding

- Keeping up with changes
- Biotic stress
  - New disease races are continuously appearing and spreading
  - Fungi, viruses, bacteria
  - Insects, nematodes, weeds …
- Abiotic stresses
  - Drought/flooding/salt, cold …
- Socio-economic changes
  - More people to feed on less land
  - Urbanization of population


Drought Responsive Genes

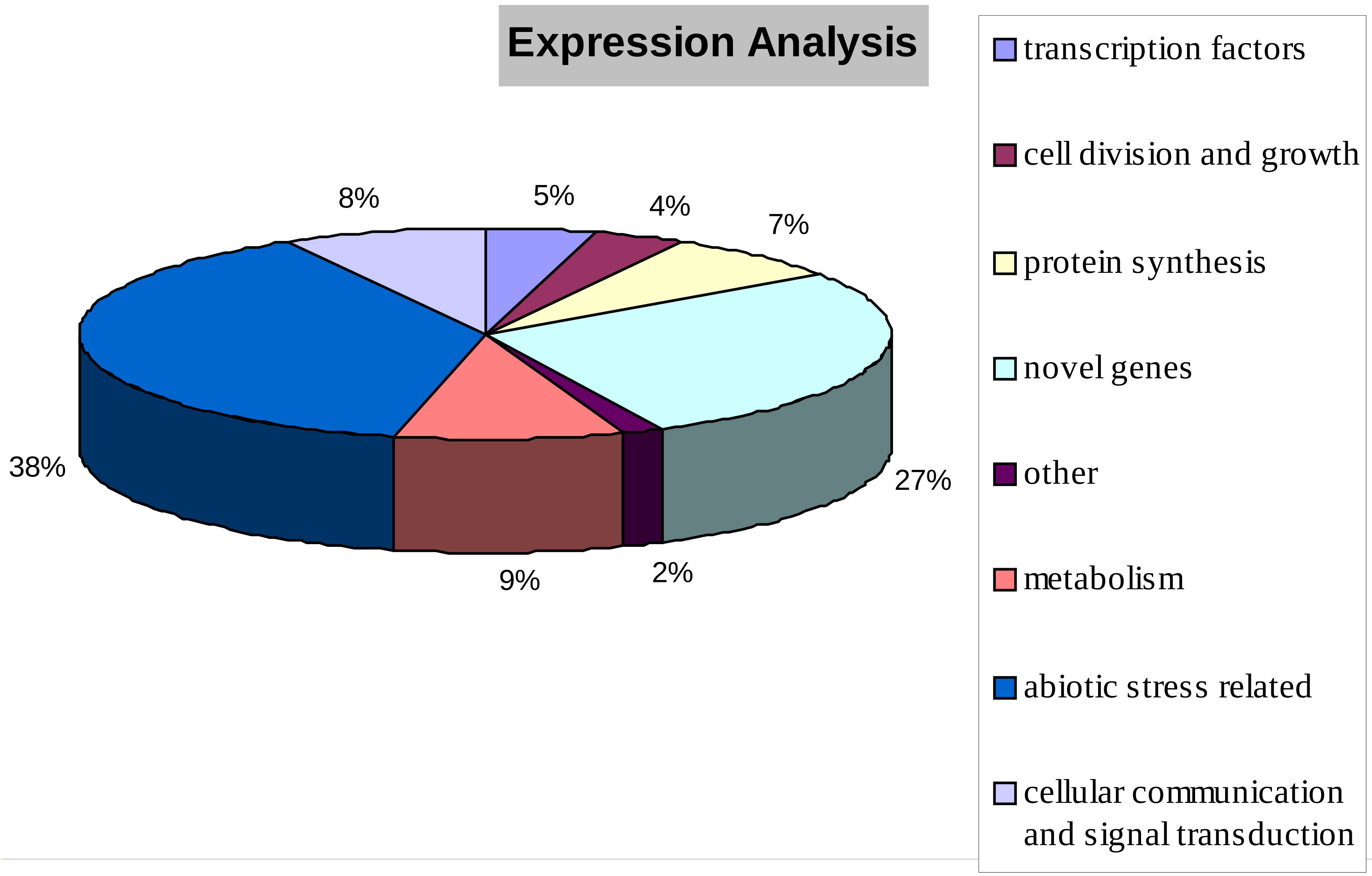
- Differential display of genes being expressed from droughted and watered *Musa* lines

Drought Responsive Genes



Differential Display

14 DD-PCR reactions using different arbitrary and Oligo dT primer combinations, a total of 22 differentially expressed bands (MDRG)



Preliminary data; Dhairyasheel Desai, HH *et al.* in prep 2007





PDCP


AICRP(TF)
COLLECTION, CONSERVATION AND
EVALUATION OF BANANA GERMPLASM
No. OF ACCESSIONS - 256.
No. OF PLANTS/ACCESSION - 5.
SPACING - 2x2.5m.
DATE OF PLANTING - 23.10.2006.

enomics.org/index.php?id=38

Go Bookmarks 6 blocked Check AutoLink AutoFill Send to

GMGC Global Musa Genomics Consortium

About GMGC | Genome resources | Research | Projects | News | Contacts | Links | Members

Site map

pharrison

GMGC is an initiative of Bioversity International

home > Research > **Genetic diversity**

Genetic Diversity

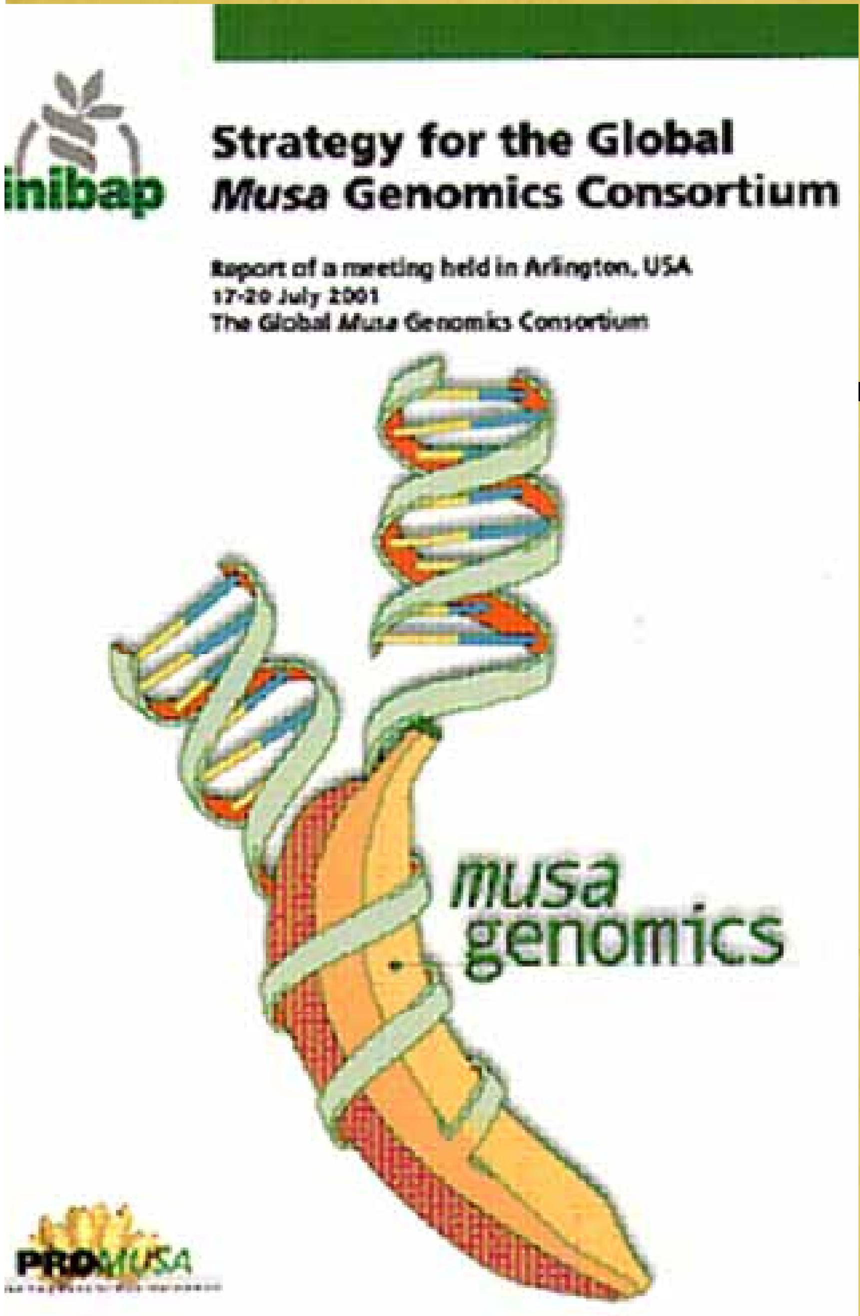
A genebank holding more than 90% of the existing diversity of cultivated bananas and a representative sample of the wild species of Musa is maintained by Bioversity International at the International Musa genebank in Leuven, Belgium. The collection has been tested for bacteria and viruses and all varieties that tested negative are available for distribution.

There is a very good knowledge of the structure of the Musa species complex based on morphological descriptors as well as molecular markers for the chloroplastic, mitochondrial and nuclear genome. Studies have revealed a great diversity in Musa, providing a good model for the study of gene regulation.

Ploidy and genome size and constitution

- Analysis of nuclear genome size in *Musa* and *Ensete* (IEB)
- Evaluation of genome identity and constitution of Philippine Musa Cultivars (especially the Balbisiana group) through flow cytometry (USM)


BANANA
GERMPLASM



The Global Musa Genomics Consortium

- To assure the sustainability of banana as a staple food crop by developing an integrated genetic and genomic understanding, allowing targeted breeding, transformation and more efficient use of Musa biodiversity

Super-domestication:
The future of banana crops

- Biotic stresses
- Abiotic stresses
- Socioeconomic factors

- … all mean current cultivars do not meet future needs

Super-domestication:
The future of banana crops

- The genepool has the diversity there which can meet these challenges

- Breeders need to get better and faster

- Banana, has extra challenges
  - Staple food
  - Major income source in many communities
  - Sterile plant

naturenews

Published online 1 October 2010 | Nature | doi:10.1038/news.2010.509

News

Uganda prepares to plant transgenic bananas

Sweet pepper gene confers resistance to bacterial wilt.

Linda Nordling

Banana plants growing at Uganda's National Agricultural Research Institute. Field trials of a GM variety are set to begin next week.

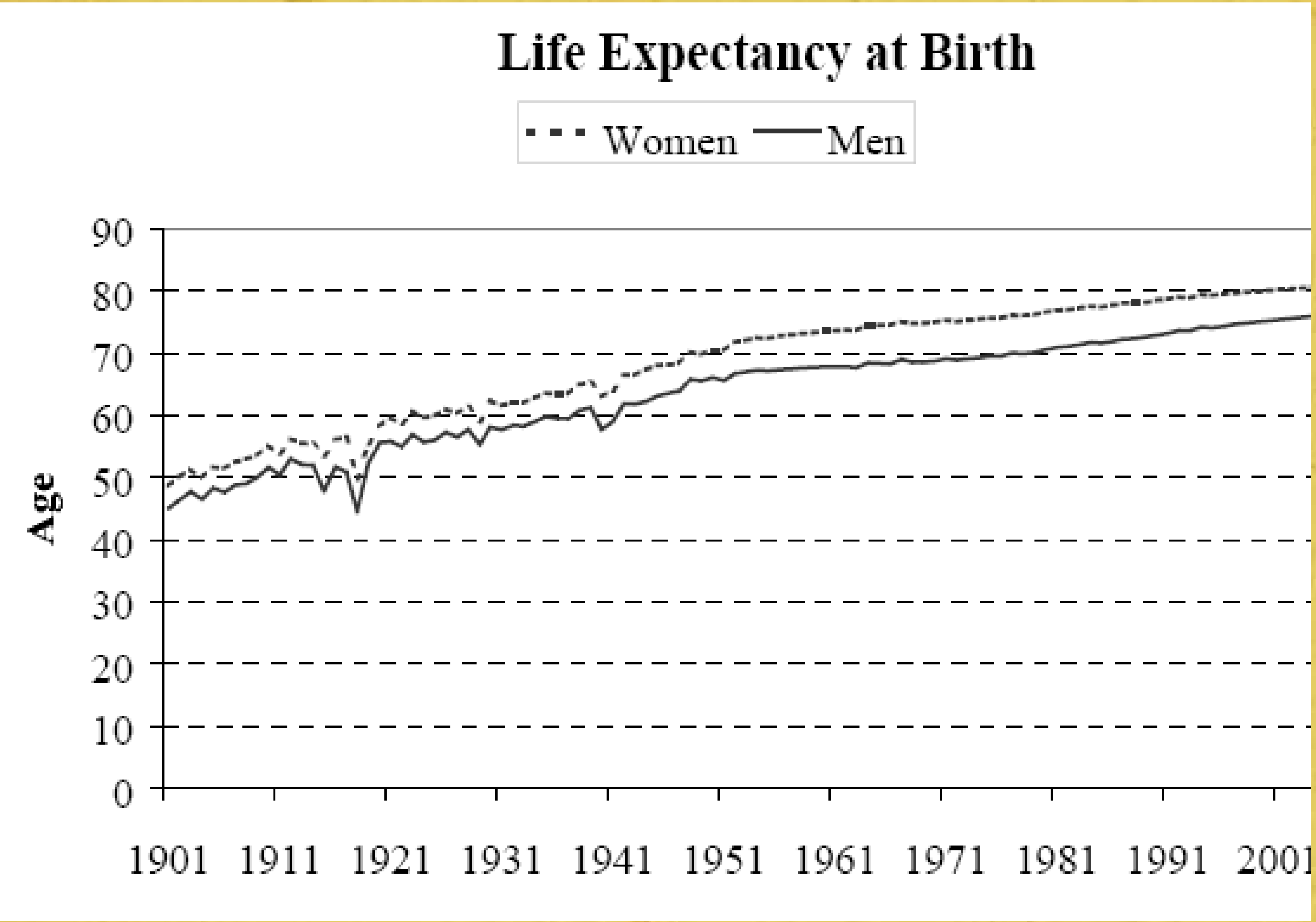
Linda Nordling

Scientists in Uganda will next week start field trials of a banana variety genetically engineered to resist a bacterial disease that has been decimating crops across central Africa.

The new variety is part of a wider effort to improve the East African Highland banana, a fruit so important to Ugandans that its name, matooke, is synonymous with 'food' in one of the local languages. But delays to a law regulating the commercial growing of genetically modified (GM) food in the country means it is not clear when the improved banana could be released to farmers.

What have farmers done?

- Increased quality and security, supporting a longer-lived, larger population



A Century of Change: Trends in UK statistics since 1900
UK House of Commons

	year (millions)
item	2007
People	6,602
Maize	785
Rice, paddy	652
Wheat	607
Potatoes	322
Sugar beet	248
Cassava	228
Soybeans	216
Oil palm fruit	192
Barley	136
Sweet potatoes	126
Tomatoes	126
Watermelons	93
Bananas	81
Seed cotton	73
Cabbages and other bra	69
Grapes	66
Sorghum	65
Onions, dry	64
Apples	64
Oranges	64
Coconuts	55
Yams	52
Rapeseed	49
Cucumbers and gherkin	45
Groundnuts, with shell	35
Plantains	34
Mangoes, mangosteens	33
Eggplants (aubergines)	32
Millet	32

FAO Statistics 2007

All plant crops with >30M tons annual production

excluding sugar cane and 'other vegetables'

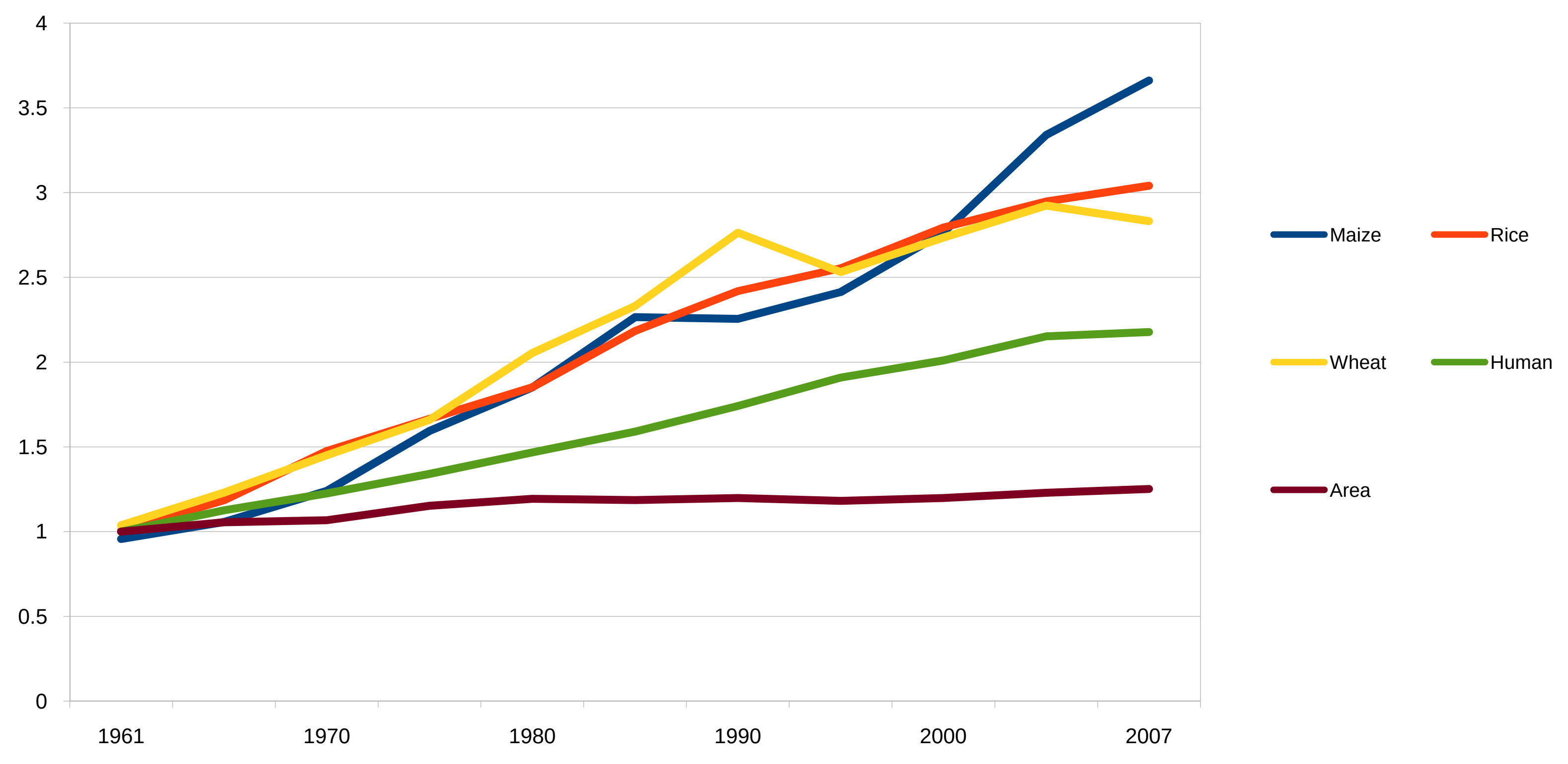
People: WHO

	year (millions)	
item	1961	2007
People	3,090	6,602
Maize	205	785
Rice, paddy	216	652
Wheat	222	607
Potatoes	271	322
Sugar beet	161	248
Cassava	71	228
Soybeans	27	216
Oil palm fruit	14	192
Barley	72	136
Sweet potatoes	98	126
Tomatoes	28	126
Watermelons	18	93
Bananas	21	81
Seed cotton	27	73
Cabbages and other bra	23	69
Grapes	43	66
Sorghum	41	65
Onions, dry	14	64
Apples	17	64
Oranges	16	64
Coconuts	24	55
Yams	8	52
Rapeseed	4	49
Cucumbers and gherkin	10	45
Groundnuts, with shell	14	35
Plantains	13	34
Mangoes, mangosteens	11	33
Eggplants (aubergines)	7	32
Millet	26	32

item	year (millions) 1961	2007	2007/1961
People	3,090	6,602	2.1
Maize	205	785	3.8
Rice, paddy	216	652	3.0
Wheat	222	607	2.7
Potatoes	271	322	1.2
Sugar beet	161	248	1.5
Cassava	71	228	3.2
Soybeans	27	216	8.0
Oil palm fruit	14	192	13.7
Barley	72	136	1.9
Sweet potatoes	98	126	1.3
Tomatoes	28	126	4.5
Watermelons	18	93	5.2
Bananas	21	81	3.9
Seed cotton	27	73	2.7
Cabbages and other bra	23	69	3.0
Grapes	43	66	1.5
Sorghum	41	65	1.6
Onions, dry	14	64	4.6
Apples	17	64	3.8
Oranges	16	64	4.0
Coconuts	24	55	2.3
Yams	8	52	6.5
Rapeseed	4	49	12.3
Cucumbers and gherkin	10	45	4.5
Groundnuts, with shell	14	35	2.5
Plantains	13	34	2.6
Mangoes, mangosteens	11	33	3.0
Eggplants (aubergines)	7	32	4.6
Millet	26	32	1.2

	year (millions)		
item	1961	2007	2007/1961
Oil palm fruit	14	192	13.7
Rapeseed	4	49	12.3
Soybeans	27	216	8.0
Yams	8	52	6.5
Watermelons	18	93	5.2
Onions, dry	14	64	4.6
Eggplants (aubergines)	7	32	4.6
Tomatoes	28	126	4.5
Cucumbers and gherkin	10	45	4.5
Oranges	16	64	4.0
Bananas	21	81	3.9
Maize	205	785	3.8
Apples	17	64	3.8
Cassava	71	228	3.2
Rice, paddy	216	652	3.0
Cabbages and other bra	23	69	3.0
Mangoes, mangosteens	11	33	3.0
Wheat	222	607	2.7
Seed cotton	27	73	2.7
Plantains	13	34	2.6
Groundnuts, with shell	14	35	2.5
Coconuts	24	55	2.3
People	3,090	6,602	2.1
Barley	72	136	1.9
Sorghum	41	65	1.6
Sugar beet	161	248	1.5
Grapes	43	66	1.5
Sweet potatoes	98	126	1.3
Millet	26	32	1.2
Potatoes	271	322	1.2

50 years of plant breeding progress



UK Wheat 1948-2007

52,909 data points, 308 varieties

Linear trends in yield

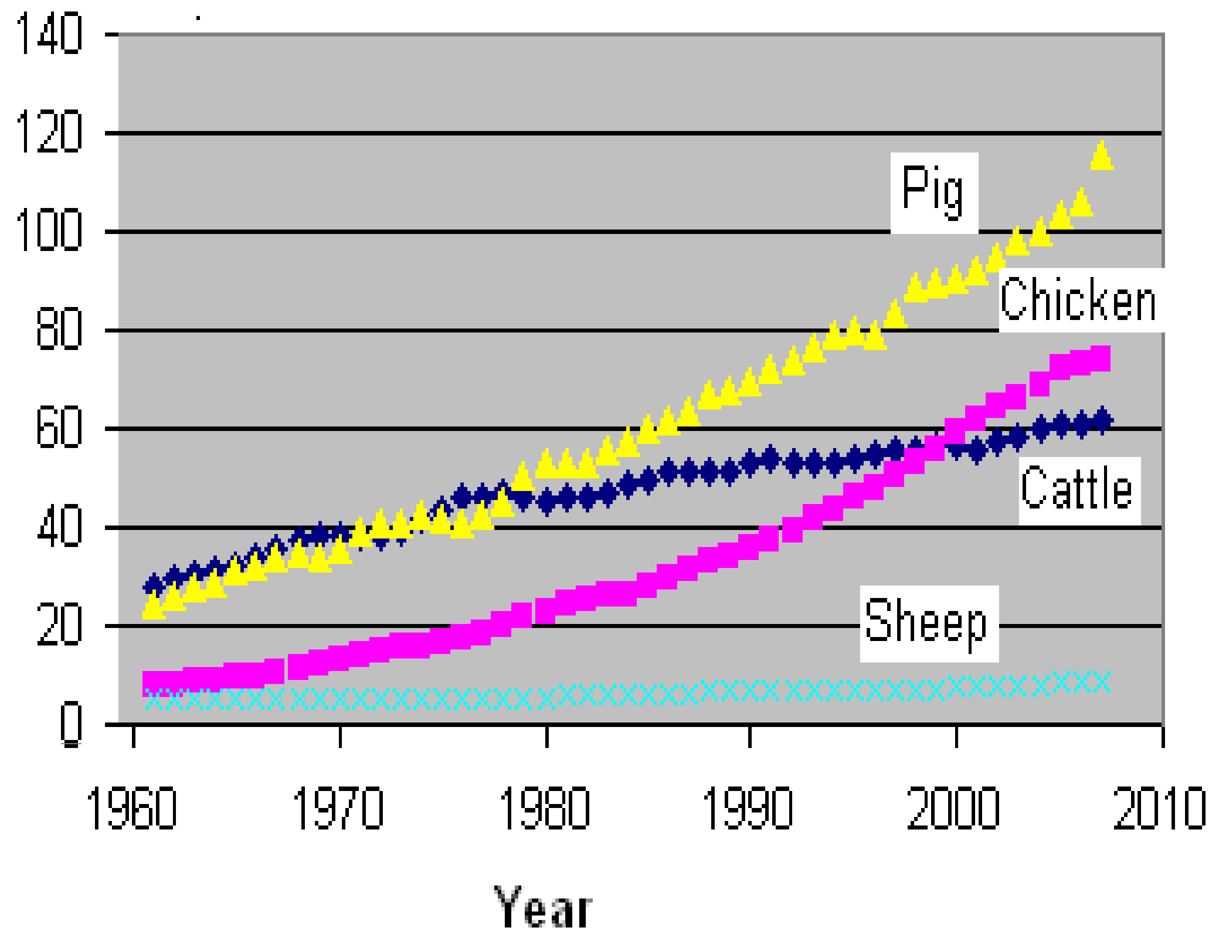
	G	E
1948 - 2007	0.071	0.069
1948 - 1981	0.061	0.041
1982 - 2007	0.074	0.010

Improvements in both agronomy and genetics brought about big improvements in yield for ~ 30 years from 1948.

However, for the last 25 years, yields have increased primarily from plant breeding alone.

From Ian Mackay, NIAB, UK. 2009. Re-analyses of historical series of variety trials: lessons from the past and opportunities for the future. SCRI website.

Meat Production



BBC News in video and audio

Last Updated: Tuesday, 15 August 2006, 09:06 GMT 10:06 UK

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Overweight 'top world's hungry'

There are now more overweight people across the world than hungry ones, according to experts.

The number of people overweight has topped 1bn across the world

US professor Barry Popkin said all countries - both rich and poor had failed to address the obesity boom.

He told the International Association of Agricultural Economists the number of overweight people had topped 1bn, compared with 800m undernourished.

Speaking at an Australian conference, he said changing diets and people doing less physical exercise was the cause.

Professor Popkin, from the University of North Carolina, said that the change had happened quickly as obesity was rapidly spreading, while hunger was slowly declining among the world's 6.5bn population.

- What are bananas?
- What is in banana DNA?
- What is the future for banana?
- What is the future for diet and farmers?

United Nations
Millennium Development Goals

- Goal 1 – Eradicate extreme poverty and hunger
- Goal 2 – Achieve universal primary education
- Goal 3 – Promote gender equity and empower women
- Goal 4 – Reduce child mortality
- Goal 5 – Improve maternal health
- Goal 6- Combat HIV/AIDS, malaria and other diseases
- Goal 7 - Ensure environmental sustainability
- Goal 8 - Develop a global partnership for development

Darwin: Final paragraph of "The Origin"

- It is interesting to contemplate … many plants of many kinds … from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved.

The Banana

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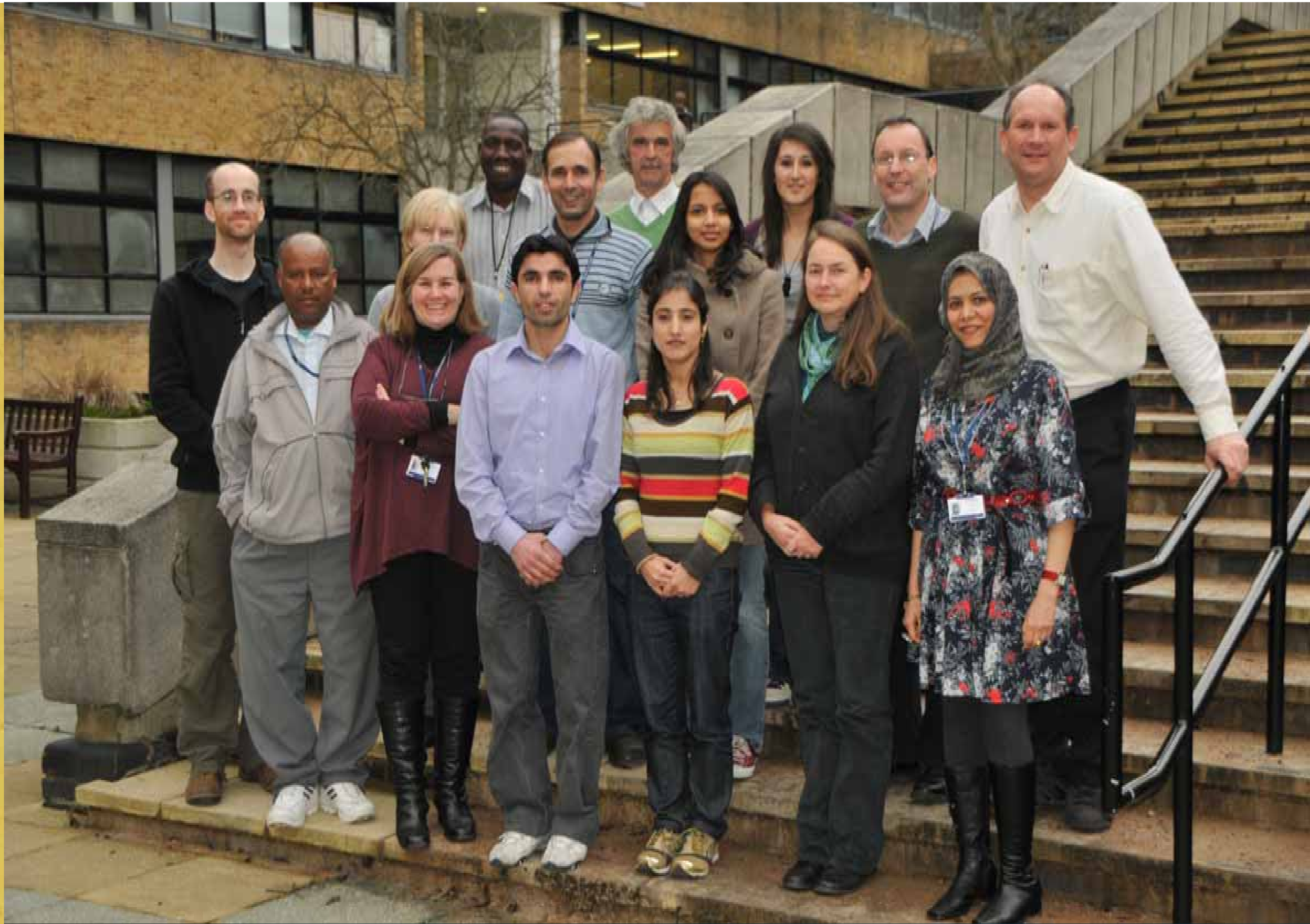

Economic growth

- Separate into increases in inputs (resources, labour and capital) and technical progress
- 90% of the growth in US output per worker is attributable to technical progress

Robert Solow – Economist

FINANCIAL TIMES

From Prof Donald Braben and others.

Sir, We the undersigned scientists write to draw attention to a neglected aspect of the current economic crisis. Robert Solow won the Nobel Prize in economics in 1987 for his 1950s discovery that *technical change* was the biggest source of growth, a discovery that seems to have been forgotten.

Scientific advances are not predictable.

University, Nobel laureate
Pat Heslop-Harrison, University of Leicester
Steve Howdle, University of