The Plant Biotechnology driven Revolution

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The Green Revolution 1950 to 2000

- Population rose from 2.5 billion to 6 billion
- genetic improvement – plant breeding
- increased fertiliser use – artificial nitrogen production
- invention of pesticides – reduction of losses by pests and diseases and improvements in food safety
- increased mechanisation
- improved agricultural efficiency
- world wheat yields rose from 1.5 t/ha to 4 t/ha
- decrease in amount spent on food – 30% to 10%

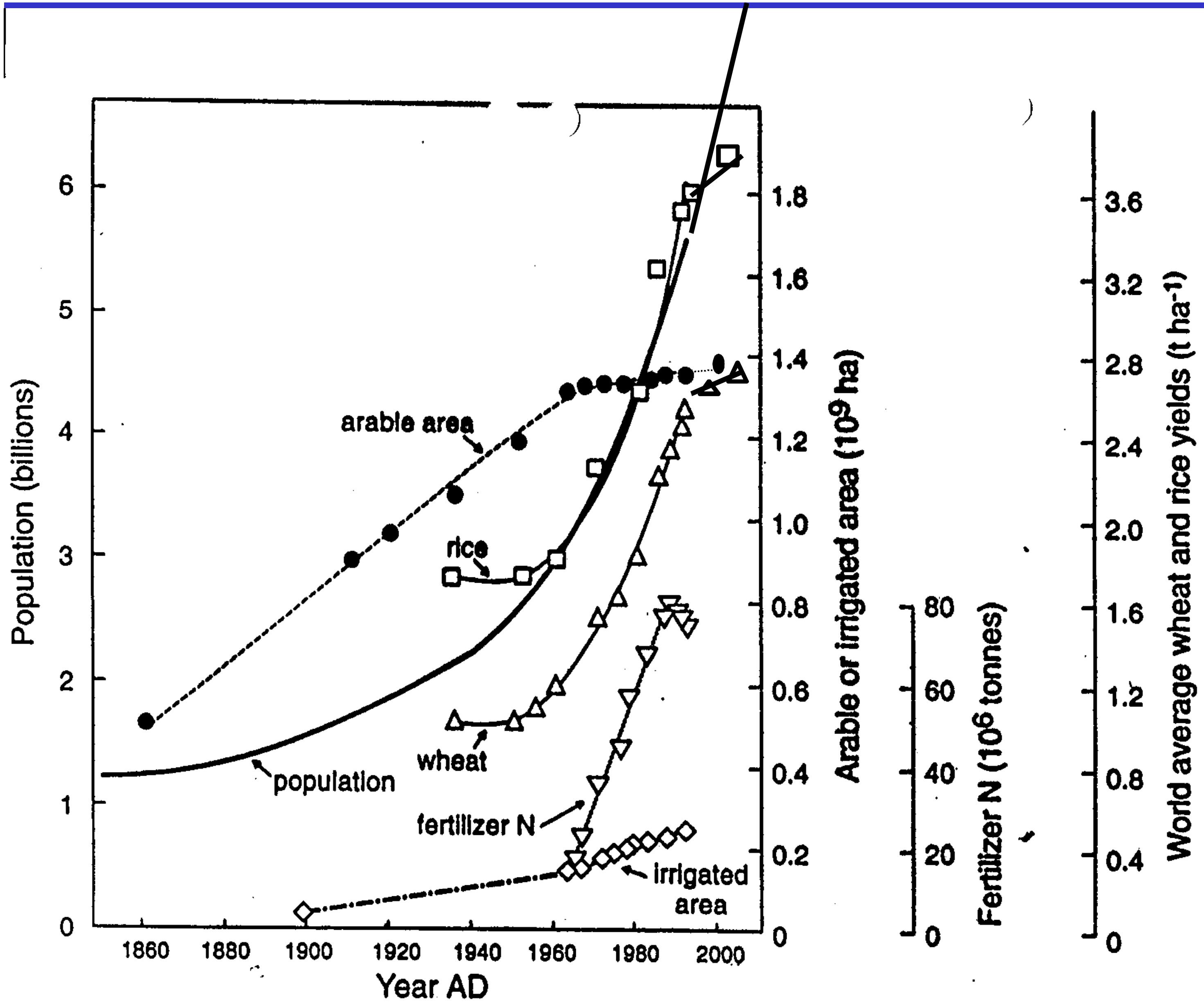
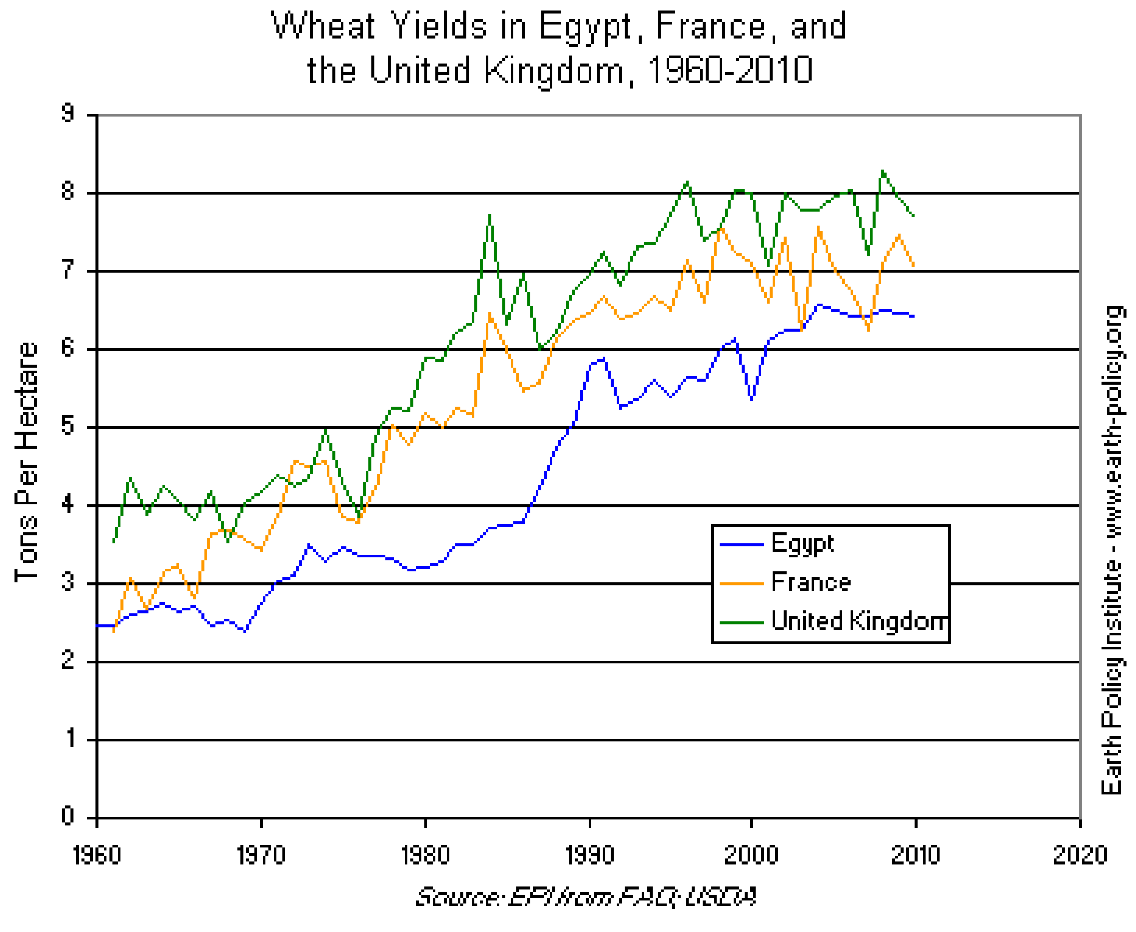
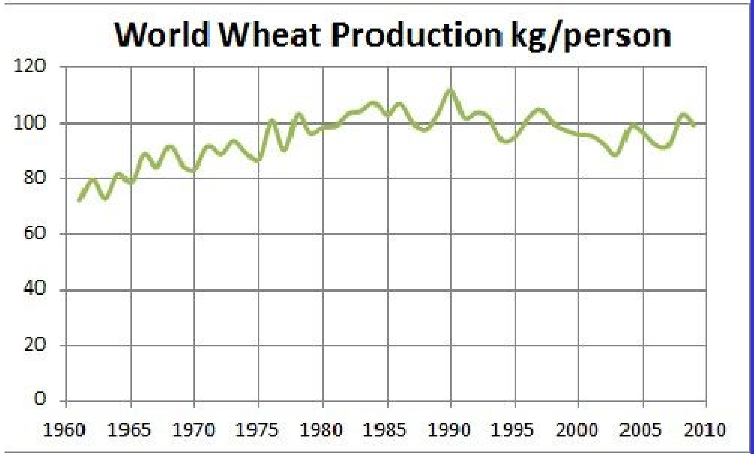
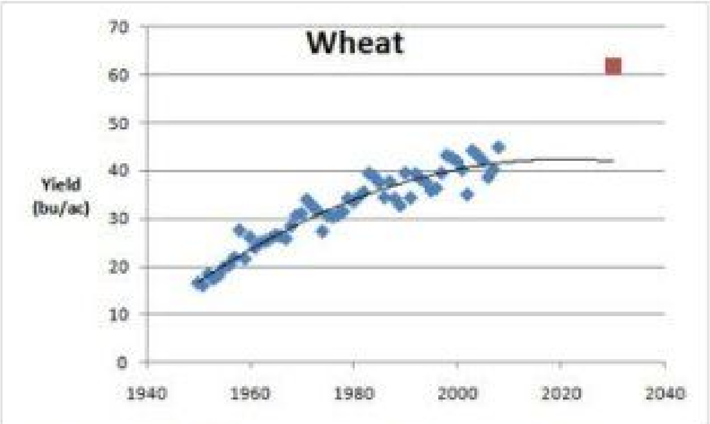


Figure 17 Increases this century in world population, arable area, the average yields of wheat and rice, the amount of N fertilizer used, and the irrigated area of the world[59].







US wheat yields between 1950 and 2008 (blue dots) with projected yield to 2030 (black line) and target yield to achieve a 50% increase between 2005 and 2030 (red square). Historical data from USDA, 2009.

The Plant Biotechnology Revolution 2000-2050

- Population will grow from 6 billion to 9 billion
- plant breeding improvements are plateauing
- fertiliser use is falling
- society demands a reduction in pesticide use
- mechanisation improvements are plateauing
- arable area per head of population is falling
- arable area is shrinking
- climate change will lead to further desertification, and loss of low lying arable lands to sea level rises eg Bangaladesh

- Food production per unit area must double

Food Security

- 1 billion people today undernourished
- Population rise by 40% expected by 2050
- Urbanisation and affluence will continue to rise
- Food production must rise
  - By 40% by 2030
  - By 70% by 2050
- The resource base is declining
- The yield per unit are <u>must</u> rise

FAO

There is a clear need to increase productivity, and optimistically there is great potential for both genetic and agronomic routes to yield improvement. Greater yields with germplasm improvements, increasing intrinsic photosynthetic mechanisms, fine tuning partitioning, and increasing resistance to stresses are all viable approaches, particularly when combined with optimized use of water and fertilizer; there is every prospect of doubling world wheat yields. Increased yields will, however, come at a cost and greater inputs are inevitable. Huge increases in water consumption, increased nitrogen fertilizer use with associated environmental impacts, and requirements for non-renewable mineral resources such as potassium and phosphorus are to be expected. It is essential, that in parallel with efforts to increase productivity, optimum resource use efficiency is also considered. Without efficiency, increased wheat production will not be sustainable

Hawkesford et al (2013), Prospects of Doubling Wheat Yields. Food and Energy Security **2**, 34-48

How does Plant Biotechnology play a part in this?

- Plant Tissue Culture
- DNA Barcoding for Plant Breeding and Ecology
- Genomics > Transcriptomics > Proteomics > Metabolomics > Phenomics
- GMO’s by Agrobacterium/Biolistics/siRNA
- Nanotechnology

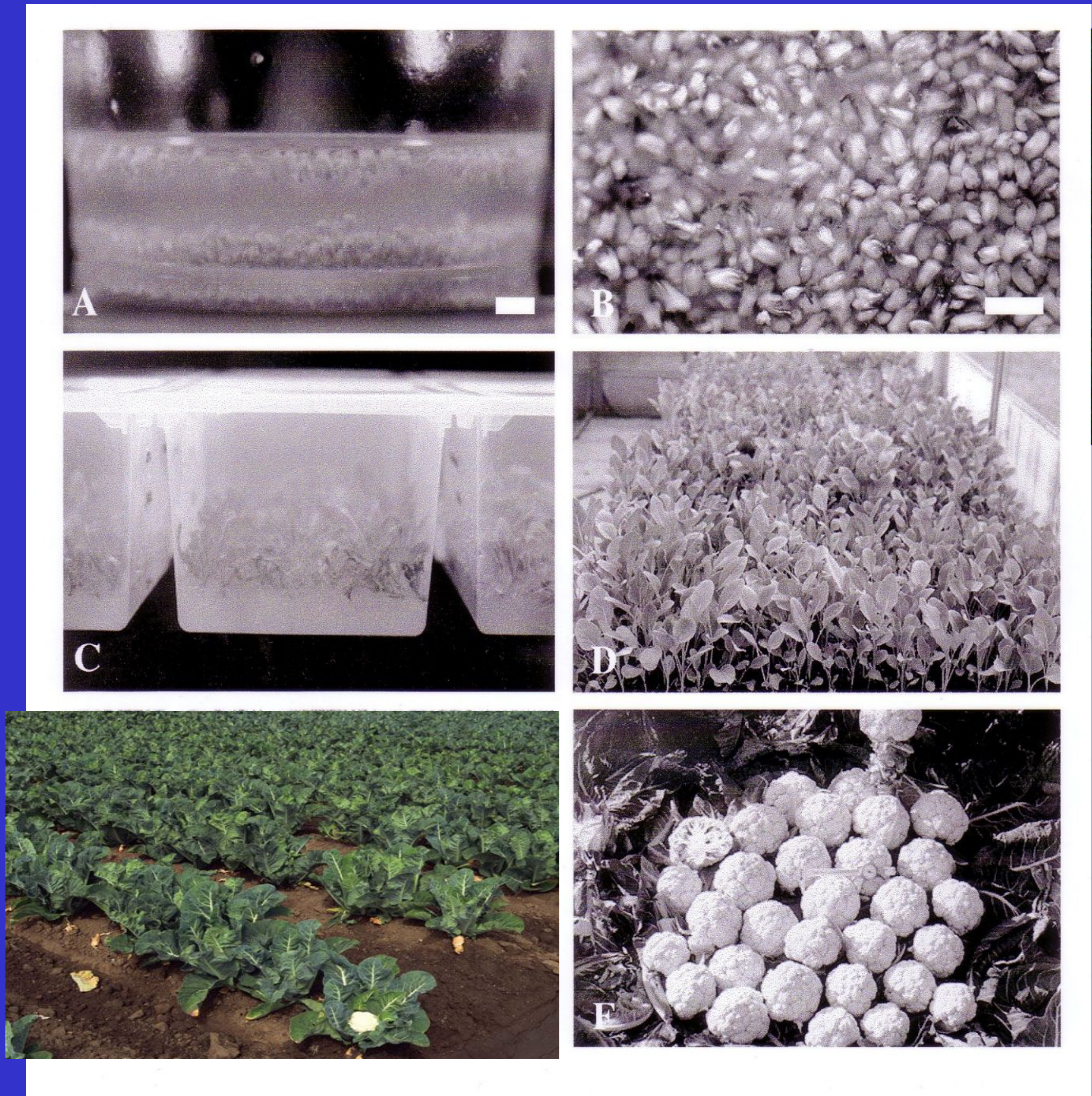


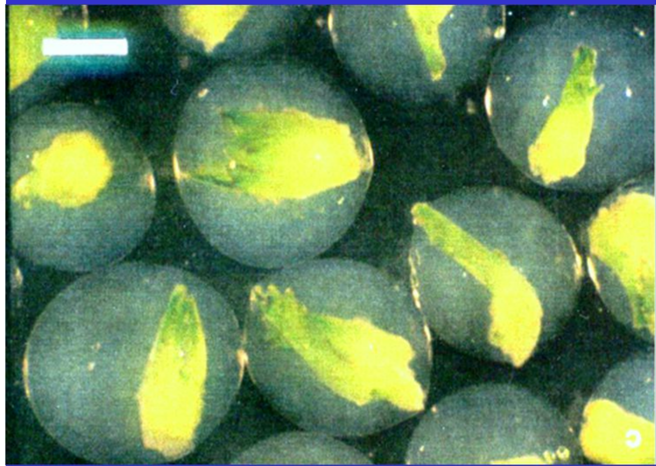

Plant Tissue Culture



The production and preservation of cauliflower artificial seeds





A
B
C
D
E



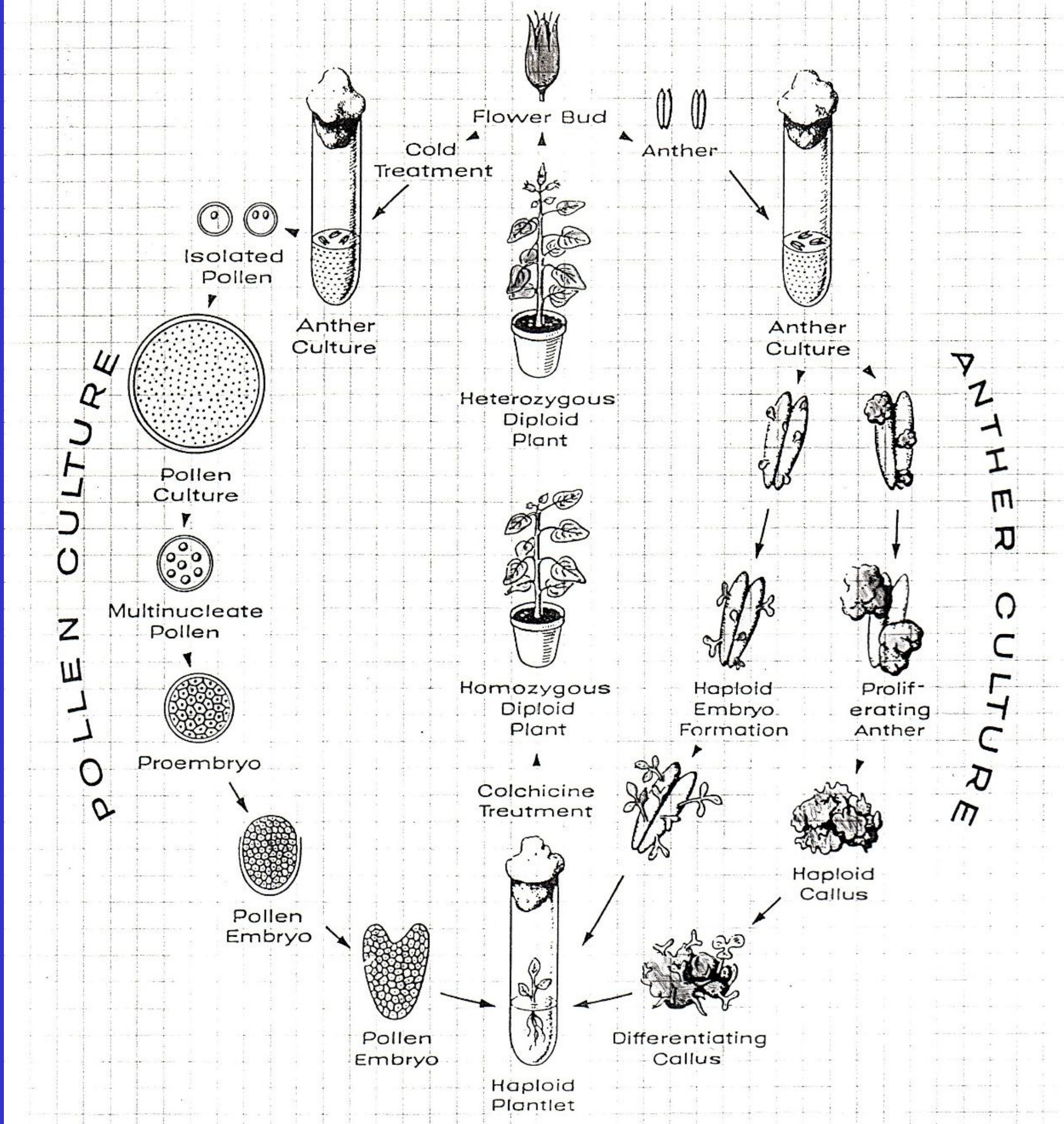
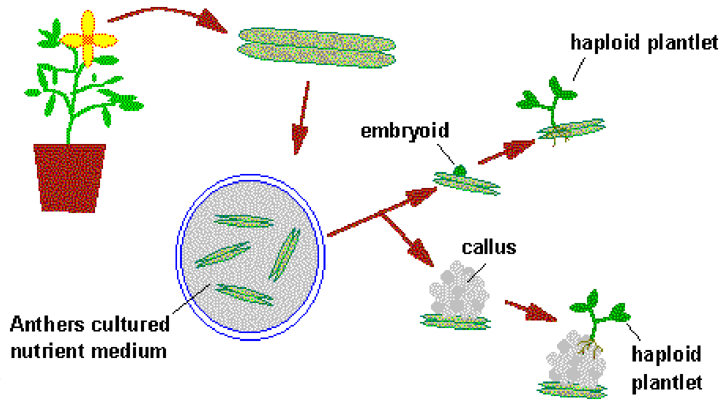
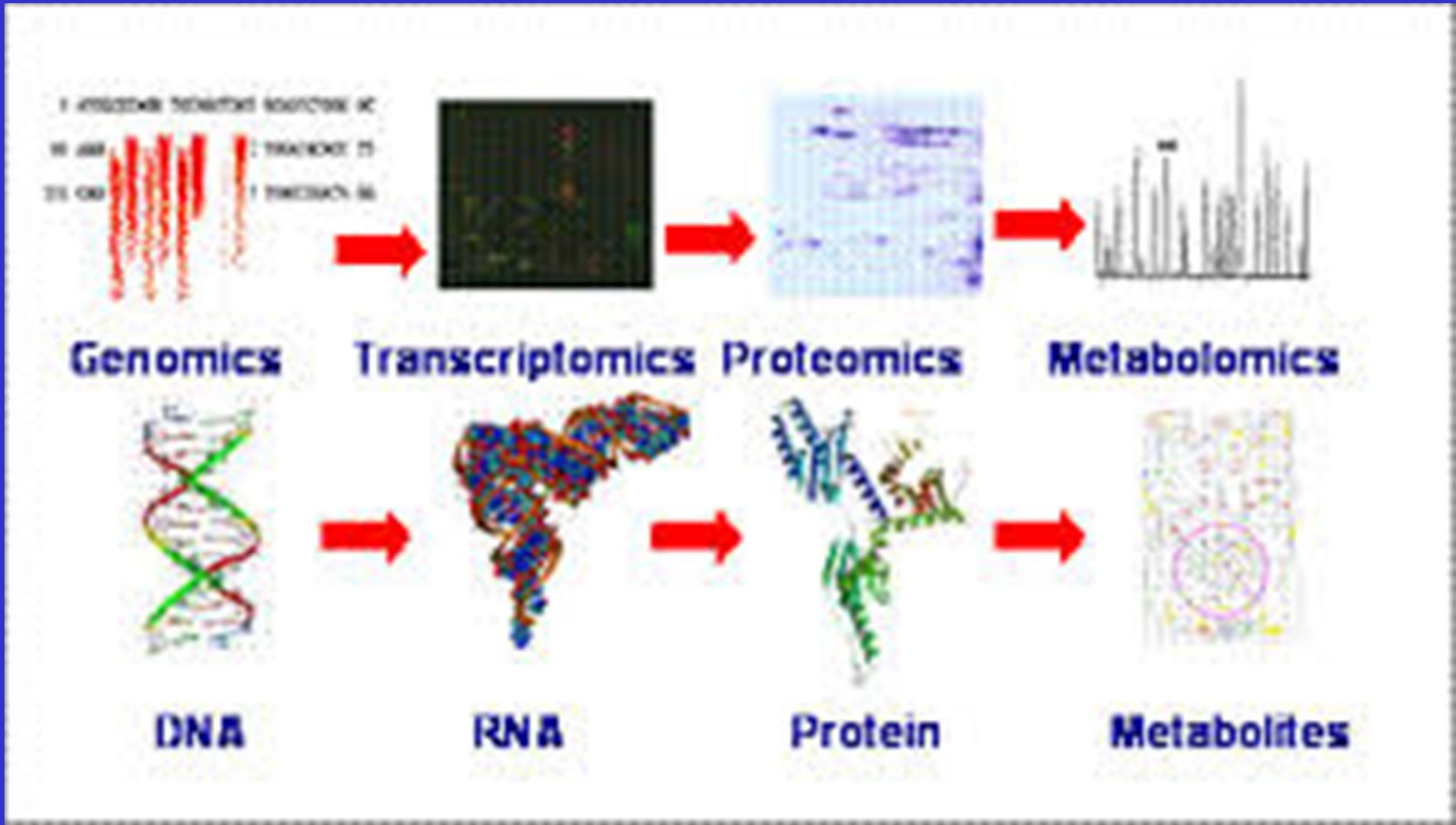


Figure 7. Diagrammatic illustration showing various modes of andro-genesis and haploid plant formation by anther and isolated pollen culture. The homozygous plants are obtained by treating haploids with colchicine.

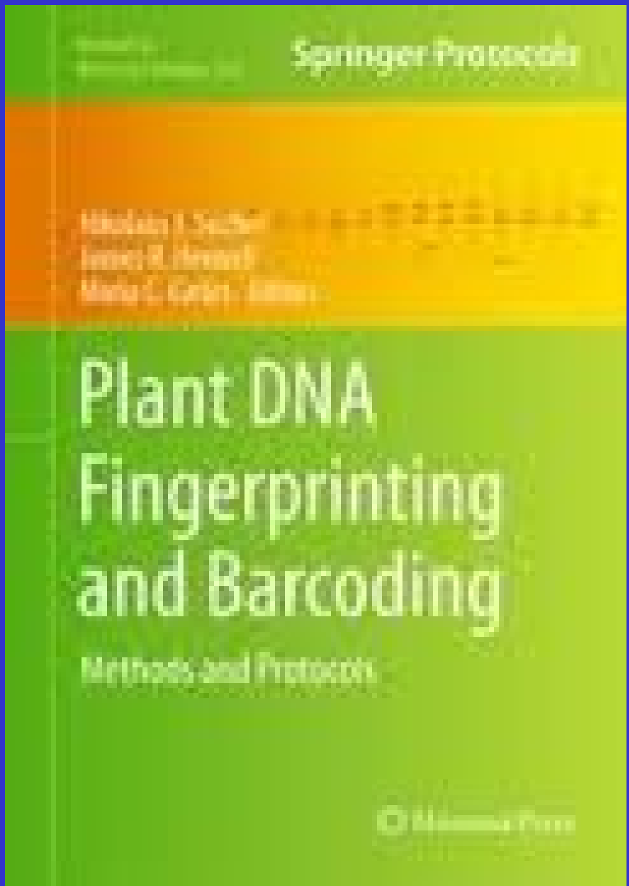


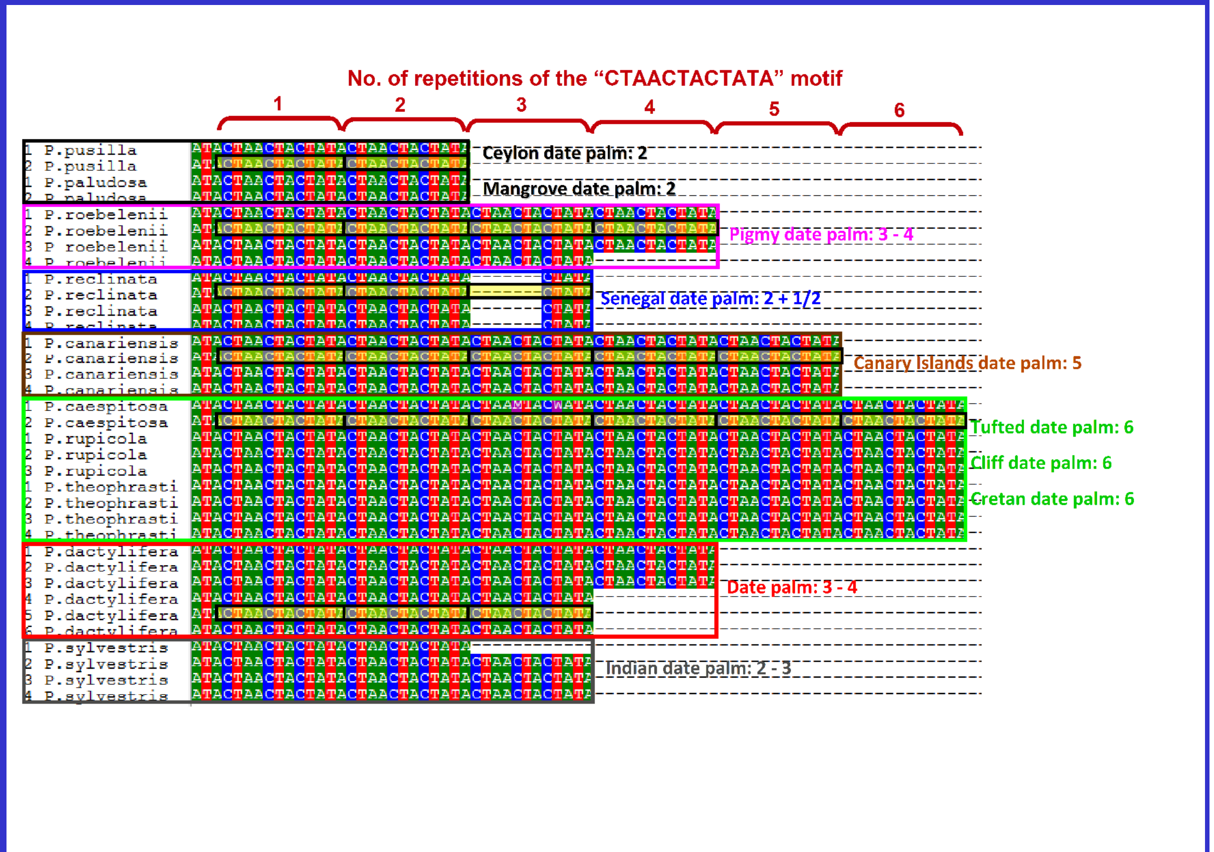
Winter cauliflower in Cornwall

Plant molecular biology and "Omic" technologies



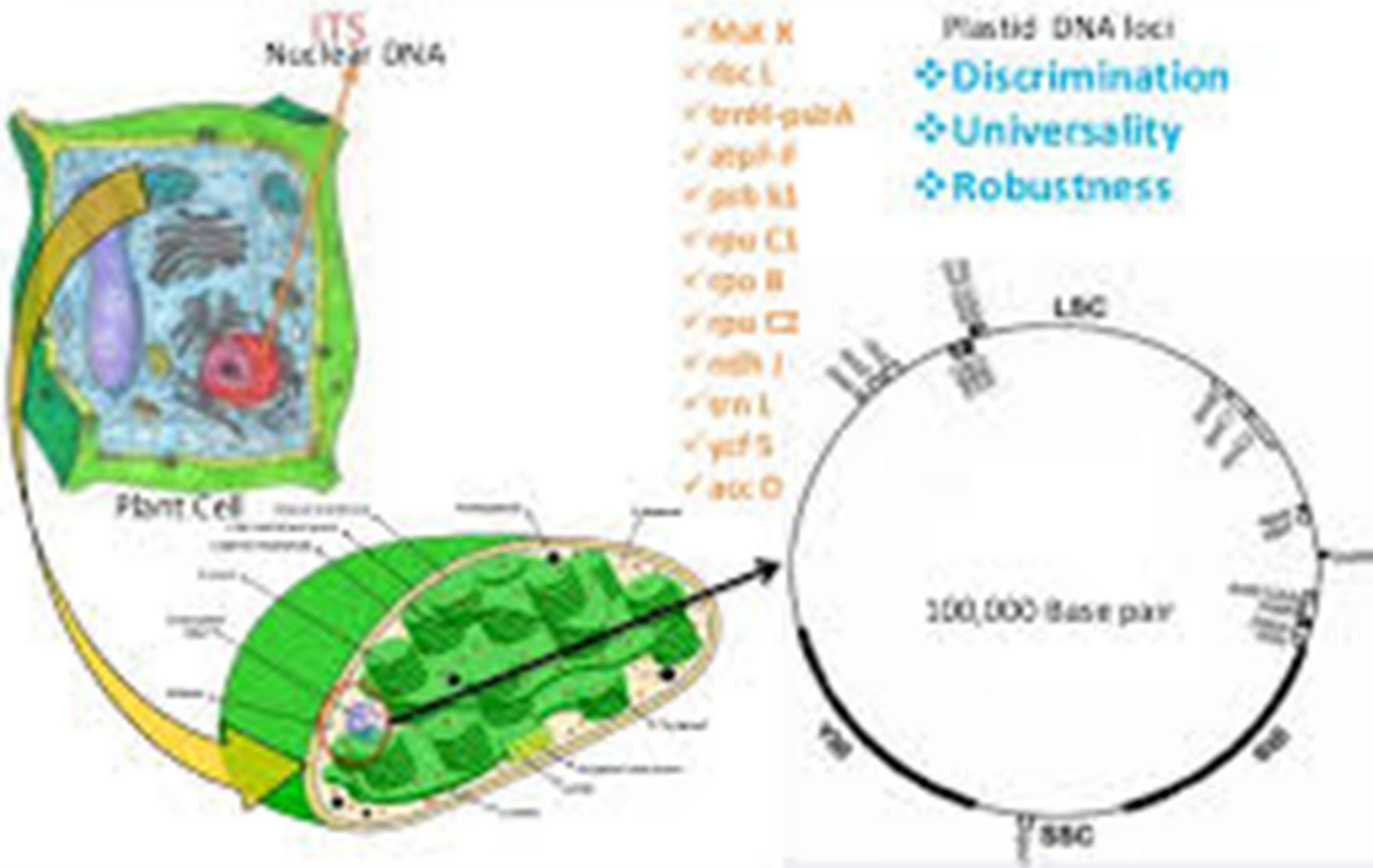
DNA Fingerprinting & Barcoding





Applications of Plant Barcoding
Taxonomy – establishing species inter-relationships
Conservation - species identification in ecological threats, cataloguing natural resources
Environmental Management – Indicator species
Legal investigation and enforcement – Forensics, Ecological crime
Health – identification of species with harmful attributes
Exploitation – agriculture, plant breeding, pharmaceutical plants
Horticulture – Stock identification

Barcode regions of plant

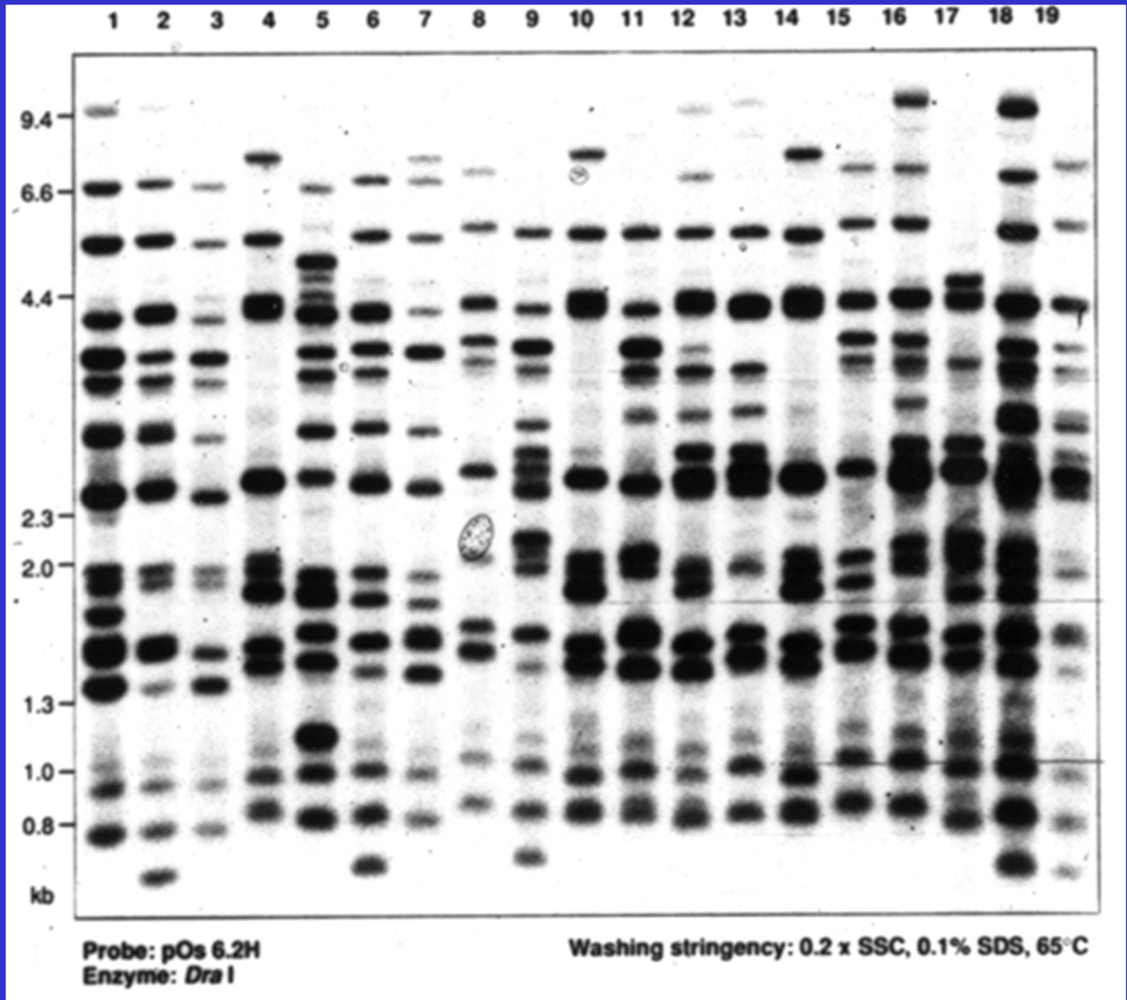


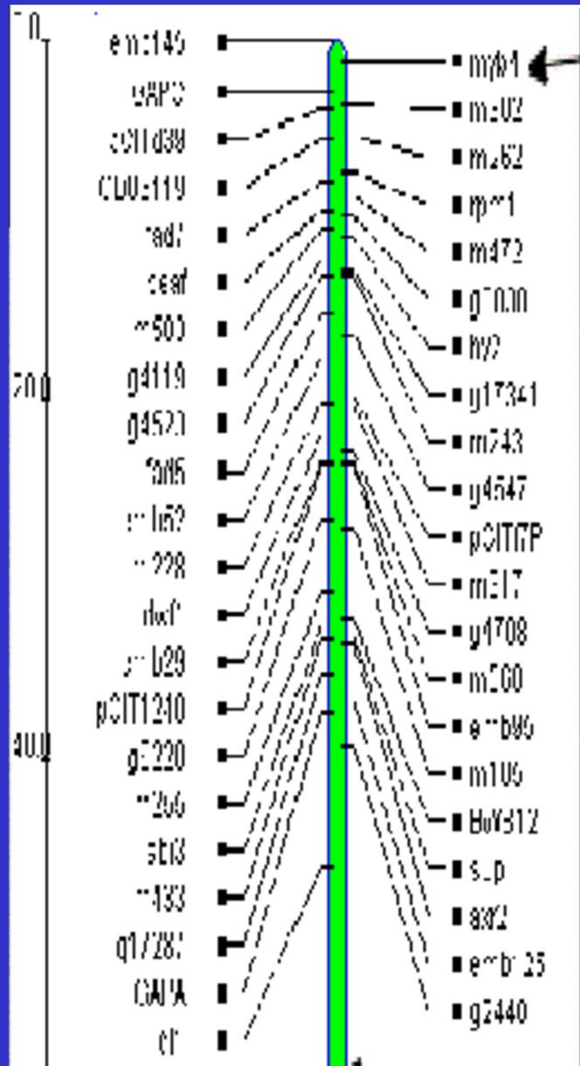
Barcoding of entire Flora

PhD graduate 2007

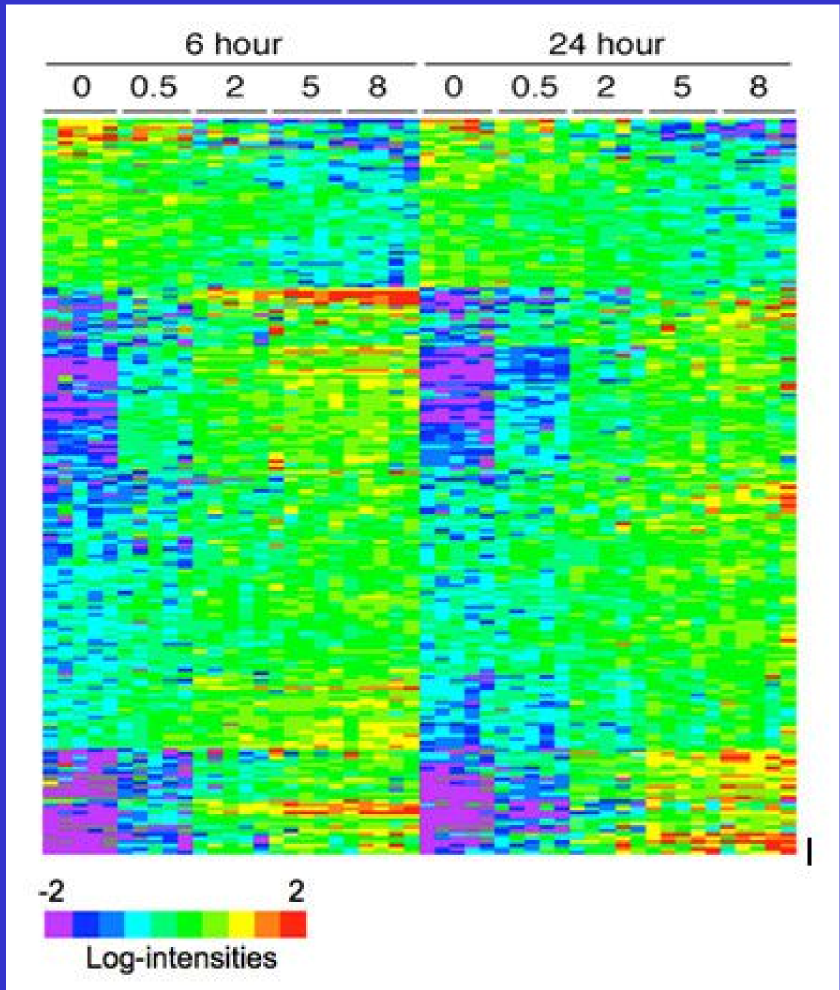
2015 successfully Barcoded all natural plant species in Wales for National Botanic Garden

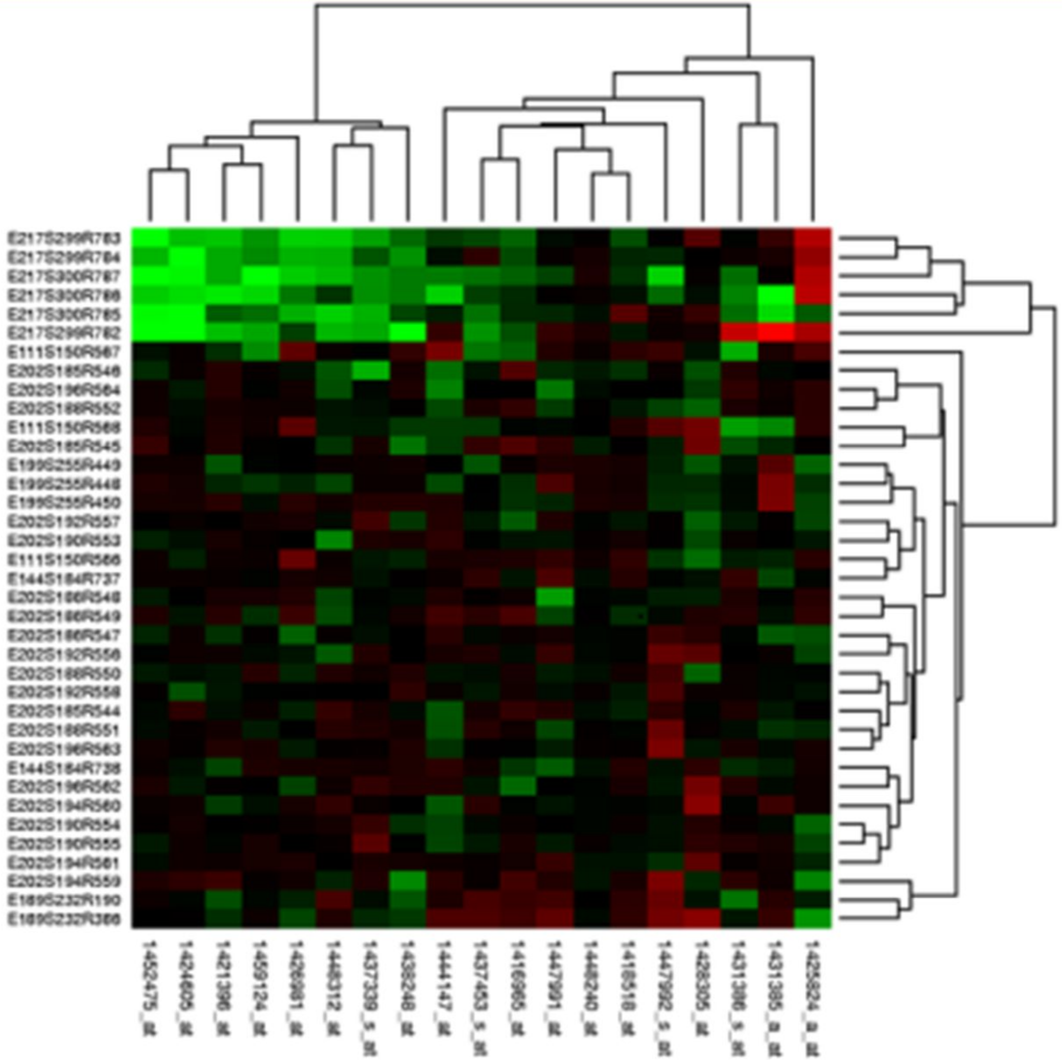
Marker Assisted Plant Breeding





Transcriptomics
candidate gene identification





Heatmap visualizing functional patterns in large scale datsets. These patterns are brought into biological context by data mining.

Proteomics – understanding proteins expression patterns

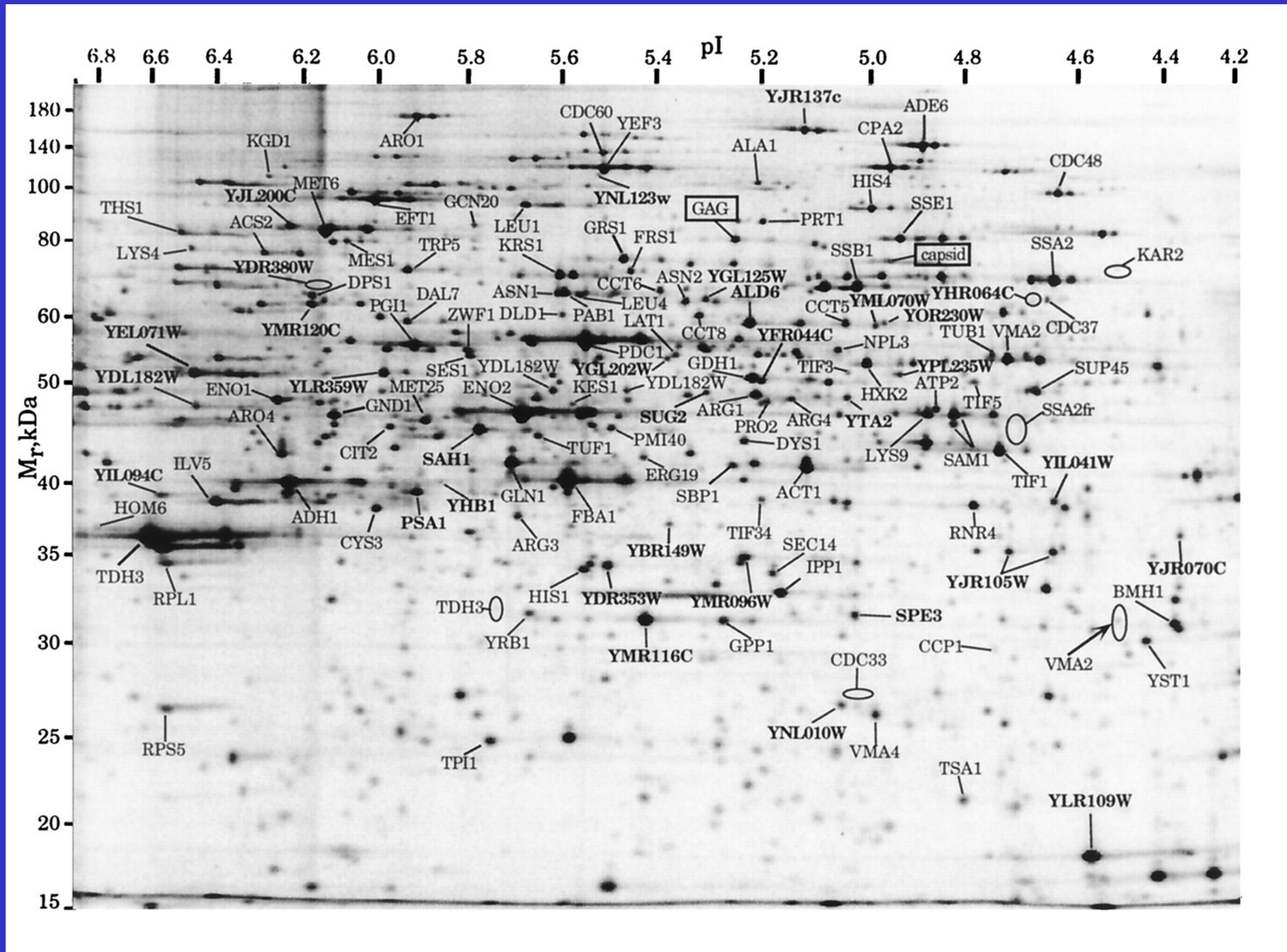
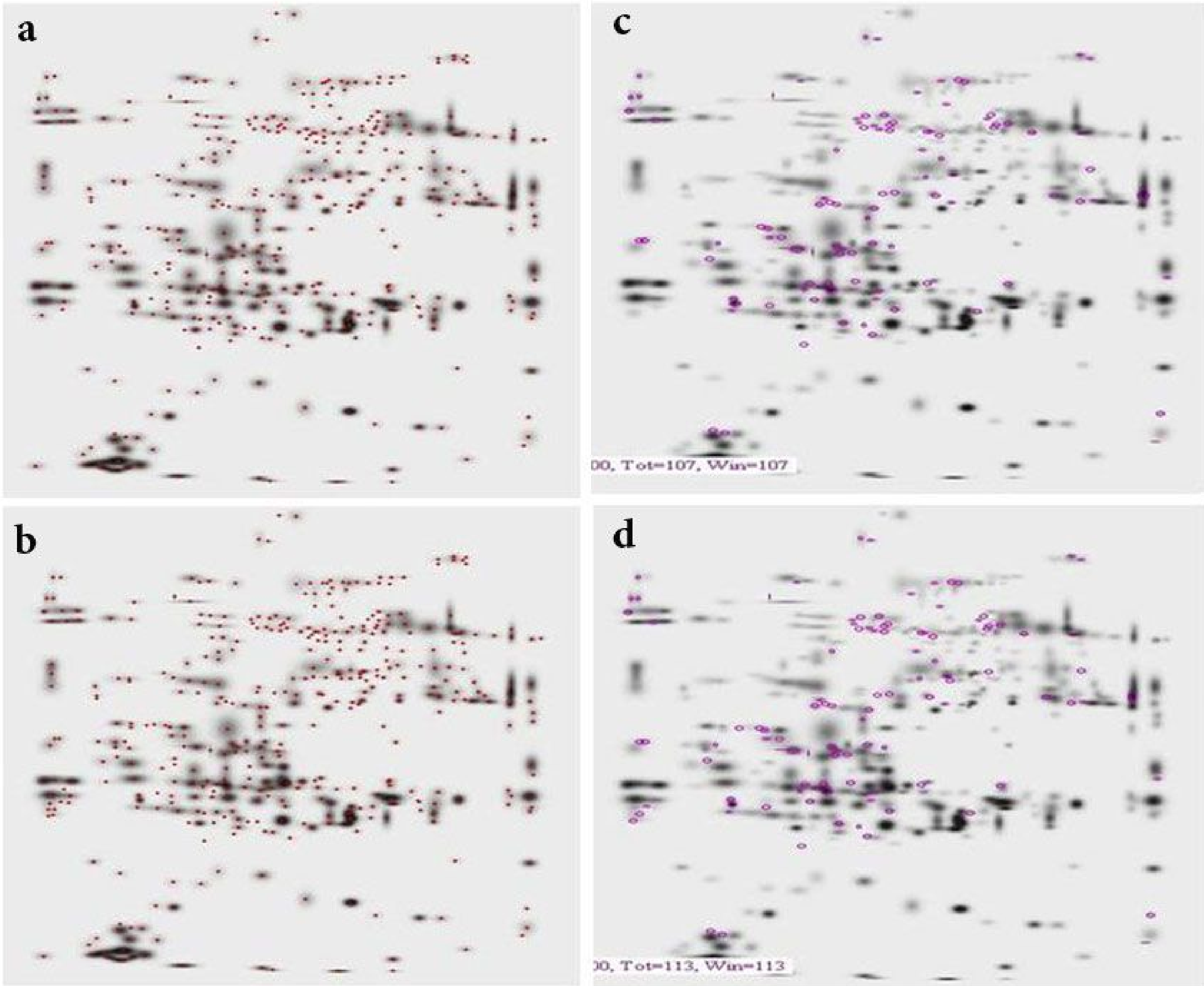
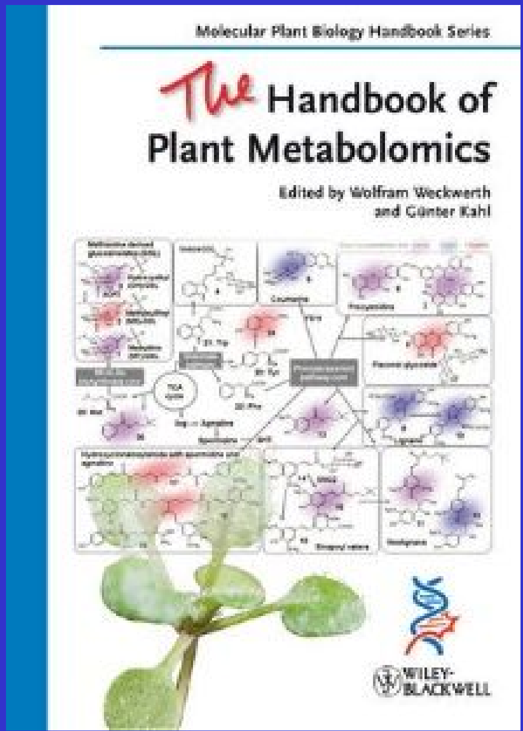
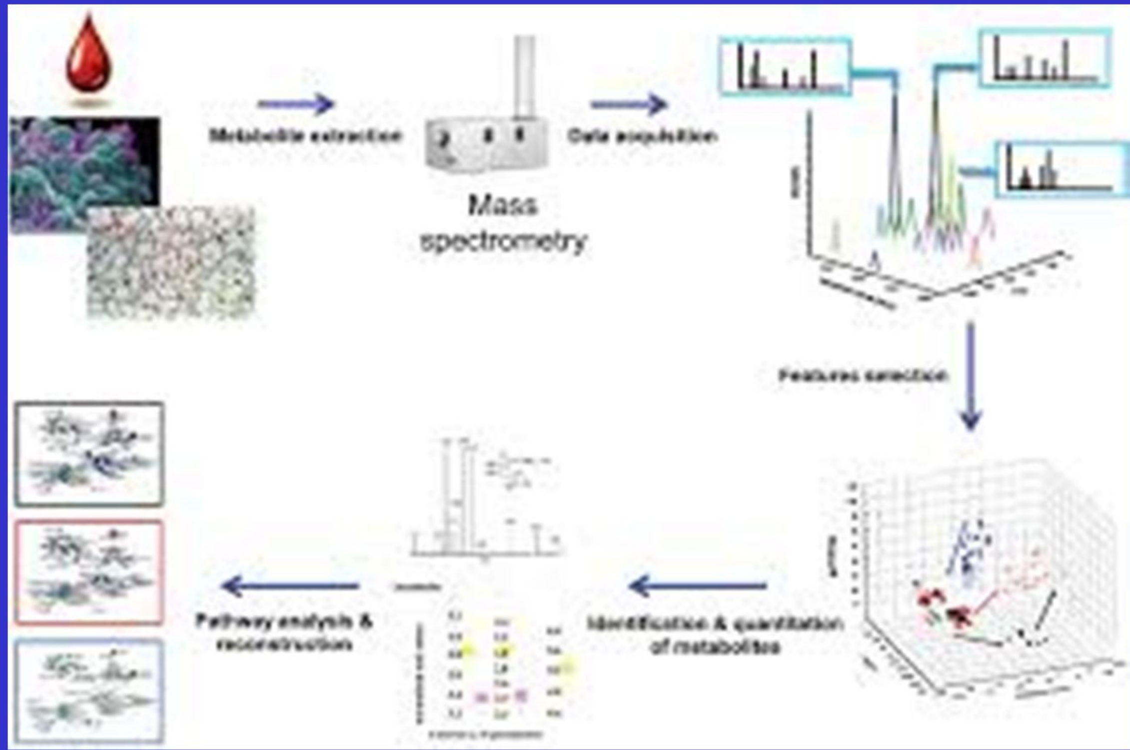


Figure S1 : Total proteins spots present in master gel of leaf protein in control (a) and under drought stress (b). Low quality spots present in master gel of leaf protein in control (c) and under drought stress (d) detected by PDQuest software.

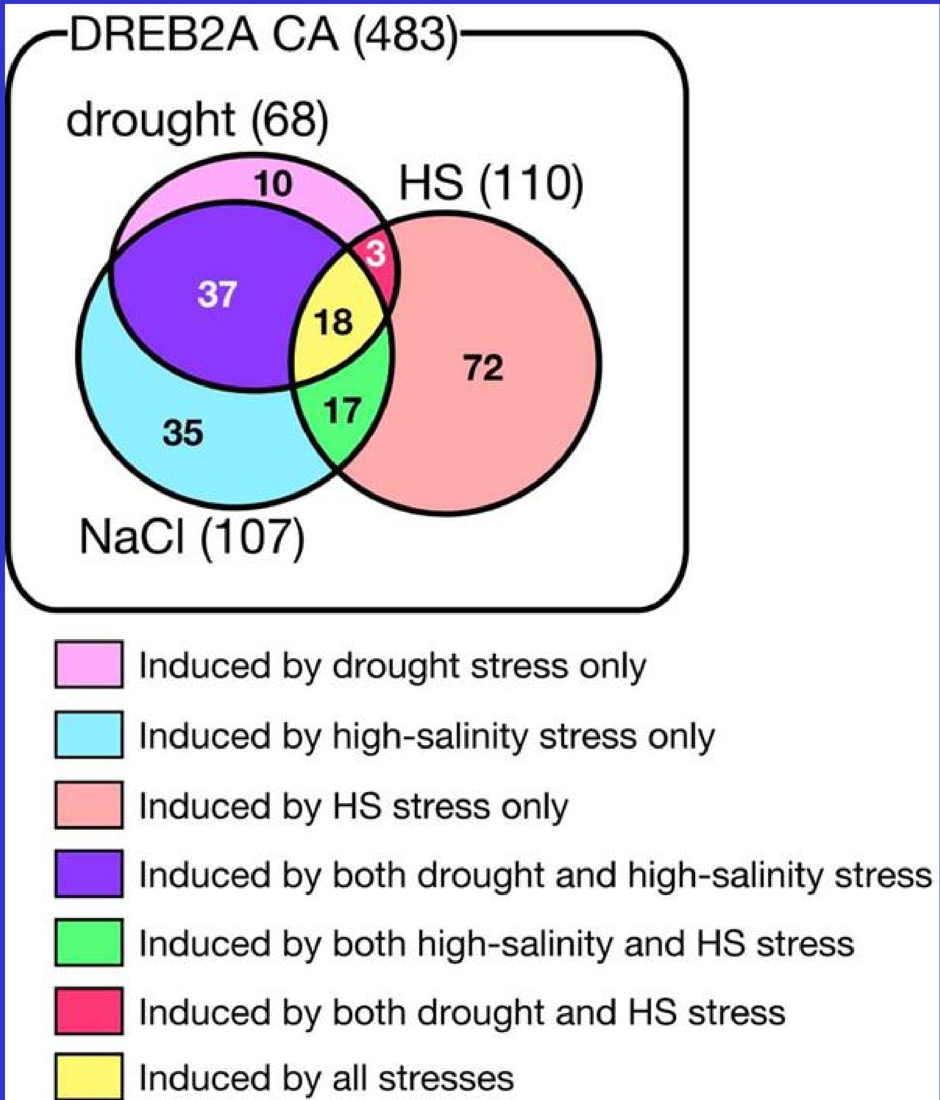


Metabolomics – understanding complex interactions

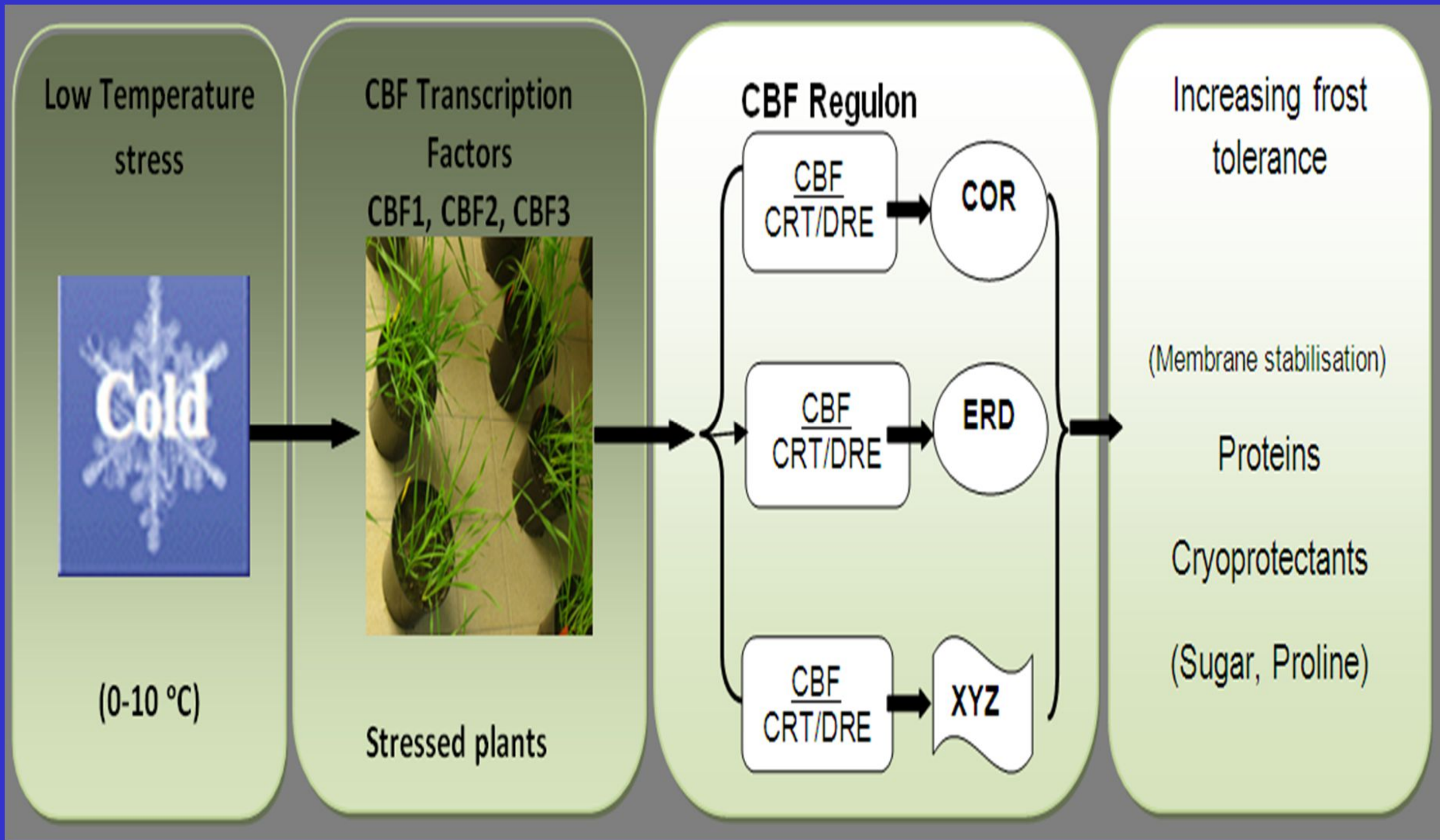


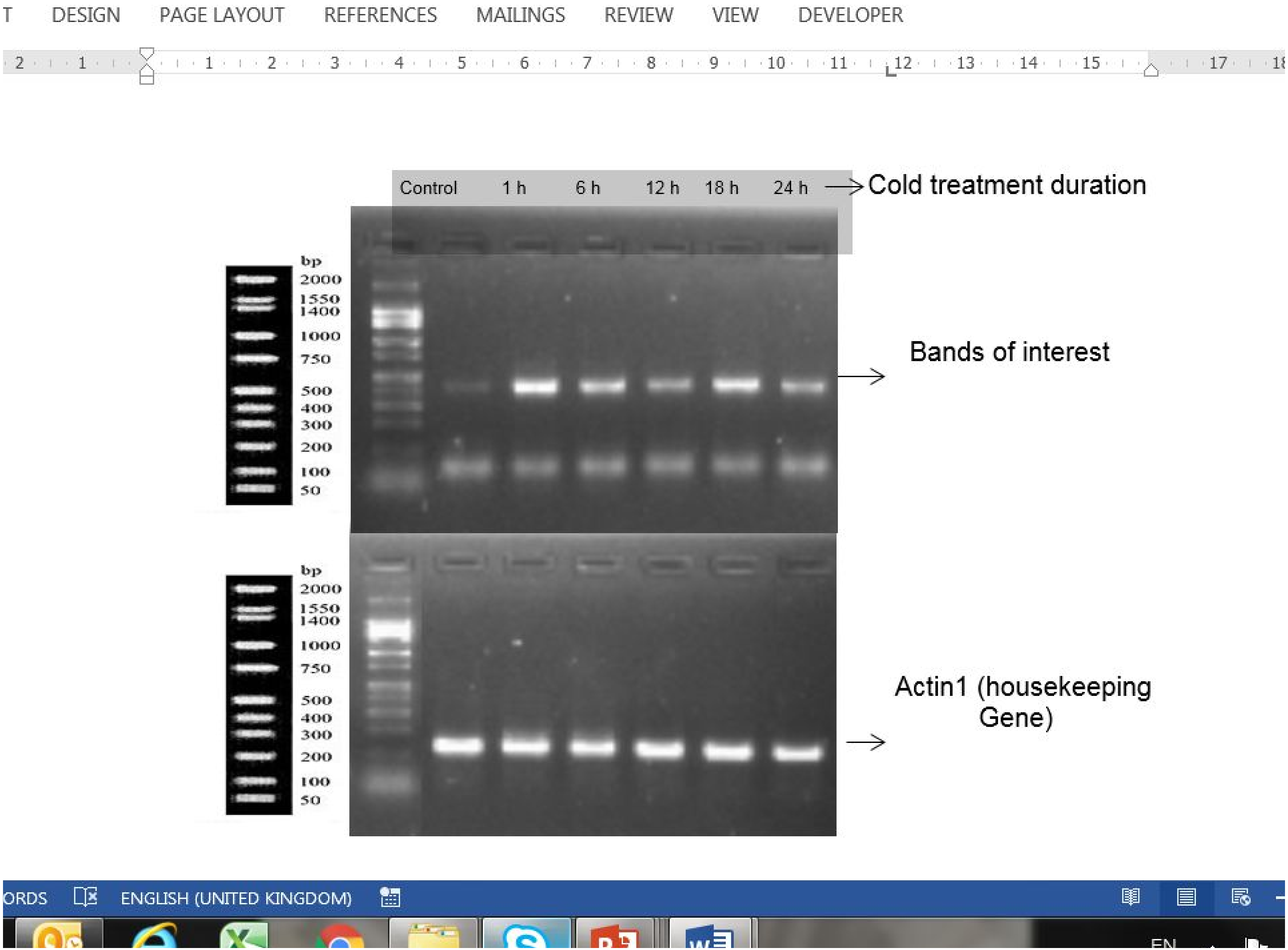


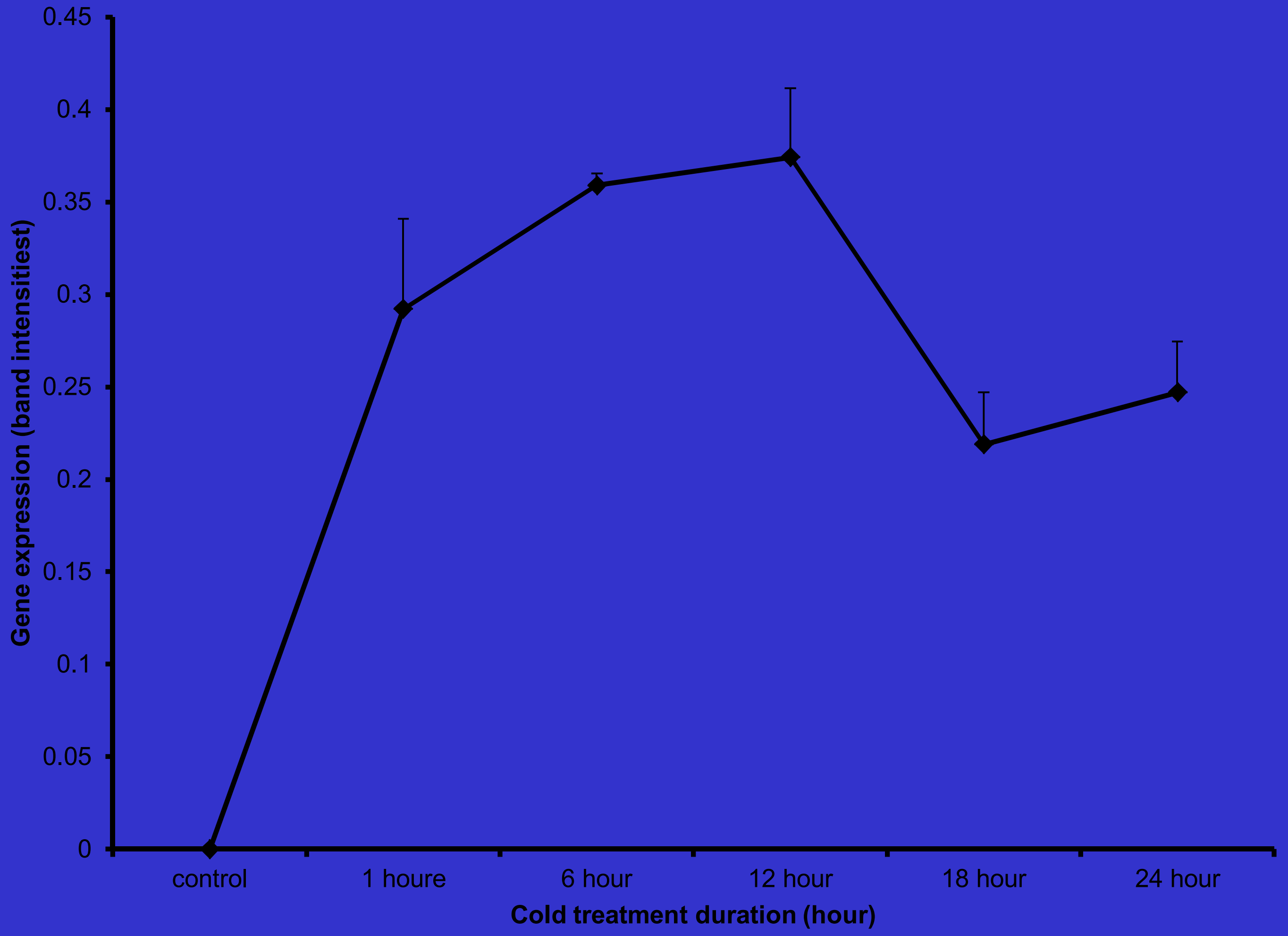
Understanding Abiotic Stress resistance drought, salt, frost, heat



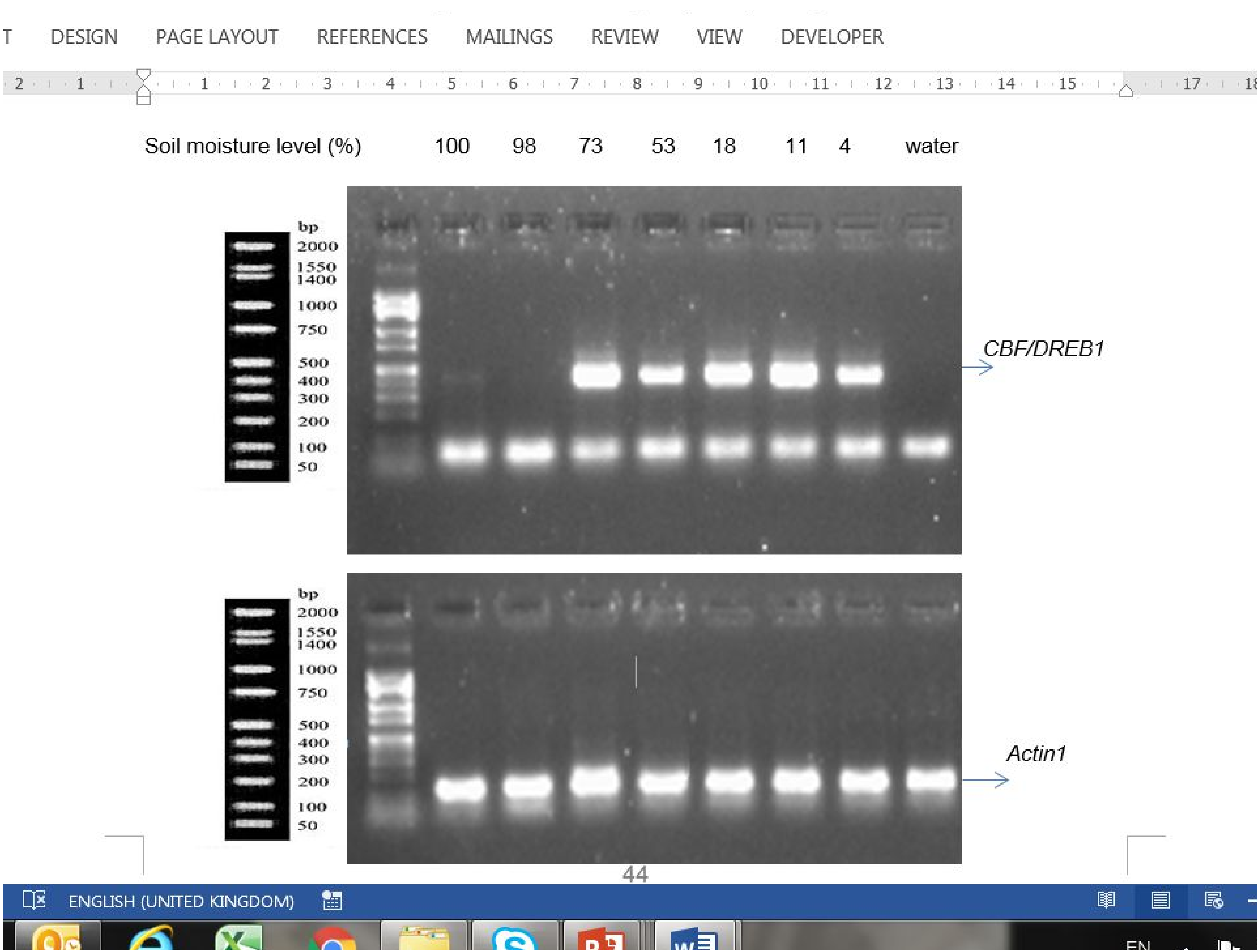
CBF pathway in plants. Low temperature leads to rapid induction of the CBF transcription factors, which in turn cause the expression of the CBF regulon of the CRT/DRE regulated genes such as COR (cold regulated genes, ERD (early responsive to dehydration) and other unidentified genes cold regulated genes XYZ, resulting in increasing cold tolerance. (Adapted from Thomashow)



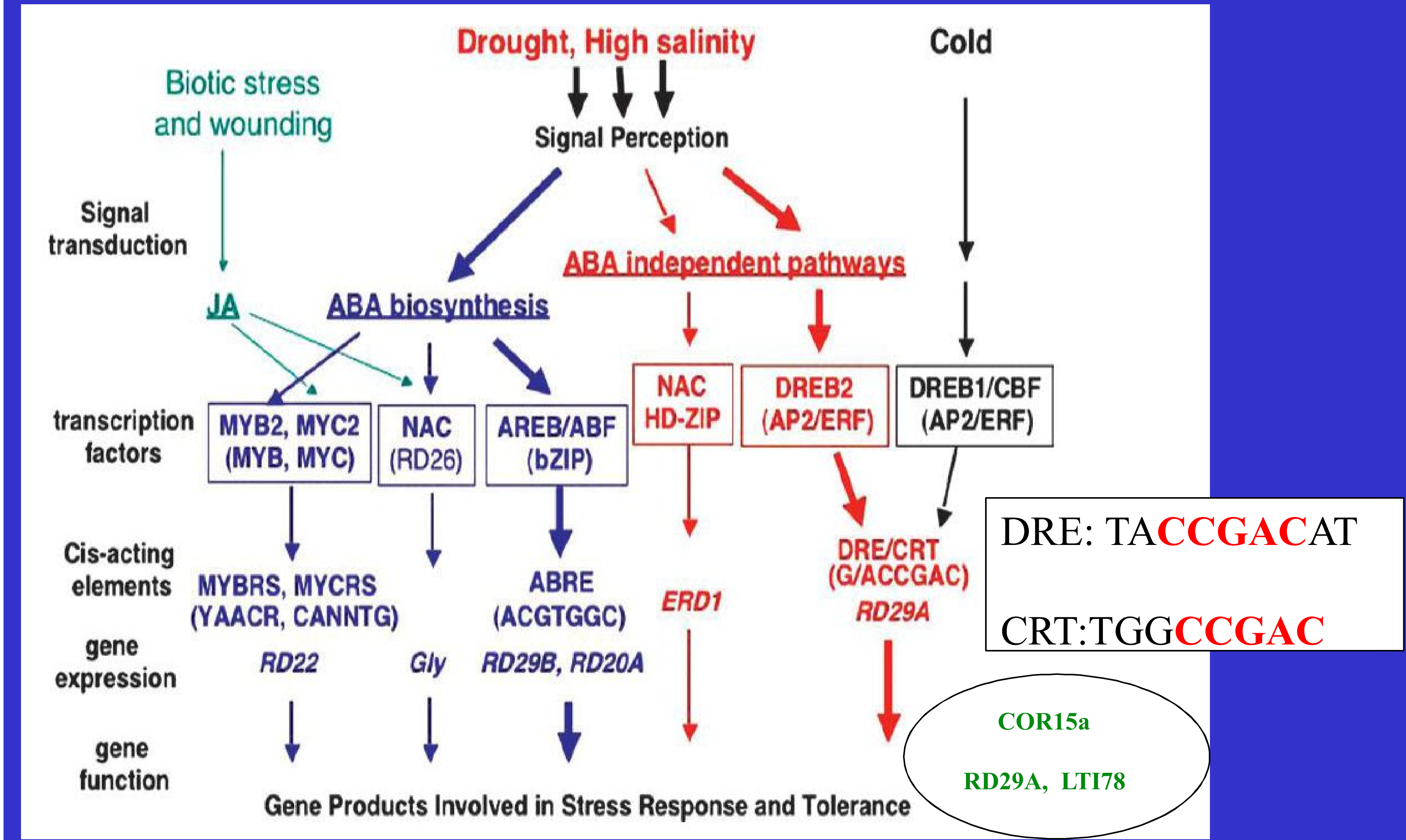

T DESIGN PAGE LAYOUT REFERENCES MAILINGS REVIEW VIEW DEVELOPER
Control
1 h
6 h
12 h
18 h
24 h
Cold treatment duration
bp
2000
1550
1400
1000
750
500
400
300
200
100
50
Bands of interest
bp
2000
1550
1400
1000
750
500
400
300
200
100
50
Actin1 (housekeeping Gene)
ORDS
ENGLISH (UNITED KINGDOM)



0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Gene expression (band intensitiest)
control
1 houre
6 hour
12 hour
18 hour
24 hour
Cold treatment duration (hour)


T DESIGN PAGE LAYOUT REFERENCES MAILINGS REVIEW VIEW DEVELOPER
Soil moisture level (%) 100 98 73 53 18 11 4 water
bp
2000
1550
1400
1000
750
500
400
300
200
100
50
CBF/DREB1
Actin1
44
ENGLISH (UNITED KINGDOM)

The Abiotic Stress Transcription Factors



http://jxb.oxfordjournals.org/content/58/2/221.full

Phenomics – understanding phenology (growth and development)

Phenomics facilities in Glasshouse and Field
Generate Big Data Sets

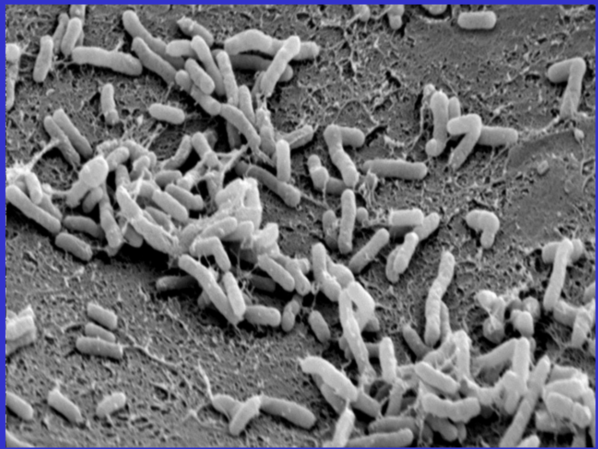
GMO technologies

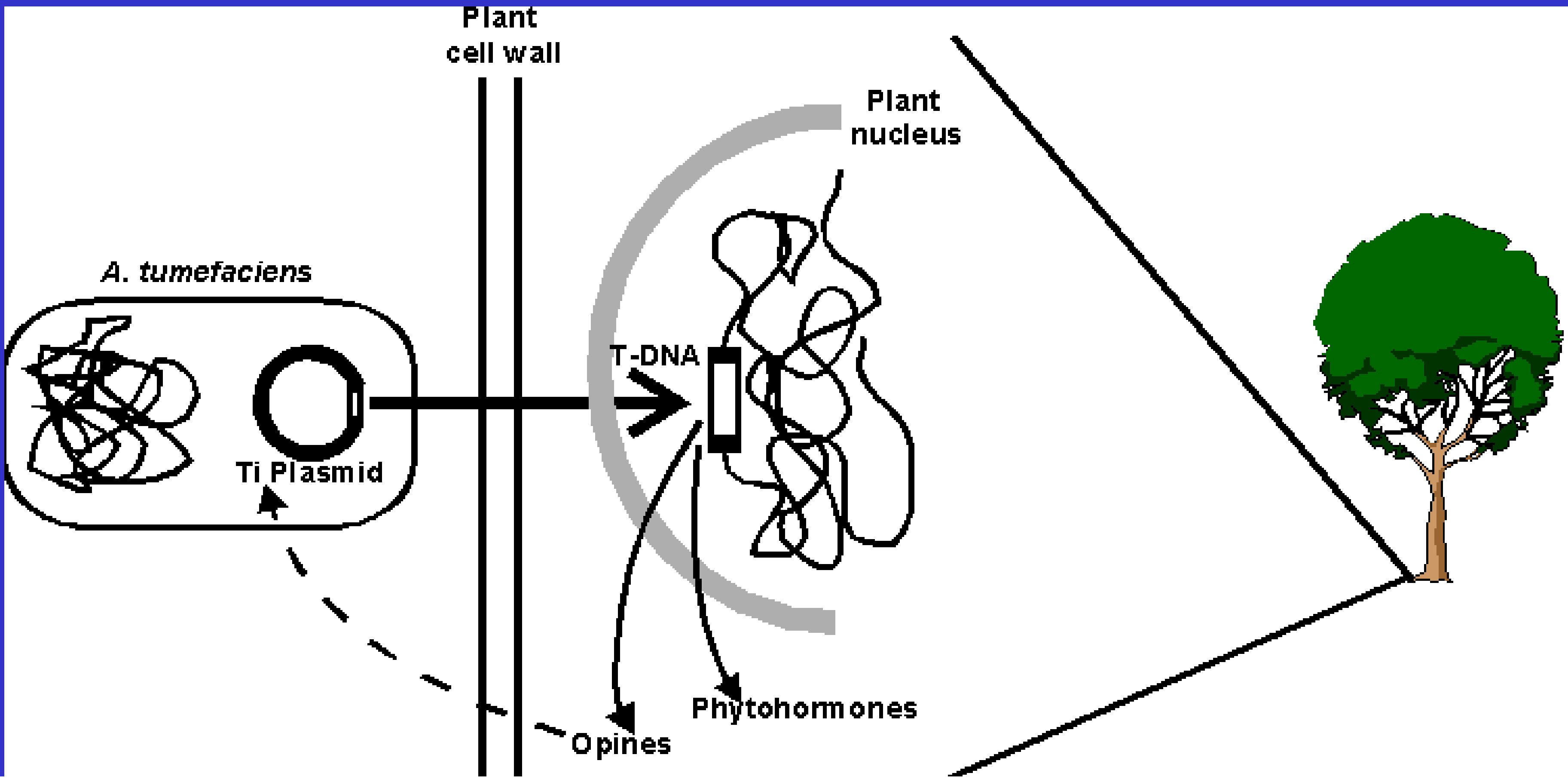
Established technology platforms

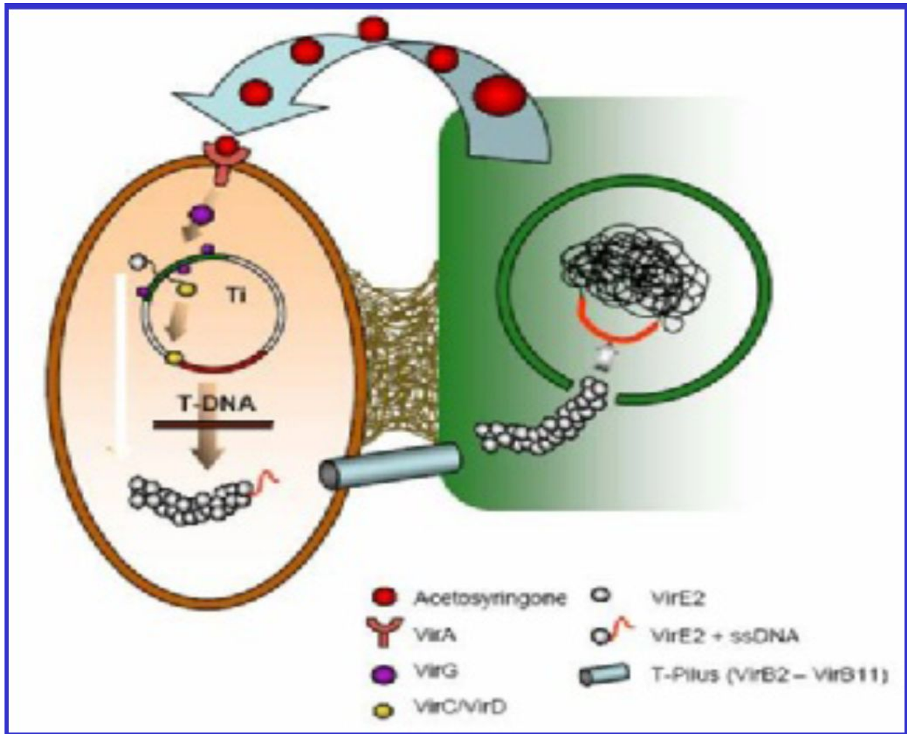
- Agrobacterium
- Gene gun

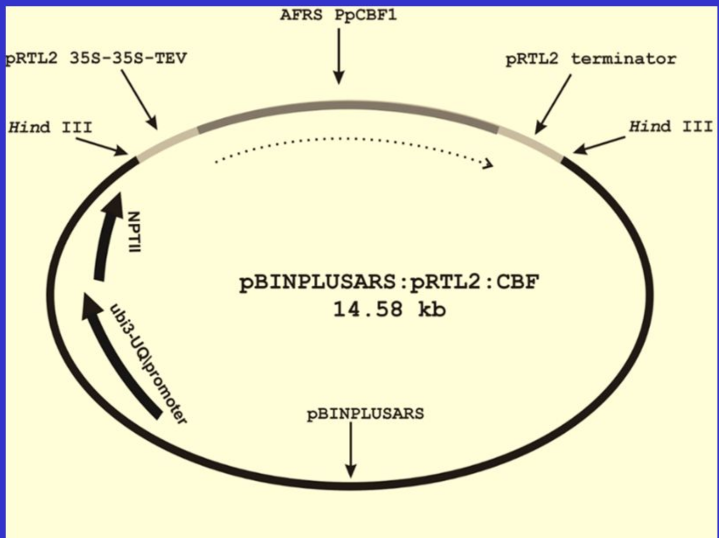
New technology platforms

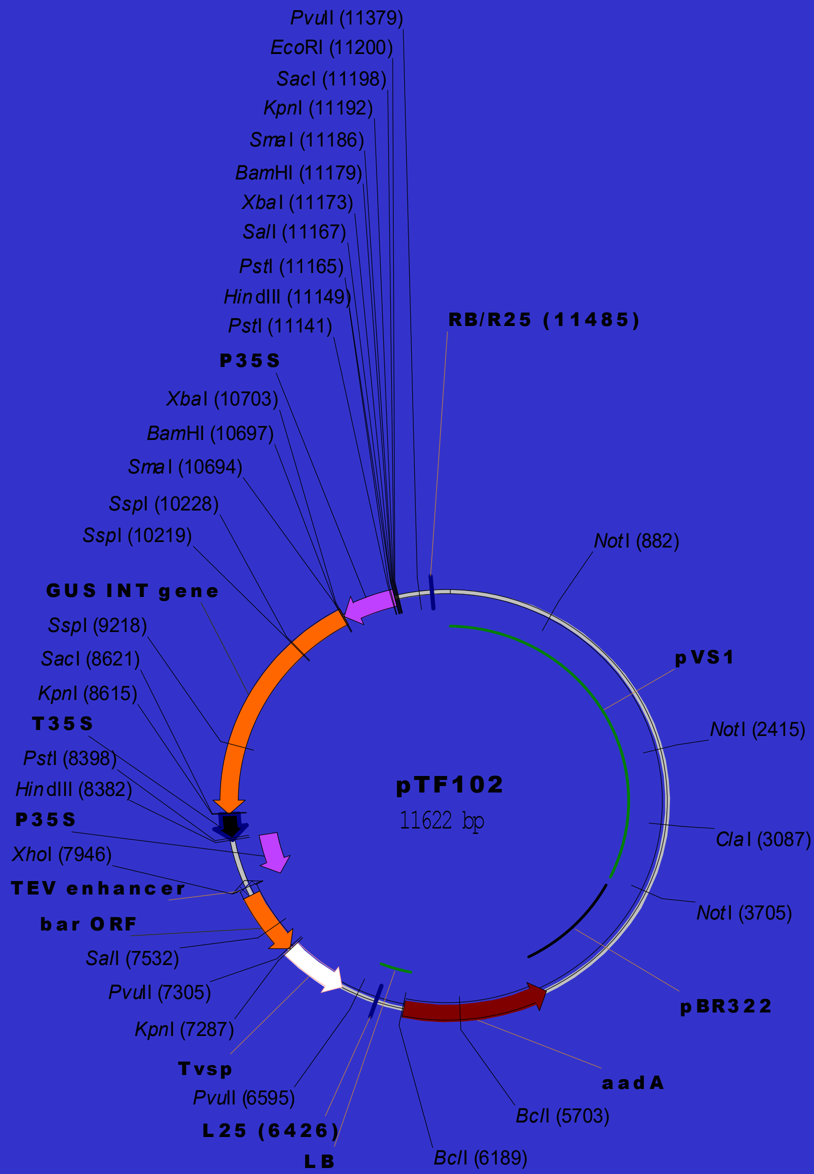
- Gene/DNA editing (gene disruption, point mutation and gene addition)
  - CRISPR
  - sRNAi
  - Zinc Finger
  - TALEN

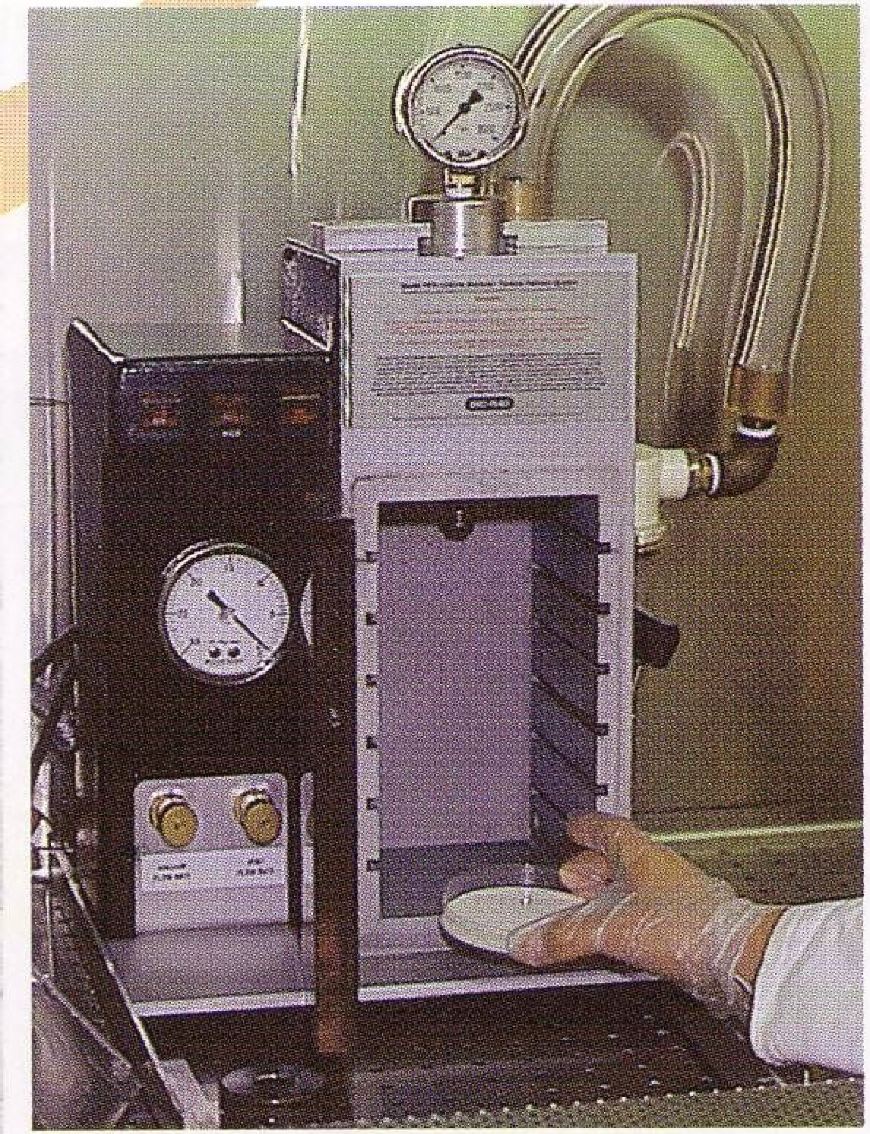



Plant
cell wall
Plant
nucleus
A. tumefaciens
T-DNA
Ti Plasmid
Phytohormones
Opines

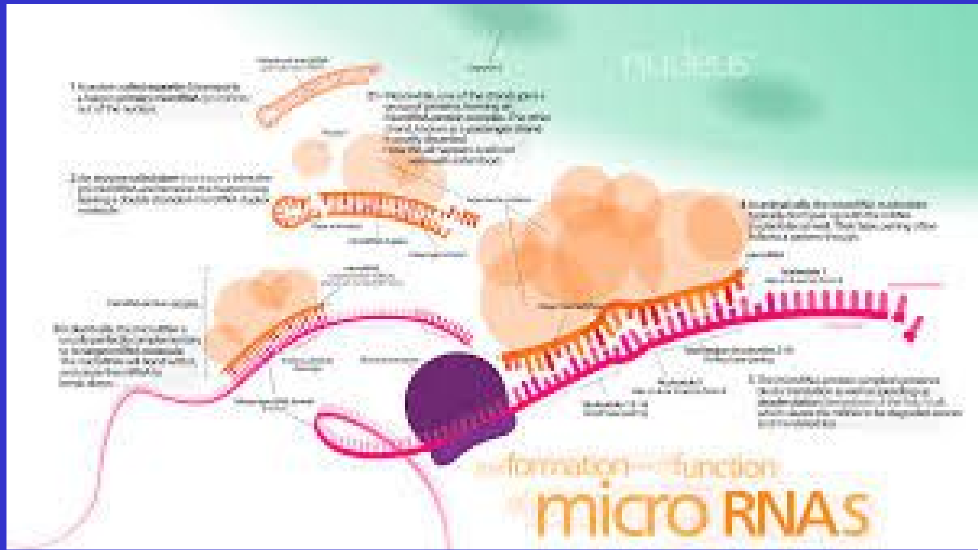

Ti
T-DNA
Acetosyringone
VirA
VirG
VirC/VirD
VirE2
VirE2 + ssDNA
T-Pilus (VirB2 – VirB11)


AFRS PpCBF1
pRTL2 35S-35S-TEV
pRTL2 terminator
Hind III
Hind III
NPTII
ubi3-UQ|promoter
pBINPLUSARS:pRTL2:CBF
14.58 kb
pBINPLUSARS

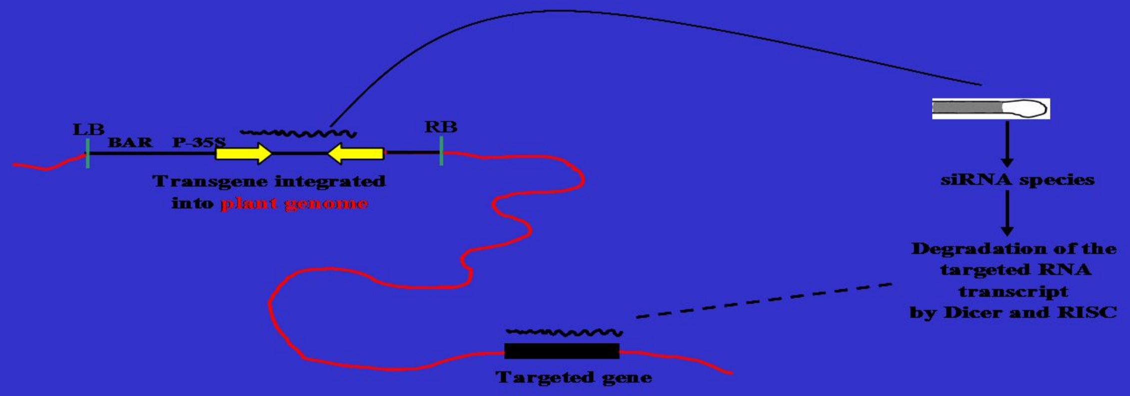

PvuII (11379)
EcoRI (11200)
SacI (11198)
KpnI (11192)
SmaI (11186)
BamHI (11179)
XbaI (11173)
SalI (11167)
PstI (11165)
HindIII (11149)
PstI (11141)
RB/R25 (11485)
P35S
XbaI (10703)
BamHI (10697)
SmaI (10694)
SspI (10228)
SspI (10219)
NotI (882)
GUS INT gene
SspI (9218)
SacI (8621)
KpnI (8615)
pVS1
T35S
NotI (2415)
PstI (8398)
HindIII (8382)
pTF102
11622 bp
P35S
ClaI (3087)
XhoI (7946)
TEV enhancer
NotI (3705)
bar ORF
SalI (7532)
PvuII (7305)
pBR322
KpnI (7287)
Tvsp
aadA
PvuII (6595)
BclI (5703)
L25 (6426)
LB
BclI (6189)

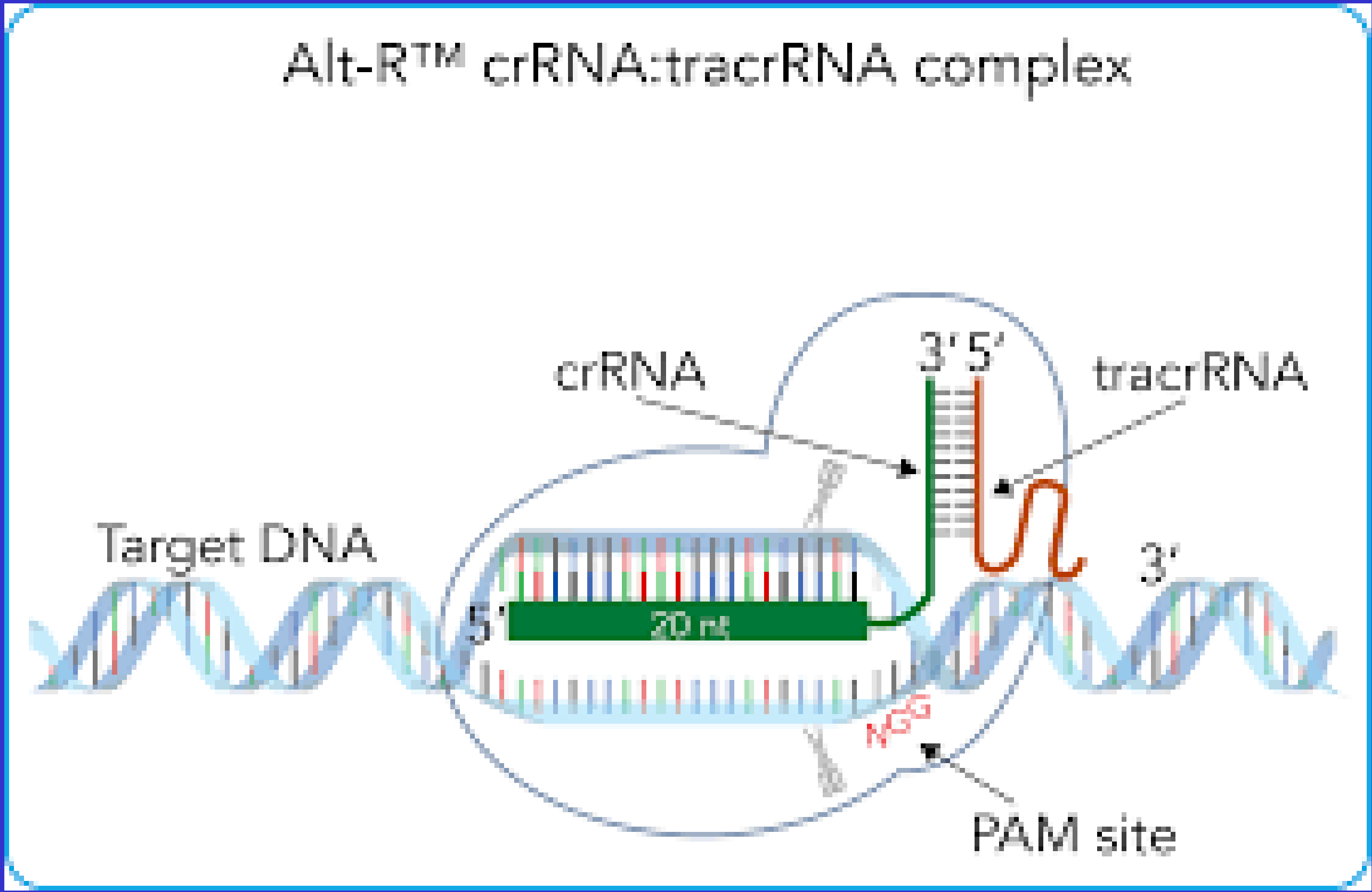


Gene gun

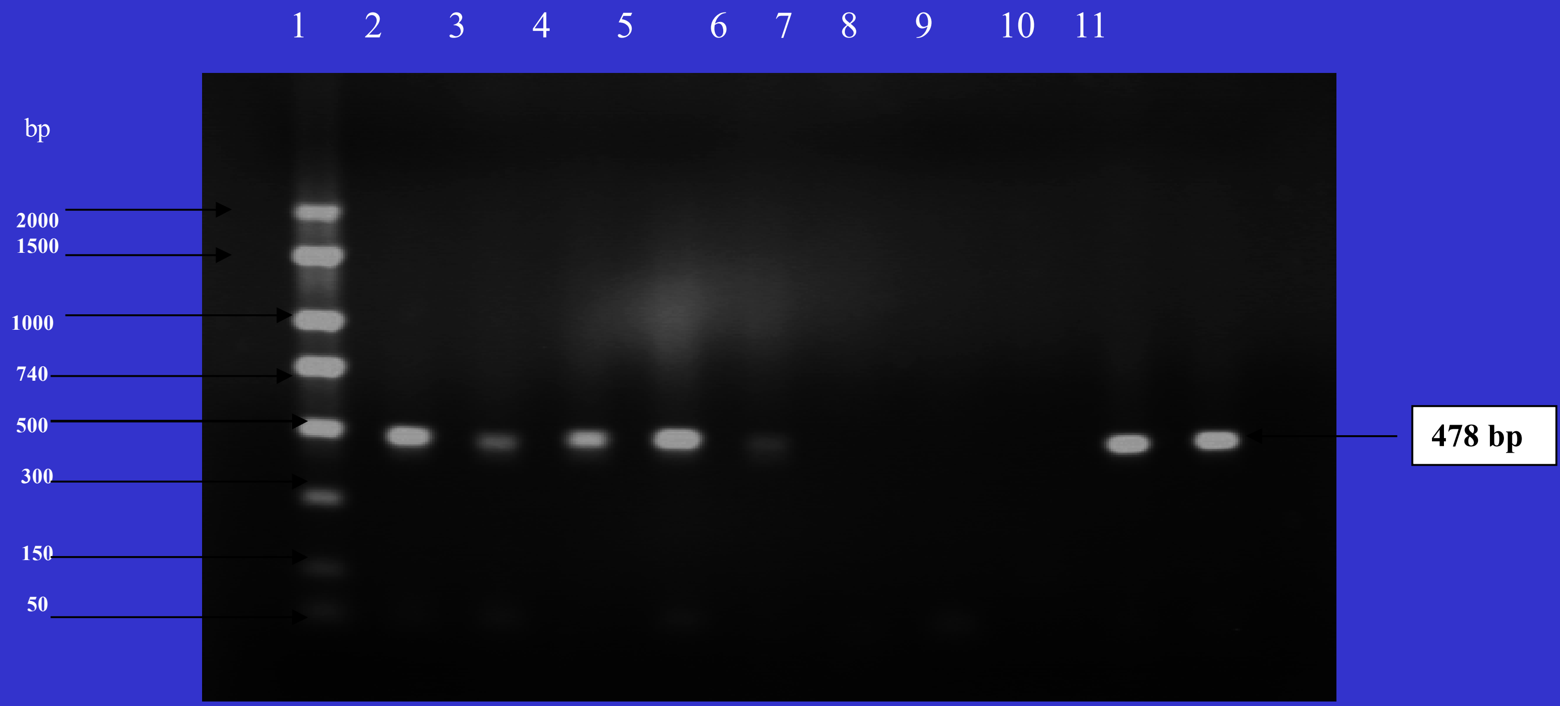


Properties	miRNA	siRNA
Origin	Distinct genomic loci. Encoded by their own genes	Encoded by transposons, viruses, heterochromatin
Biogenesis (nature of precursor)	Single RNA molecules that include an imperfect stem–loop secondary structure	Long bimolecular RNA duplexes or extended hairpins
Evolutionary conservation	Nearly always conserved in related organisms	Rarely conserved in related organisms
Nature of regulatory target	Regulate different genes	Mediate the silencing of the same (or very similar) genes from which they originate


LB
BAR
P-35S
RB
Transgene integrated
into plant genome
siRNA species
Degradation of the
targeted RNA
transcript
by Dicer and RISC
Targeted gene


Alt-R™ crRNA:tracrRNA complex
crRNA
3'
5'
tracrRNA
Target DNA
5'
20 nt
3'
NGG
PAM site

Confirmation of transformation



- PCR analysis of the presence of the APX and SOD gene in putative transgenic plant.
- DNA molecular size marker (lane 1),
- negative control (non-transformed cauliflower leaves) (lane 7 & 9), transformed plants carrying SOD gene (lane 2, 4 & 5),
- positive control (*Agrobacterium* DNA of SA or TA Strain) (lane3 & 6), transformed plant carrying APX gene (lane 10),
- positive control (*Agrobacterium* DNA of APX strains) (lane 11)
- (lane 8) water.

Transgenic plant growing on Salt containing medium

The additional gene(s) in the GM variety will confer a measurable change on the variety such as:-

- **resistance to something** – pest (caterpillars, aphids, grazing insects), disease,
  chemical (herbicide)
- **improvement in structural composition** – bread-making potential, oil composition, reduction in skin deterioration, delay in over-ripening, ability to remain standing during adverse weather.
- **change in physiology** – stress resistance; improvement in water use, improvement in nutrient use, improved efficiency of production (photosynthesis, respiration).
- **improvement in levels of health-promoting compounds** – vitamins, anti-cancer compounds, anti-oxidants
- **production of novel compounds** – pharmaceutical products.

GM cabbages protected against caterpillars using Bt toxin

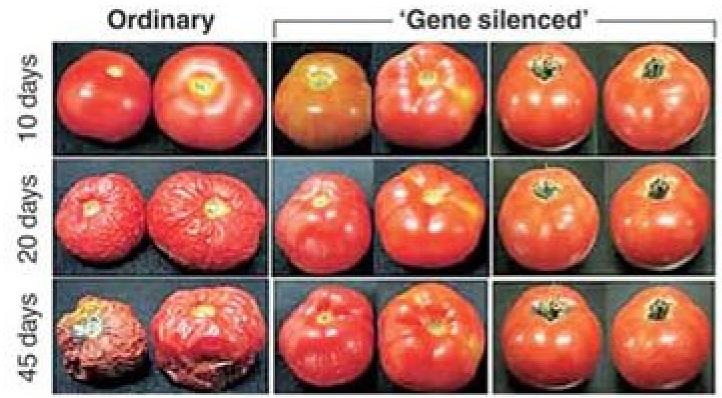
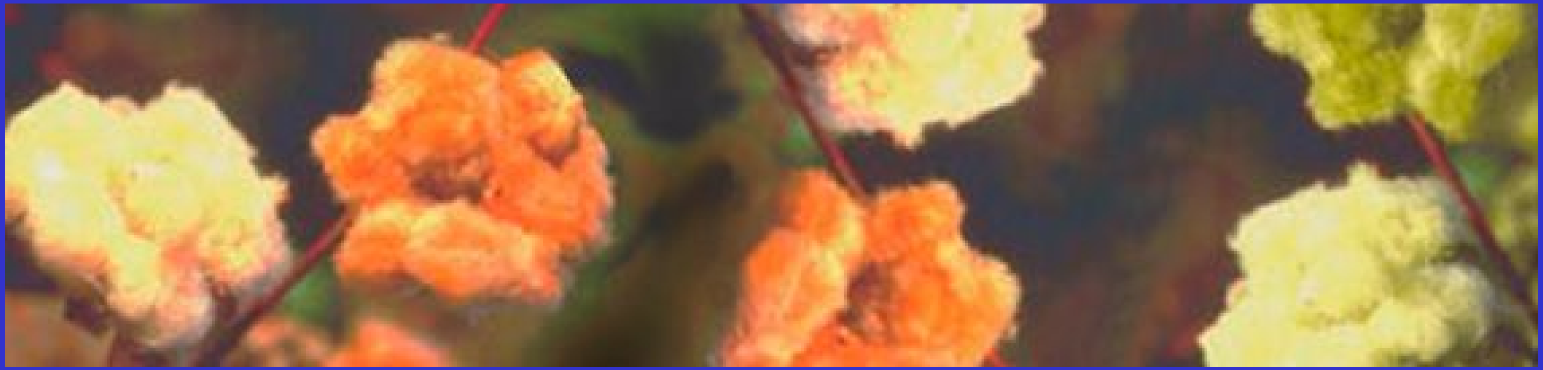


Image shows three sets of tomatoes. The ordinary control tomatoes (extreme left) soften and shrivel up, while texture of gene-silenced tomatoes remains intact for up to 45 days.

Photo credit: Asis Datta, Subhra Chakraborty, National Institute of Plant Genome Research, New Delhi





Benefits of GM crops since 1996

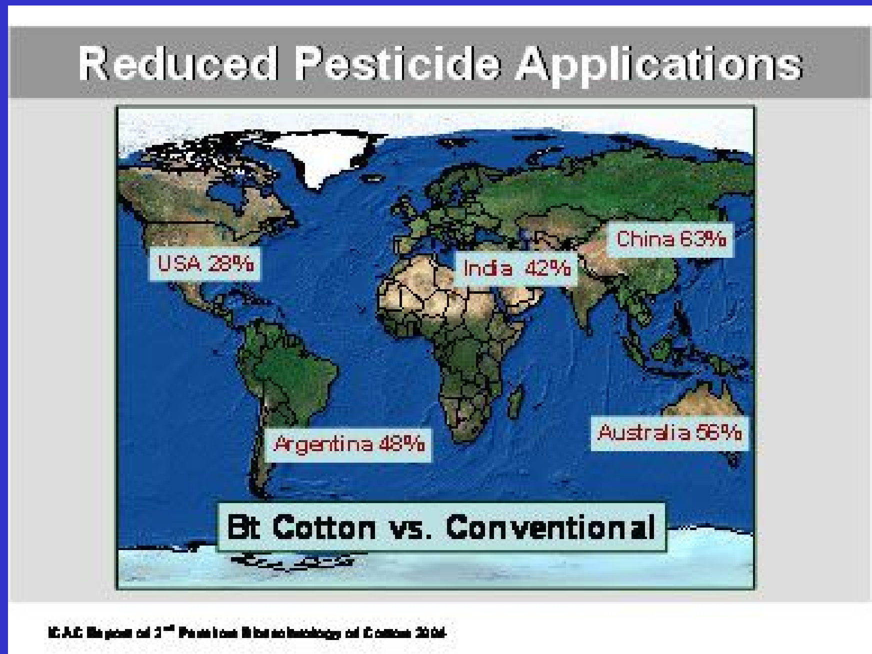
- Global farm income benefit in 2010 $14B
- Accumulated farm income 96-2012 $78.4B

- Reduction in pesticide by 9%   448 Mkg a.i.
- Reduction in environment impact quotient 17.9%

- CO_2 emissions reductions in 2010 equivalent to removal of 8.6M cars from the road - reduced farm fuel use and sequestration

GM offers opportunities for environmentally friendly, economical farming with more targeted use of pesticides and reduced use of fossil fuels.

- GM cotton (Bt), has led to an 80% reduction in usage of pesticides.
- The farmers that grow this cotton are reducing the pesticide input into the environment and reducing the risks to their own health.



	Change in volume pesticide use million kg a.i.	Farm income benefits from use of GM vars millions US$ 1996-05
GM HT soy	-51.4	11,686
GM HT maize	-35.5	795
GM HT cotton	-28.6	927
GM HT canola	-6.5	893
GM BT maize	-7.0	2,367
GM BT cotton	-94.5	7,510
Others	-0.1	66
TOTAL	**-224.3**	**24,244**

- **Adapted from G. Brookes & P. Barfoot, 2006, GM Crops the first 10 years, ISAAA Brief 36, ISAAA, Ithaca, NY, USA.**

There are considerable potential advantages of GM for infertile land

- Salt resistance – salt inundation and salinisation through irrigation
- Drought resistance – arid and semi-arid conditions create variable yields
- Frost resistance – extremely low winter temps reduce capability for overwintered crops. Occasional spring frosts damage blossomcrops

Next Generation GM plants/crops

Direct consumer benefits – healthier diets

- Micronutrients (Golden Rice – Phillipines launch)
- Fatty acid composition (Plenish[R] & Vistive Gold[R] ready for US and China launch)
- Resistant Starch
- Antioxidants

Next generation GM plants/crops

Trait	crop	Base level	GM level	Health effect
Beta-carotene	Golden Rice	0 μg/g	37 μg/g	Vit A deficiency
Iron	Rice	trace	6 fold	Anaemia & Brain development
Folate	Rice	1 μg/g	17 μg/g	Neural tube development
Ascorbate	Maize	18 μg/g	107 μg/g	Scurvy
Omega-3	Rapeseed	12%	50%	Cardiovascular health
Amylose	Wheat	28%	75%	Diabetes & Bowel disease
Anthocyanin	Tomato	trace	2.83 μg/g	Anti-cancer

Golden Rice

- Golden Rice is a GM variety enriched in beta-carotene -> vitamin A and is helping to reduce VAD in many developing countries of the world.

Farmaceutical plants – Golden Rice

- Lack of sufficient vitamin A leads to Vitamin A Deficiency (VAD)
- VAD is endemic in 26 countries and serious in a further 13 countries worldwide
- VAD affects over 124M children worldwide leading to irreversible blindness.
- UNICEF estimate there are 1.2 to 1.4M child deaths every year due to VAD

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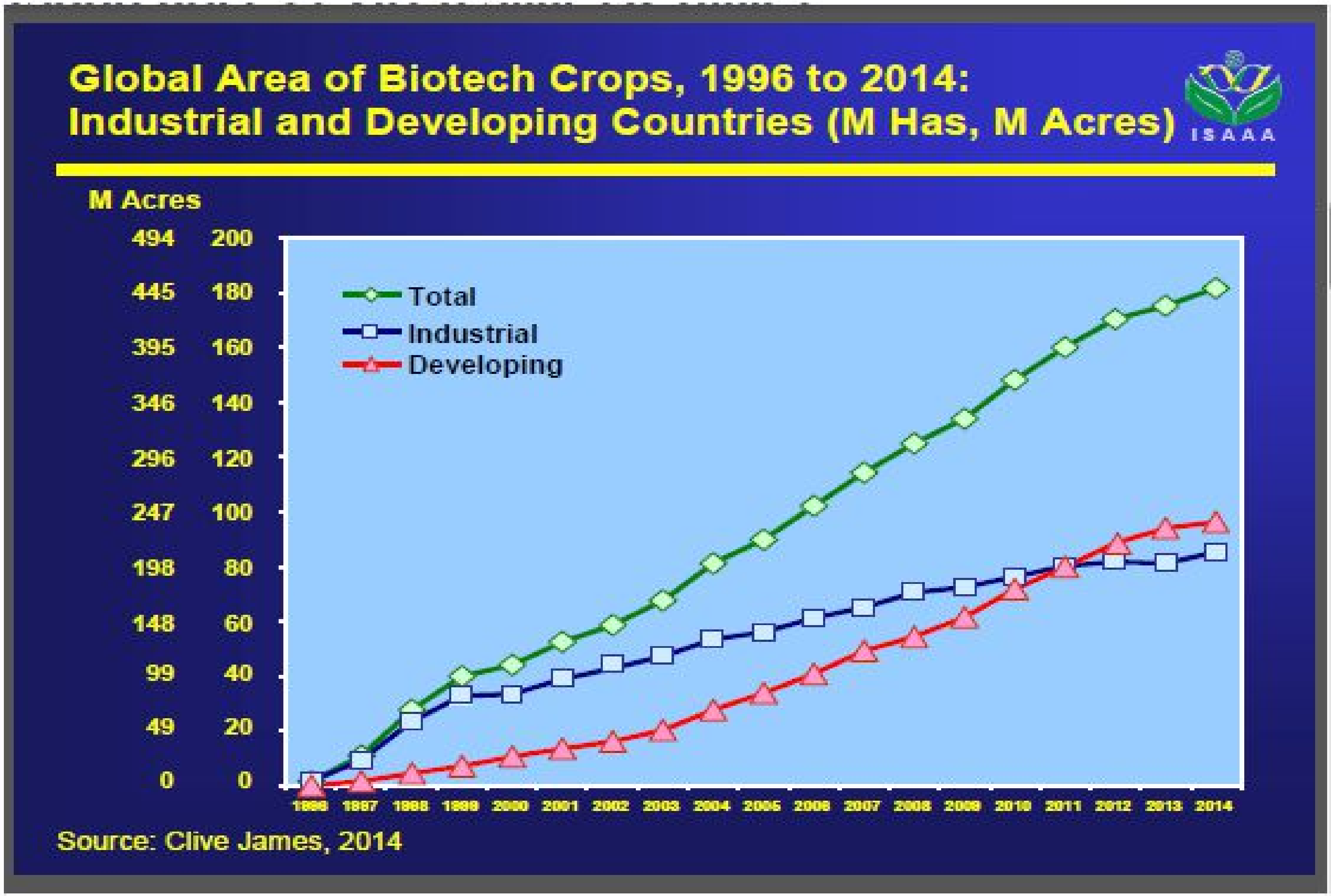

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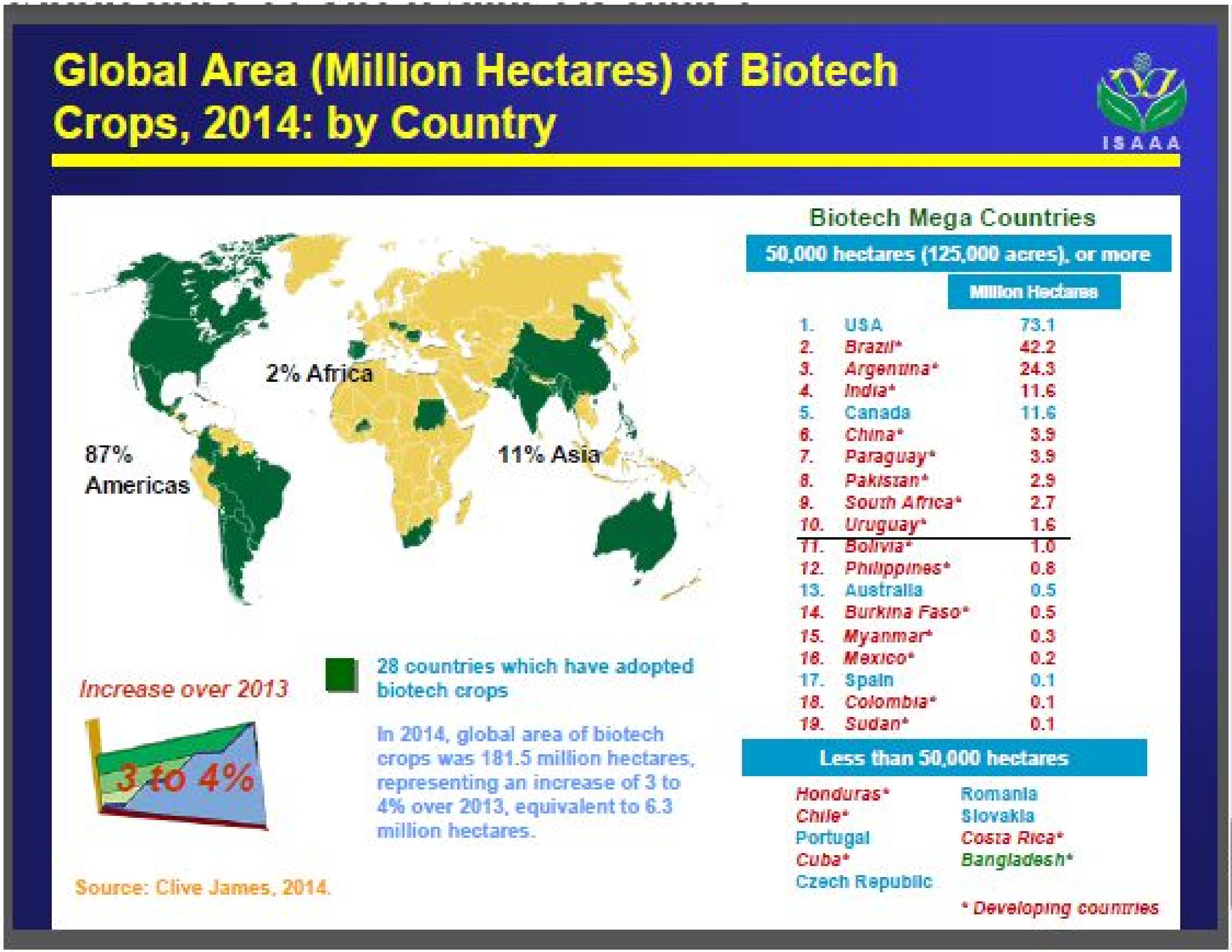

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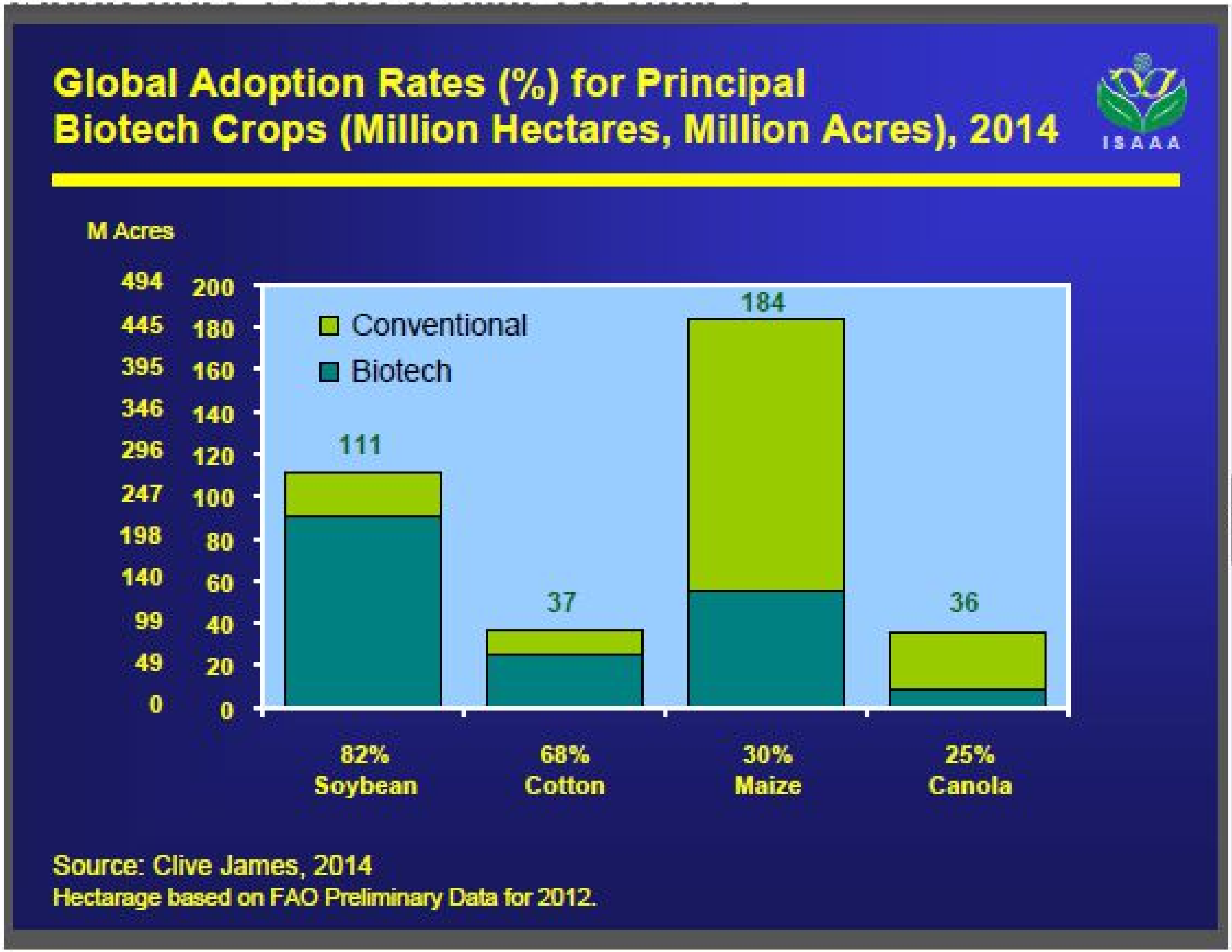

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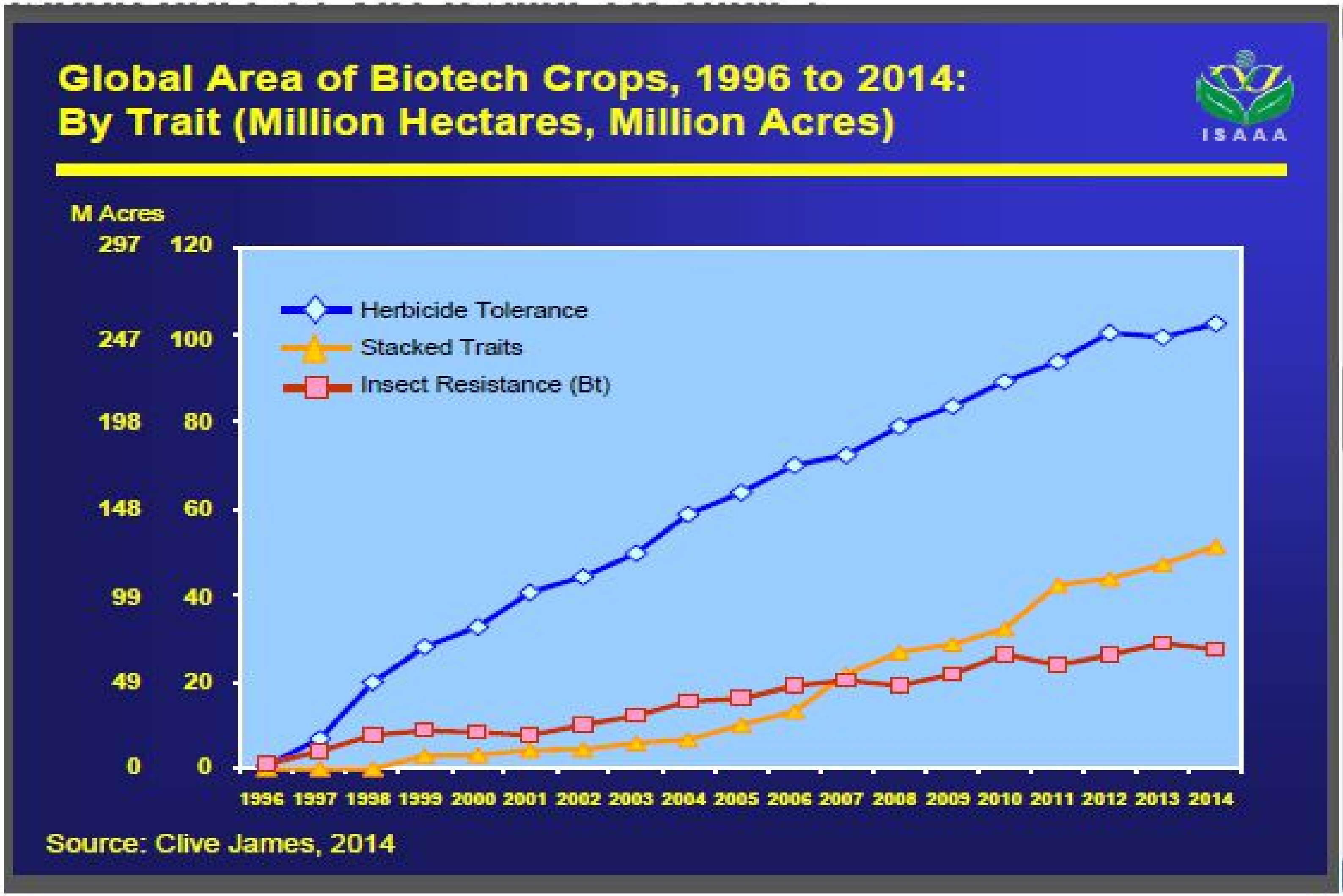
/ Briefs / Global Status of Commercialized Biotech/GM Crops: 2014 / Slides & Tables

ISAAA Brief 49-2014: Slides & Tables



Do GM crops affect the environment per se?

- Gene flow between farm crops and wild plants is possible if the species are sexually compatible. (natural Introgression)
- Generally this is a very low frequency event.
- Introgressed genes will only persist in the wild population if they show a selective advantage.
- The possibility and consequence of any such gene flow is a primary concern of the regulatory authorities.

Ownership and Control

- GM crop technology is principally owned by Private Industry although there a lot of the scientific breakthroughs are owned by Universities.
- The UK and other western Governments systematically sold off their plant breeding capabilities in the 1980’s and 1990’s.
- The development of GM technology has been very expensive and the Government has been keen to see Private Industry bear this cost.
- Private Industry requires a return on investment and now needs GM varieties to start to show such a return.
- This is a “developed” world’s technology
- The greatest impact for this technology is in the “developing” world who will have difficulty paying for it!
- GM crops for the “developed” world’s needs will be where the Private industry obtains its revenue
- Government has a duty of Control and Regulation.

GM crop varieties are proving to be dependable and safe

- GM crops are being grown worldwide on approximately 148 million hectares (nearly 1% of total world arable area)
- Repeat sales of GM crop varieties demonstrate that the varieties offer advantages over competitor non-GM varieties
- There have been no instances of human or animal health problems associated with the consumption of these GM products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中国农业大学
生物学院
College of Biological Science
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扬麦158（感病对照）
转基因H55
非转基因

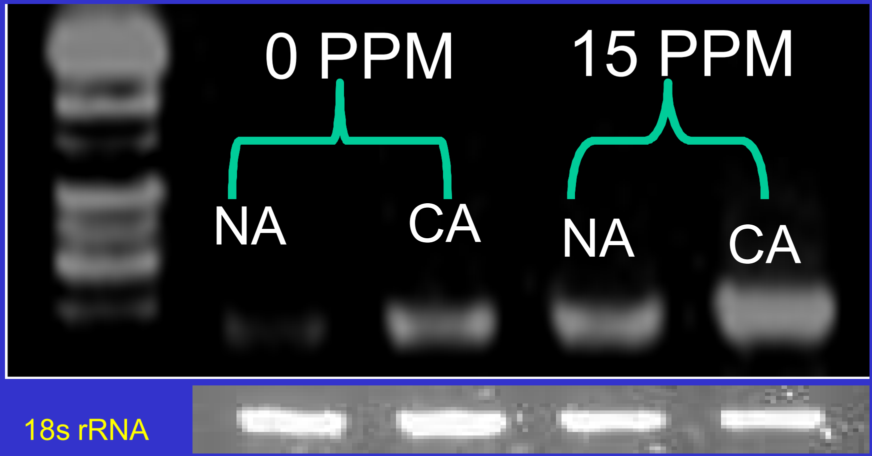
China's investment in GM crops

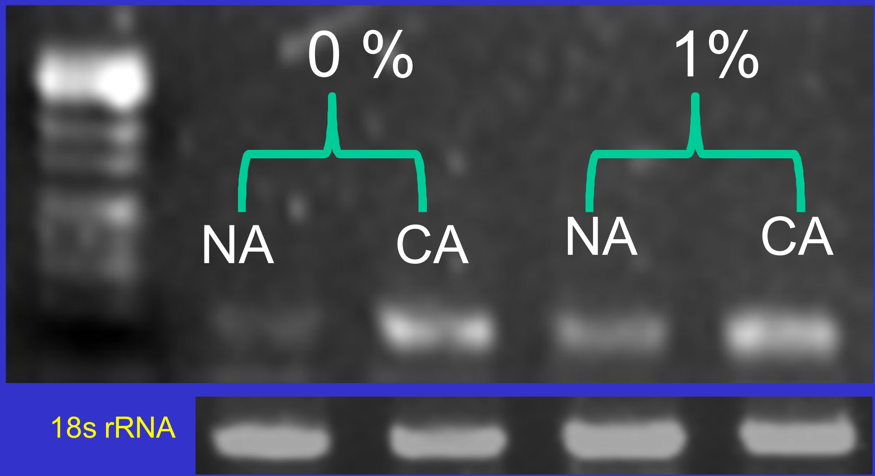
- 2008 announced a new investment
- 15 year programme
- £2,600,000,000

Nanotechnology

- Nanoparticles can switch on genes
  - Can induce pathogen resistance mechanisms – could replace Fungicides
  - Can induce abiotic stress resistance

Results： CBF expression under Mo effect.





Nanotechnology

CARBON NANOTUBES DELIVER DNA WICH INCORPORATE INTO THE PLANT CELL STRUCTURE