Indian Agriculture: Priority Traits

- Increased productivity
  - CMS systems
  - High photosynthesis
- Abiotic stress tolerance (drought, salt, high temperature)
- Insect/pest and disease resistance (viral, fungal, bacterial)
- Nutritional quality improvement
  - Biofortification → β-carotene (wheat, rice, mustard)
  - Iron, Zinc (wheat and rice)
  - Lycopene, Zeaxanthin, Lutein (tomato)
- Processing quality of fruits and vegetables
- Extended shelf life (tomato, mango, banana, papaya)
- Efficient resource utilization: N,P,K and micronutrients
- Biofertilizers; biofuels
Plant Breeding Components – Then and Now

- **Mendelian genetics** • Inheritance of simple traits
- **Quantitative genetics** • Inheritance of quantitative traits
- **Cytogenetics** • Genetic stocks
- **Molecular breeding**
  - MAS
  - Transgenics
- **Plant Breeding**

Institutions Instrumental in Developing GM crops

- **Public institutions**
  - ICAR Laboratories and SAUs (NARS)
  - CSIR Institutions
  - Delhi University
  - DBT Institutions
  - Central Universities

- **International Institutions**
  - ICRISAT
  - ICGEB

- **NGO/Others**
  - MSSRF
  - TERI

- **Private seed companies**
ICAR and DBT Network Initiatives

- Transgenics in Crops – 14 crops
- Molecular Breeding in Crops
- Gene Pyramiding for Disease Resistance
- Introgression of QTLs from Wild and Weedy Relatives
- Application of Microbes in Agriculture
- Pigeonpea Genomics
- Virus resistance in crops
- Tomato Genomics
- Functional Genomics of Rice for Yield and Biotic Stress Tolerance

Biotechnology for Sustainable Agriculture

- High water use efficiency
- High nitrogen use efficiency
- High photosynthesis
- Thermo tolerance
- Marker assisted breeding
- Nutritional quality improvement
> 60 per cent of cultivated area is rain-fed

Drought prone regions of India

Indian Agriculture is Dependent on Monsoon

Total food grain production in India

<table>
<thead>
<tr>
<th>Year</th>
<th>Production (mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>209</td>
</tr>
<tr>
<td>2002</td>
<td>185</td>
</tr>
</tbody>
</table>

ICAR Network on Transgenics in Crops

ABIOTIC STRESS TOLERANCE

- TOMATO
  - NRCPB
  - IIVR
  - ICHR
- MUSTARD
  - NRCPB
  - NRCRM
- GROUNDNUT
  - NRCG
- COTTON
  - CICR
- WHEAT
  - NRCPB
- RICE
  - NRCPB
  - DRR
  - CRRI

Development of Transgenic Tomatoes Tolerant to Salt and Water Stress

Wild type Transgenic Osmotin

Wild type Transgenic codA

(150mM NaCl for 25 days)

Wild type Transgenic codA

(Water stress for 7 days)
Transgenic Tomato Field Trial under Irrigated and Un-irrigated Conditions

Performance of transgenic mustard to soil moisture deficit stress
TRANSGENIC MUSTARD

Transgenic plants and wild type plants under Water stress of 18 days

Transplastomic Brinjal cv. Pusa Shyamla under Salt Stress of 300mM NaCl

Photographs were taken after 3 weeks of salt stress
Transplastomic Brinjal cv. Pusa Shyamla under Water stress

Photographs were taken after 2 weeks of water stress

Improved drought resistance of SNAC1-overexpressing transgenic rice at reproductive stage

Transgenic Crops undergoing Field Trials at the International Level

<table>
<thead>
<tr>
<th>Transgenic Crop</th>
<th>Gene</th>
<th>Stress</th>
<th>Location</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean</td>
<td>NF-YB1</td>
<td>Drought</td>
<td>Argentina</td>
<td>Monsanto</td>
</tr>
<tr>
<td>Wheat</td>
<td>DREB</td>
<td>Drought</td>
<td>Mexico</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>Rice</td>
<td>Stz</td>
<td>Drought &amp; Salinity</td>
<td>Belgium</td>
<td>Crop Design</td>
</tr>
<tr>
<td>Rice</td>
<td>DREB1</td>
<td>Drought</td>
<td>Philippines</td>
<td>IRRI</td>
</tr>
<tr>
<td>Tomato</td>
<td>AtNHX1</td>
<td>Salinity</td>
<td>USA</td>
<td>Arcadia Bioscience</td>
</tr>
</tbody>
</table>

**Projected Changes in Global Temperature**

*From the Intergovernmental Panel on Climate Change (IPCC)*
Wheat challenges

**NHZ:** The major constraints is water stress, yellow and brown rusts, late sowing and low plant population. 0.8 mha

**NWPZ:** The major constraints of this zone are weed infestation particularly *Phalaris minor* and wild oat, Yellow and brown rusts, Karnal bunt, high temperature and water stress. 9.5 mha

**NEPZ:** Major constraints of this zone are leaf blight and brown rust, high temperature, leaf and stem rust, termites, rodents and prevalent drought conditions. 4.5 mha

**CZ:** Major constraints of this zone are high temperature, leaf and stem rust, termites, rodents and prevalent drought conditions. 4.5 mha

**PZ:** Major constraints of this zone are high temperature, leaf and brown rust, attack of aphid, grain discoloration and water stress. 1.5 mha

**SHZ:** Major constraints of this zone are attack of termites followed by lodging, attack of birds, delayed sowing and black rust. 0.2 mha

The Times of India October 16, 2004
Iron Fortification of Rice Seeds by Genetic Engineering

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Iron Content (µg Fe/g - DW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seed</td>
</tr>
<tr>
<td>Transformant 1</td>
<td>38.1</td>
</tr>
<tr>
<td>Transformant 2</td>
<td>35.9</td>
</tr>
<tr>
<td>Non – transformant</td>
<td>14.3</td>
</tr>
</tbody>
</table>


Meal size “ferritin rice” (= 5.7 mg Fe / 150g DW) will provide 30 – 50% of the daily adult iron requirement which is approximately 13 – 15 mg Fe
Functional Genomics of Tomato for Improved Post-harvest Characteristics

P.I. - Dr. K.C. Bansal
National Research Centre on Plant Biotechnology
Indian Agricultural Research Institute, New Delhi – 110012

Background

- Huge monetary loss (~Rs. 15,000 crores per year) due to post-harvest spoilage of fruits and vegetables
- Malnourishment – a serious national problem

Objectives

- To extend shelf life by delayed ripening
- To enhance β-carotene (Vitamin A) and lycopene levels in GM tomatoes
Achievements

A. Transgenic tomatoes under testing for extended shelf life
B. Genes identified for high lycopene levels – being incorporated in elite Pusa cultivars

Extended Shelf life tomato fruits

Dates

<table>
<thead>
<tr>
<th></th>
<th>May 22</th>
<th>24</th>
<th>27</th>
<th>29</th>
<th>June 03</th>
<th>07</th>
<th>16</th>
<th>22</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT (PR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pA4A2AB (PR# 7-9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p286 (PR#5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

non transgenic tomato fruits. Fruits were harvested at the mature green stage and stored at 32°C ± 2°C. The onset of spoilage is indicated by wrinkling of the fruit skin.
Indo-US Technology Partnership
Indian Farmers adopt Better Hybrids with Bt Gene developed by Indian Seed Companies – driving India’s leadership in Global Cotton Trade

Source: Economic Survey 2007-08
GM Crops: Points of discussion

- No need to carry out soil micro-flora studies
- Are there compatible species of the crop in the area?
- Use existing information on pollen flow
- Whether the related species are already resistant. If yes, gene flow via pollen may not add enough to the invasiveness
- High level of Bt gene expression - to avoid resistance development by insects
- Corn flakes and corn oil – all from GM Corn in USA
- No effect of Bt maize on cows

Marker-Assisted Selection

MAS: Defined

Indirect selection for a primary trait (trait of economic importance) via direct selection for a secondary trait (marker), which is independent of growth stage, environment and G X E interaction.
National Facility on Development of markers and molecular maps

- Div. of Genetics, IARI: MAS in Basmati
- PAU: MAS in irrigated rice
- DRR: MAS in irrigated rice
- CRRI: MAS in upland and low land rice

IARI initiated molecular breeding research activities in different crop plants, including rice, wheat, maize, Brassica etc.

Mapping QTLs for downy mildew resistance in maize

Susceptible L-24+L-28

Leaf rust resistance in wheat

Xa21

Bacterial blight resistance in rice
Combining bacterial blight resistance and Basmati quality characteristics by phenotypic and molecular marker-assisted selection in rice

M. Joseph1, S. Gopershalalzana2,3, R.K. Sharma1,2, V.P. Singh1, A.K. Singh1, N.K. Singh7 and T. Mitamura2

MAS – Some Indian examples

MAS in Hybrid Breeding – Indian Examples
Pre-breeding at IARI - Preparing for the future

• Creation of novel plant types (wheat, rice)
• Male sterile sources for hybrid breeding (Brassica, wheat, pearl millet)
• Identification and utilization of sources of resistance to biotic and abiotic stresses in diverse crop plants

Public sector's investment in pre-breeding and genetic enhancement is crucial for the survival of agricultural growth.

Thank You!
Transgenic IR72 with Xa21 showing bacterial blight resistance with excellent agronomic performance under field conditions in the Philippines.

Transgenic MH63 (T) showing resistance to YSB and control MH63 (C) showing YSB symptoms.

Biotech hubs of ICAR

<table>
<thead>
<tr>
<th>Centre</th>
<th>Activity</th>
</tr>
</thead>
</table>
| NRCPB   | Lead Centre  
Transgenics, Molecular markers, Structural and Functional genomics |
| IARI    | Genetics and Plant Breeding  
Marker-assisted breeding: Wheat, Rice, Chickpea, Cowpea  
Virology Unit  
Characterization of viruses, gene constructs – development and sharing for tomato, banana, papaya and potato transgenics |
| CICR    | Cotton - Transgenic development: Bt cotton varieties |
| CPRI    | Potato - Transgenic development: Late blight, Quality Genomics |
| DRR     | Rice – Transgenic development: YSB, Abiotic stress tolerance, Quality, Sheath blight and BLB resistance  
Molecular breeding and functional genomics |
| DWR     | Wheat – Molecular Breeding: rust resistance, Quality improvement |
| IIHR    | Fruit and Vegetable crops  
Transgenic development |
| IIVR    | Vegetable crops – Tomato, Brinjal (Egg plant)  
Transgenic development, Marker-assisted breeding |
| IIPR    | Pulse crops – Transgenic development: Chickpea, Pigeon pea for resistance to pod borer |
Target Crops and Traits in the ICAR Network on Transgenics in Crops

- **Insect pest resistance**
  - Stem borer
  - Rice
  - Sorghum
  - Maize
  - Pod Borer
  - Pigeon pea
  - Chick pea
  - Boll worm
  - Cotton
  - Fruit borer
  - Tomato
  - Brinjal
  - Aphid
  - Brassica

- **Drought stress**
  - Brassica

- **Delayed ripening and quality**
  - Tomato

- **Virus resistance**
  - Cotton
  - Soybean
  - Tomato
  - Potato
  - Banana
  - Papaya
  - Cassava

- **Fungal resistance**
  - Rice
  - Banana
Several crop species have been engineered to produce their own insecticide, \textit{Bt-toxin}, making them resistant to certain insects.
Trend in cotton productivity due to Bt-cotton

<table>
<thead>
<tr>
<th>Year</th>
<th>Productivity m bales</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002-03</td>
<td>13.7</td>
</tr>
<tr>
<td>2003-04</td>
<td>16.4</td>
</tr>
<tr>
<td>2004-05</td>
<td>18.5</td>
</tr>
<tr>
<td>2005-06</td>
<td>22.6</td>
</tr>
<tr>
<td>2006-07</td>
<td>23.4</td>
</tr>
</tbody>
</table>

From net importer to now net exporter (4.7 m bales exported in 2005-06)
Transgenic Plants with Resistance to Viruses

Transgenic tomato with resistance to Leaf Curl Virus

Squash: Comparative Performance with CZW, ZW, & Z Resistance

<table>
<thead>
<tr>
<th>Genotype</th>
<th>No-Fr</th>
<th>Yield/kg</th>
<th>Mar Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CZW</td>
<td>1226</td>
<td>371</td>
<td>369 (97%)</td>
</tr>
<tr>
<td>ZW</td>
<td>1020</td>
<td>321</td>
<td>288 (90%)</td>
</tr>
<tr>
<td>Z</td>
<td>679</td>
<td>141</td>
<td>166 (77%)</td>
</tr>
<tr>
<td>Control</td>
<td>531</td>
<td>92</td>
<td>4 (4%)</td>
</tr>
</tbody>
</table>

A chart showing the performance of different genotypes in terms of yield and market yield.
Research efforts for developing viral resistant transgenic plants in India

<table>
<thead>
<tr>
<th>Crop</th>
<th>Trangen</th>
<th>Resistant against</th>
<th>Research centre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato</td>
<td>Replicase (ToLCV), RNAi constructs (ToLCV)</td>
<td>Tomato leaf curl virus, Bud necrosis virus, Cucumber mosaic virus</td>
<td>IARI, New Delhi</td>
</tr>
<tr>
<td>Papaya</td>
<td>CP (PRSV), Rep (PLRV)</td>
<td>Papaya ring spot</td>
<td>IARI, New Delhi</td>
</tr>
<tr>
<td>Banana</td>
<td>CP (BBTV), Rep (BSV)</td>
<td>Banana bunchy top, Banana streak virus</td>
<td>IARI, New Delhi, NRC banana, Trichy</td>
</tr>
<tr>
<td>Potato</td>
<td>PVY and PVX</td>
<td></td>
<td>CPRI, Shimla</td>
</tr>
</tbody>
</table>

The Golden Rice

β-carotene Pathway Genes Added

\[
\text{IPP} \rightarrow \text{Geranylgeranyl diphosphate} \\
\text{Daffodil gene} \rightarrow \text{Phytoene synthase} \\
\text{Phytoen} \rightarrow \text{Phytoene desaturase} \\
\text{Lycopene} \rightarrow \text{β-carotene desaturase} \\
\text{Lycopene-beta-cyclase} \rightarrow \text{β-carotene} \rightarrow (\text{vitamin A precursor})
\]

Vitamin A Pathway is complete and functional
Story of Golden Rice.................
MAS technology has not been around long enough
Most papers were not necessarily aimed at variety development
Lack of saturated molecular map
Lack of prioritization of target traits
MAS technology not properly integrated into the breeding programme
Infrastructure and human resource

Transgenic Flowers
Global plantings of biotech crops increased by 12 percent in 2007

Global Area of GM Crops

Source: International Service for the Acquisition of Agri-biotech Applications

Genetically Engineered Foods: Should be there in our homes?
Agriculture in the 21st century

- Global food security
- Nutritional security
- Sustainable Agriculture
- Plants - source of pharmaceuticals
- Plants - biomass for a less polluting industry
- Biological solutions for environmental pollution
Suppression of Ethylene Biosynthesis