Innovative Approaches for Increasing Cotton Productivity: A Way Forward

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## Cotton, Textiles & Indian economy

### Value of agriculture output

- India has World’s highest area (13 M ha)
- India is 2nd largest consumer (300 lakh bales) & 3rd largest exporter (50-70 lakh bales)
- Provides 59% raw material to Textile industry
- 6.0 million cotton farmers
- 40-50 million engaged processing and trade
- Contributes 29.1 % of total textile exports and 4.9% value of agriculture output

### Value of textile industry

- Contributes 4 per cent to GDP
- 14 per cent to industrial production
- 11 per cent to country’s export earnings
- Value of textiles and apparel industry
  - $ 165 billion (125 bn domestic & 40 bn export)

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**Indian Textile industry:** Second largest employer & largest exporter of cotton yarn (26.7%)
Cotton acreage is spread across 26 Agro-ecological Sub-Regions (AESRs) across three main cotton growing zones in 11 states.
## Cotton Productivity & factors: India vs Global

<table>
<thead>
<tr>
<th>Parameter</th>
<th>India</th>
<th>China</th>
<th>Australia</th>
<th>Brazil</th>
<th>USA</th>
<th>Pakistan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton area (lakh ha)</td>
<td>130</td>
<td>32.5</td>
<td>2.8</td>
<td>15.5</td>
<td>36.4</td>
<td>22.0</td>
</tr>
<tr>
<td># Farmers</td>
<td>60 Lakhs</td>
<td>86 lakhs</td>
<td>182</td>
<td>1240</td>
<td>8103</td>
<td>1.8 lakhs</td>
</tr>
<tr>
<td>Farm size (ha)</td>
<td>1.2</td>
<td>0.4</td>
<td>450</td>
<td>1339</td>
<td>624</td>
<td>1.4</td>
</tr>
<tr>
<td>Irrigated area (%)</td>
<td>33</td>
<td>80</td>
<td>89</td>
<td>4*</td>
<td>32</td>
<td>100</td>
</tr>
<tr>
<td>Seed (Insect resistance &amp; Herbicide tolerant)</td>
<td>IR</td>
<td>IR, HT</td>
<td>IR, HT</td>
<td>IR, HT</td>
<td>IR, HT</td>
<td>IR</td>
</tr>
<tr>
<td>Dominant planting method</td>
<td>Dibbling, wider spacing</td>
<td>Planter, HDPS</td>
<td>Planter, HDPS</td>
<td>Planter, HDPS, UNR</td>
<td>Planter, HDPS, UNR</td>
<td>Dibbling, Wide spacing</td>
</tr>
<tr>
<td>Crop duration (days)</td>
<td>180</td>
<td>160</td>
<td>150</td>
<td>150</td>
<td>160</td>
<td>170</td>
</tr>
<tr>
<td>Productivity (kg lint/ha)</td>
<td>448</td>
<td>1879</td>
<td>2071</td>
<td>1803</td>
<td>950</td>
<td>550</td>
</tr>
<tr>
<td>Cultivation cost /ha (US $/ ha)</td>
<td>600 – 1137 (mean 850)</td>
<td>3510</td>
<td>2716</td>
<td>2264</td>
<td>1543</td>
<td>855</td>
</tr>
<tr>
<td>Production Cost per Kg lint (US $)</td>
<td>1.15</td>
<td>1.57</td>
<td>1.69</td>
<td>1.09</td>
<td>1.35</td>
<td>0.71</td>
</tr>
</tbody>
</table>

*Assured high rainfall in remaining area
Challenges for higher Productivity
Genetics x Environment x Management

Genotype
- Genetic gain
- Novel traits

Environment
- Climate Change
- Abiotic stress
- Biotic stress

Narrow genetic base
Low Harvest index
Low Ginning outturn
Fibre Quality

Elevated CO2
Increasing temperature
Variable rainfall
Deteriorating soil health

Drought tolerance
Heat tolerance
Water logging tolerance

Weeds
Insects
Diseases
Nematodes
Productivity constraints specific to different zones

- **North Zone**
  - Thrips
  - Jassid
  - Stem weevil
  - Tea mosquito bug

- **Central Zone**
  - Jassid
  - Thrips
  - Nematodes

- **South Zone**
  - Whitefly
  - ClCuD

- **All India**
  - Pink boll worm
  - Boll rot
  - Erratic rainfall in rainfed
  - Deteriorating soil health
Transgenic Cotton to tackle Bollworms

<table>
<thead>
<tr>
<th>Genes/Event</th>
<th>Target Bollworms</th>
</tr>
</thead>
<tbody>
<tr>
<td>cry1Ac BG MON 531 (2002)</td>
<td>American BW</td>
</tr>
<tr>
<td>cry1Ac + cry2Ab2 MON 15985 BG II (2006)</td>
<td>Spotted BW</td>
</tr>
</tbody>
</table>

Potential yield
Attainable yield
Actual yield

*YL= Yield loss due to weeds, pathogens and insect pests
Bt cotton hybrids released for commercial cultivation

- **2002 to 2014**
  - 1127 private sector Bt cotton hybrids approved by GEAC between 2002 to 2014
- **Since 2017**
  - 130 private sector Bt Cotton hybrids released through multi-location testing through AICRP on Cotton network
  - 21 Bt varieties released by public sector notified

- Every year hybrid cotton seed is produced by private sector seed firms
- 50 million packets (450 g each) produced and supplied to farmers to plant in over 12 million ha area (>95% cotton area)
Bt Cotton Varieties (21) released by ICAR-CICR

1. **ICAR-CICR B16**
   - Released for irrigated conditions of Haryana and Punjab

2. **ICAR-CICR GJHV374 Bt**
   - Released for irrigated & rainfed conditions of Maharashtra

3. **ICAR-CICR PKV081 Bt**
   - Released for irrigated & rainfed conditions of Maharashtra

4. **ICAR-CICR Rajat Bt**
   - Released for rainfed conditions of Maharashtra

5. **ICAR-CICR Suraj Bt**
   - Released for rainfed conditions of Maharashtra, Madhya Pradesh, and Gujarat

6. **ICAR-CICR BT 14**
   - Released for rainfed conditions of Maharashtra

7. **Yugank Bt (Bt 183059-5)**
   - Released for rainfed conditions of Maharashtra, Gujarat, and Madhya Pradesh

8. **Tejas Bt (Bt 183059-4)**
   - Released for rainfed conditions of Maharashtra, Gujarat, and Madhya Pradesh

9. **Namami Bt (CICR 19-32 Bt)**
   - Released for rainfed conditions of Maharashtra, Gujarat, and Madhya Pradesh

10. **Samrat Bt (Bt 183059-2)**
    - Released for rainfed conditions of Tamil Nadu, Karnataka, Telangana, and Andhra Pradesh
Development of Pink bollworm resistance to Cry toxins

Widespread occurrence of Resistant populations – posing a serious threat to cotton production

- Since 2015, cotton productivity became stagnant or showed a declining trend

BG cry1Ac field evolved resistance observed in 2008-09

BG II field evolved resistance observed in 2014-15
Screening of wild species and introgressed derivatives for Pink bollworm resistance (n=18 bolls)

No durable resistance in cultivated species report so far against PBW

Innovative On-plant bioassay method
**Pre-breeding - a flagship initiative**

<table>
<thead>
<tr>
<th>Centre</th>
<th>Characters of interest in Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAU, Faridkot</td>
<td>CLCuD resistance</td>
</tr>
<tr>
<td></td>
<td>Sucking pest tolerance</td>
</tr>
<tr>
<td>MPKV, Rahuri</td>
<td>Fibre quality traits</td>
</tr>
<tr>
<td>TNAU, Coimbatore</td>
<td>Jassid tolerance</td>
</tr>
<tr>
<td>NAU, Surat</td>
<td>High Ginning Out turn</td>
</tr>
<tr>
<td></td>
<td>Sucking pest tolerance</td>
</tr>
<tr>
<td>CICR, Nagpur</td>
<td>Jassid tolerance,</td>
</tr>
<tr>
<td></td>
<td>Drought tolerance</td>
</tr>
<tr>
<td></td>
<td>Bacterial Blight tolerance</td>
</tr>
<tr>
<td></td>
<td>Fibre quality traits</td>
</tr>
</tbody>
</table>
Breeding for CLCuD resistance using exotic germplasm

Cotton leaf curl virus is endemic to the cotton growing zone in the north, causes ~30% yield loss.

- GVS 8 and GVS 9 imported from USDA (Dr. Jodi A Scheffler)
- Introgression into high yielding locally adapted elite genotypes: CSH 3129, CSH 3075 and F2228
- CLCuD resistant cultures now in advance stage of development (BC 3 /F 7 )
Transfer of Cotton leaf curl virus resistance from wild species

**a. Gossypium armourianum**

- Fibre length: 26.6 to 27.7 mm
- Fibre strength: 26.7 to 29.8 g/tex
- Micronaire: 3.3 to 3.9
- CLCuD resistant
- *cry 1Ac* and *cry 2Ab*
- Tolerant to whitefly

Resistant BC₁F₁

Resistant BC₄F₆

- Susceptible
- Resistant F₁
- Resistant BC₁F₁

Chromosome D01
## Revamping classical breeding programs:
Product profile for Rainfed light soils in Central and South Zones

<table>
<thead>
<tr>
<th>Target Traits</th>
<th>Product Profile: Target area: 60%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturity</td>
<td>120-140 days</td>
</tr>
<tr>
<td>Plant ht.</td>
<td>100-120 cm</td>
</tr>
<tr>
<td>Plant Type</td>
<td><strong>Compact &amp; Early maturity</strong></td>
</tr>
<tr>
<td>BW</td>
<td>4 gm (medium)</td>
</tr>
<tr>
<td>Boll No.</td>
<td>10-12</td>
</tr>
<tr>
<td>Sucking pest tolerance</td>
<td><strong>Good</strong></td>
</tr>
<tr>
<td>TSV</td>
<td>HR-R</td>
</tr>
<tr>
<td>HDPS</td>
<td>90 x 15 cm (~29K/acre)</td>
</tr>
<tr>
<td>Seed cotton yield</td>
<td>10 q/acre</td>
</tr>
<tr>
<td>Abiotic stress</td>
<td>Drought, heat, salinity/alkalinity tolerance</td>
</tr>
</tbody>
</table>

**Bt varieties released**

- Samrat bt
- Yugank bt
## Genomics of cultivated Cotton (*Gossypium spp.*)

<table>
<thead>
<tr>
<th>Cotton Species</th>
<th>Genome Code</th>
<th>Sequenced genome size</th>
<th>No. of predicted protein coding genes</th>
<th>Percent repeat sequences</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>G. raimondi</em></td>
<td>$D_5$</td>
<td>775.2Mb</td>
<td>40,976</td>
<td>57.0</td>
<td>Wang et al., 2012</td>
</tr>
<tr>
<td><em>G. raimondi</em></td>
<td>$D_5$</td>
<td>737.8 Mb</td>
<td>37,505</td>
<td>61.0</td>
<td>Paterson et al., 2012</td>
</tr>
<tr>
<td><em>G. arboreum</em></td>
<td>$A_2$</td>
<td>1694 Mb</td>
<td>41,330</td>
<td>68.5</td>
<td>Li et al., 2014</td>
</tr>
<tr>
<td><em>G. hirsutum</em></td>
<td>$(AD)_1$</td>
<td>2,173 Mb</td>
<td>76,913</td>
<td>67.2</td>
<td>Li et al., 2015</td>
</tr>
<tr>
<td><em>G. hirsutum</em></td>
<td>$(AD)_1$</td>
<td>2400Mb</td>
<td>70,478</td>
<td>64.8</td>
<td>Zhang et al., 2015</td>
</tr>
<tr>
<td><em>G. barbadense</em></td>
<td>$(AD)_2$</td>
<td>2470Mb</td>
<td>77,526</td>
<td>63.2</td>
<td>Liu, X. et al 2015</td>
</tr>
<tr>
<td><em>G. barbadense</em></td>
<td>$(AD)_2$</td>
<td>2570Mb</td>
<td>80876</td>
<td>69.1</td>
<td>Yuan D et al 2015</td>
</tr>
<tr>
<td><em>G. herbaceum</em></td>
<td>$A1$</td>
<td>1556Mb</td>
<td>43952</td>
<td>-</td>
<td>Huang et al. 2020</td>
</tr>
</tbody>
</table>

$G.spp = 8.0$

Important resource for Genomics Assisted Breeding and MAS
Molecular markers for Cotton Improvement

- Cotton Marker Database (https://www.cottongen.org/data/markers) has more than 276,221 genetic markers consisting of 3,541 RFLPs, 78,340 SSRs, 183,035 SNPs.
- Marker information includes sequence, germplasm, DNA library, repeat motif, restriction enzyme, reference, etc. New markers are being added at a greater pace.
- >6000 QTLs have been mapped in cotton for traits of various interest like yield, fibre quality, stress tolerance, plant architecture, etc. Many new genes/QTLs are being identified using genome-wide association mapping using SSR/SNP markers.
- There are hardly any reports on introgression of genes/QTLs through Marker Assisted Selection except very few studies by Chinese group who have employed MAS for introgression of fibre quality traits (Guo et al., 2005; Guo et al., 2014)
- Marker assisted selection for Bacterial Leaf Blight resistance in Cotton is in progress at ICAR-CICR, Nagpur.
<table>
<thead>
<tr>
<th>Target Genes</th>
<th>Traits</th>
<th>Functional validation</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>GhPHYA1 (Phytochrome A1)</em></td>
<td>Fibre quality, yield &amp; agronomic traits</td>
<td>• RNAi validated (Abdurakhmonov et al 2014)</td>
</tr>
<tr>
<td><em>GhADF1 (Actin depolymerizing factor 1)</em></td>
<td>Fibre quality and drought tolerance</td>
<td>• RNAi validated (Wang et al 2009; Qin et al 2022)</td>
</tr>
<tr>
<td><em>GhNB (Nulliplex-branch)</em></td>
<td>Compact architecture, determinate sympodia</td>
<td>• CRISPR/Cas validation (Chen et al 2019)</td>
</tr>
<tr>
<td><em>GhFAD2-1</em></td>
<td>Seed oil quality</td>
<td>• RNAi validated (Liu et al 2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• CRISPR/Cas validation (Chen et al 2021)</td>
</tr>
<tr>
<td><em>GhPEPC2</em></td>
<td>Seed oil content and salt tolerance</td>
<td>• RNAi validated (Zhao et al. 2018)</td>
</tr>
<tr>
<td><em>GhGalT1 (β-Glycosyltransferase1)</em></td>
<td>Fibre quality, yield &amp; agronomic traits</td>
<td>• Overexpression and RNAi validated (Qin et al 2016)</td>
</tr>
</tbody>
</table>

*Under ICAR initiative on “Genome editing for sustainable food systems”*
COTTON SPEED BREEDING – LED lighting/ climate control

- 3 generations per year
- 5-10 bolls per plant
- Good germination
Embryo culture assisted speed breeding in cotton

(Raghavendra et al., 2022)
Precision water management for productivity enhancement and WUE

Effect of sensor based irrigation on seed cotton yield and WUE

<table>
<thead>
<tr>
<th>Irrigation Treatments</th>
<th>Seed Cotton Yield (kg/ha)</th>
<th>Water Used (ha cm)</th>
<th>Water Use Efficiency (Kg seed cotton/ ha cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET based Irrigation (Drip at 1.0 ET)</td>
<td>2267</td>
<td>51.04</td>
<td>44.4</td>
</tr>
<tr>
<td>Sensor based (Drip at 25 % DASM)</td>
<td>2523</td>
<td>45.34</td>
<td>55.6</td>
</tr>
<tr>
<td>Sensor based (Drip at 50 % DASM)</td>
<td>2621</td>
<td>45.34</td>
<td>57.8</td>
</tr>
<tr>
<td>Conventional Irrigation</td>
<td>2003</td>
<td>78.4</td>
<td>25.5</td>
</tr>
<tr>
<td>C.D. (P=0.05)</td>
<td>226.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sensor based irrigation produced highest seed cotton yield in CICR 23 Bt

Sensor based irrigation resulted in lesser water consumption and higher WUE
Towards variable rate application of Nitrogen

Spectral signatures of local cotton cultivars to N stress assessment through drone

- Establish field zones based on nitrogen sufficiency
- Fertilizer-N saving and improved use efficiency by variable rate application
Drip-mulch-Fertigation technique in irrigated cotton

Production protocol standardized for higher productivity with Hirsutum and ELS HxB hybrids
Productivity enhancement through legume inter-cropping systems in Cotton – enriching soil health

Arboreum cotton

- Cotton + Cowpea
  - CEY=1853; Additional Gross Income: Rs. 14015

- Cotton + Cluster bean
  - CEY=1956; A.G.I.: Rs. 19987

- Cotton + Green gram
  - CEY=2211; A.G.I.: Rs. 32571

Hirsutum cotton

- Cotton + Black gram
  - CEY=1899; A.G.I.: Rs. 19691

- Cotton + Groundnut
  - CEY=2125; A.G.I.: Rs. 30844

- Cotton + Soybean
  - CEY=2412; A.G.I.: Rs. 45007

CEY: Cotton equivalent yield Kg/ha  A.G.I.: Additional gross income Rs./ha
Sensor based applications in agriculture -
AI Smart Trap for monitoring Cotton Pink Bollworm

- Field trap catch data images transferred to App
- >90% accuracy in detection of trap catch
- Enables Economic threshold level based spray decisions
Diagnostics for early detection of viral diseases for timely management

Rapid diagnosis of cotton leaf curl virus disease and Tobacco streak Virus in Cotton

Colorimetric LAMP detection of CLCV by using different stains

Colorimetric detection and diagnosis of TSV using RT-LAMP

Gawande et al 2019, 2022
SoP for Drone based pesticide spray delivery

Assessment of spray distribution and bio efficacy of insecticide applied through unmanned aerial vehicle (UAV) against sucking pests on cotton

- Constant Altitude (2 m) and speed (2.5 m/s) of the UAV
- Parameters assessed: Variable spray fluid volumes 10L/ac, 15 L/ac, 20 L/ac, 25 L/ac), spray fluid distribution and bio efficacy
- Treatments 20 L/ac & 25 L/ac recorded significantly uniform spray fluid distribution in the top, middle and bottom canopy of cotton plant with superior bio-efficacy against sucking pests

Policy launched for drone applications in agriculture

- ICAR, State Agricultural Universities, Service providers developing SoPs for drone use in different field crops & horticulture
- Skill development trainings to rural youth & women
Cotton advisories: Voice messages to farmers in local languages

#Voice messages (30 sec) to registered farmers throughout the season
voice messages in local languages in Hindi, Marathi, Telugu and Tamil

Season long
Weekly advisories issued to all stakeholders in States & periodical pest situation alerts issued for dissemination to farmers
Initiatives for promoting productivity of G. *hirsutum* cotton & specialty cottons (color, ELS and desi cottons)

- Genotypes with higher ginning out turn (GoT, 2% higher) promoted in multi-location testing under AICRP & identified for release
- Fast track release of genotypes developed through MAS (2 year testing)
- Fast track release of compact genotypes amenable for high density planting system (2 year testing)
- Color cotton varieties (light to dark brown) released for commercial cultivation in the central and southern zones
- ELS cotton *G. barbadense* varieties released by CICR with superior fibre quality. Productive HxB hybrids spinnable to 120s count developed by private sector.
- Long linted varieties of *G. arboreum* released – most suitable for organic cotton production (No risk of GM contamination, sucking pest, drought and salinity tolerant), tailored agronomy developed
Joint Initiative of Ministry of Agriculture & Farmers Welfare & Ministry of Textiles

Launch of Special Project on Cotton for Productivity enhancement in 8 states in 2023-24 in Public Private Partnership mode

Technology targeting to agro-ecology:
large scale demonstrations on HDPS & Closer spacing for higher yield in shallow to medium soils

Technology
• Compact hybrids in rainfed light soils (90 x 15 cm spacing)
• Machinery support: planters & shredders
• Need based PGR sprays

Partnership
• Implementation by ICAR-CICR
• Seed & Textile industry associations
• Extension support: ATARI & KVKs
• State Dept of Agriculture
• 10000 farmers in 61 districts
Way forward

- Broadening the genetic base through transfer of useful traits from wild and un-adapted germplasm into better adapted lines for further breeding
- Breeding for early maturing, dwarf compact plant varieties with high harvest index and big boll size suitable for high density planting and mechanical picking
- Development of superior fiber traits in *G. hirsutum* and development of *G. barbadense* varieties better than Suvin in yield to meet the shortage of ELS cotton
- Development of heterotic pools of *G. hirsutum*
- Strengthening and harnessing the superior traits values of native Desi cotton species *G. arboreum* and *G. herbaceum*
- Discovery of new genes, promoters and constructs to develop GM cotton resistant to abiotic stresses (water logging, high temperature and drought) and possessing high strength
- Exploring advances in genomics and genome editing for development of transgenic cotton resistant to prevailing and emerging pests and diseases (bollworms, whitefly, leaf curl virus, boll rot etc)
- Use of sensors, Drones, AI and IoT based production and protection technologies
THANK YOU