EFFECTS OF CLIMATE CHANGE ON SUGARCANE PRODUCTION, AND ROLE OF TISSUE CULTURE TECHNOLOGY IN THEIR MITIGATION

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Climate Change

- Major area of concern of scientific community
- Poses greater threat than terrorism
- As per Dr. David King- Every economic decision has a climate consequence, and every climate decision has an economic consequence.
  - Rising surface temperature: Last century- 0.6-1.0 °C; – Projections for 2100-1.6-5.8 °C
  - Increasing atmosphere [CO₂] 280 ppm (1789); 380 ppm (2004); 550 ppm (2050)
  - Rainfall patterns
  - Rising sea levels
Climate change, food and farming:

According to the Fifth Assessment Report of the IPCC, climate change is affecting food and farming now.

It is affecting crop yields
Maize and wheat yields show climate impacts:
- Maize: China -7%, Brazil -8%, France -3%, Global (-4%)
- Wheat: China -2%, Russia -14%, France -5%, Global (-5%)

It is putting up prices
Recent price spikes for food have been linked to extreme weather events:

Seasonal climate extremes and the food price index

Percentage of people undernourished (2011-13):
- South Asia: 17%
- Sub-Saharan Africa: 25%

Poor people are worst affected
Poor people spend a higher proportion of their income on food - so price rises affect them more.

How much of their income do poor people spend on food?
- Malawi: 78%
- Pakistan: 75%
- Vietnam: 74%
- USA: 21%

Adaptation is happening, but is not enough

Changes in planting dates, adjusting marketing arrangements, using different crop cultivars and species.
Climate Change in Pakistan

- Among top 10 countries effected by climate change
- Listed as one of the most vulnerable countries in the world to climate change, UNDP
- List of countries at most risk of climate related threats
  - Floods
  - Agriculture
- Droughts are more intense
- Glaciers are melting in the region
- Freshwater availability is also projected to decrease
- Climate change is estimated to decrease crop yields in Pakistan which in turn will affect livelihoods and food production

Verisk Maplecroft, UK; UNDP, 2015; IPCC Report;
Effects on Sugarcane Production

- World’s largest commodity with respect to production; 70% global sugar production
- Major cash crop of Pakistan, 0.7% value addition in GDP, 3.4% in agriculture sector, 99% sugar production
- Water stress
  - Reduction of rainy days (400-700 mm); Dry seasons
- Increasing temperature
  - Cane and sugar yield decline 10% for every 1°C increase
  - Irrigation demand 10% for an increase in 1°C
- Precipitation extremes
- Winds
- Sudden weather changes
- Higher input costs- pesticides, fuels, water

Zhao and Li, 2015
Climate-Sugarcane Linkage, Yield

Genotype
- Development of stress tolerant genotypes
  - Breeding
  - Genetics
  - Biotechnology
- Novel methodologies to evaluate and screen cultivars
  - Molecular Selection
  - Rate of Photosynthetic activity
  - Rate of starch accumulation

Environment
- Abiotic stress
  - Temperature
  - Water
  - Humidity
  - Wind
  - \( \text{CO}_2 \)
- Biotic stress
  - Fungi
  - Bacteria
  - Insects
  - Weeds

Management Practices
Climate Change
Mitigation of Climate Impact on Sugarcane

- Climate is the key factor determining sugarcane production
  - Adaptive, and stress tolerance capacity
  - Development of the stress tolerant and high yielding sugarcane cultivars that can contribute to adaptation to climate change events
  - Tissue Culture, Conventional Breeding, GM Sugarcane
  - Irrigation efficiency
  - Management practices
  - Nutrient use efficiency
  - Agricultural weather information systems; climate predictions
### Production, Area, and Yield, in Sugarcane Growing Countries of the World

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (Million Tonnes)</th>
<th>Rank</th>
<th>Area (X1000 ha)</th>
<th>Rank</th>
<th>Yield (t ha(^{-1}))</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>739.27</td>
<td>1</td>
<td>9835.2</td>
<td>1</td>
<td>75.17</td>
<td>29</td>
</tr>
<tr>
<td>India</td>
<td>341.20</td>
<td>2</td>
<td>5060.0</td>
<td>2</td>
<td>67.43</td>
<td>40</td>
</tr>
<tr>
<td>China</td>
<td>126.14</td>
<td>3</td>
<td>1827.3</td>
<td>3</td>
<td>69.03</td>
<td>39</td>
</tr>
<tr>
<td>Thailand</td>
<td>100.10</td>
<td>4</td>
<td>1321.6</td>
<td>4</td>
<td>75.74</td>
<td>26</td>
</tr>
<tr>
<td>Pakistan</td>
<td>63.75</td>
<td>5</td>
<td>1128.8</td>
<td>5</td>
<td>56.48</td>
<td>51</td>
</tr>
<tr>
<td>Mexico</td>
<td>61.18</td>
<td>6</td>
<td>782.8</td>
<td>6</td>
<td>78.16</td>
<td>25</td>
</tr>
<tr>
<td>Colombia</td>
<td>34.88</td>
<td>7</td>
<td>405.7</td>
<td>9</td>
<td>85.95</td>
<td>19</td>
</tr>
<tr>
<td>Indonesia</td>
<td>33.70</td>
<td>8</td>
<td>450.0</td>
<td>7</td>
<td>74.89</td>
<td>31</td>
</tr>
<tr>
<td>Philippines</td>
<td>32.00</td>
<td>9</td>
<td>435.4</td>
<td>8</td>
<td>73.49</td>
<td>37</td>
</tr>
<tr>
<td>USA</td>
<td>27.91</td>
<td>10</td>
<td>368.6</td>
<td>11</td>
<td>75.71</td>
<td>27</td>
</tr>
<tr>
<td>World total</td>
<td>2165.23</td>
<td></td>
<td>26522.7</td>
<td></td>
<td>81.64</td>
<td></td>
</tr>
</tbody>
</table>

Ranked at 8\(^{th}\) position in sugar recovery and sugar yield (9.2 \%, 4.63 t/ha; against 13.8 \%, and 13.85 t/ha of Australia, and 9.9 \%, 6.62 t/ha of India)

*FAO, United Nations, FAOSTAT, and Factfish*
Options for Sugarcane Improvement to Cope with Changing Climatic Conditions

- Conventional breeding?

- Non flowering or sporadic flowering with poor seed setting under natural conditions

- If seed setting occurs, germination is very poor and mortality rate is very high

- Lack of facilities for induction of flowering by artificial means

- Solution: Biotechnology, Exotic germplasm evaluation, Mutagenesis,
Methods and Objectives

- Tolerance to different stresses in climate change.
- High cane yield
- High sugar content
- Early maturity

Parent Plant (NIA-2010)
Callus Culture Technology using 2,4-Dichlorophenoxyacetic acid
Preliminary Selection Morphological and Molecular Selection
Field Trials Performance of selected plantlets in field
Methodology Cont.

- NIA-2010, Pedigree of the parent: CP67-1026
- Apical meristematic region on agar solidified medium containing 1-5 mg/L 2,4-D, aseptic conditions
- Callus induction; Somaclonal variations through different cycles
- Shoot multiplication was done by transferring the embryogenic calli with induced shoot into MS medium containing recommended concentrations of hormones
- Root induction- hormonal concentrations changed
- Molecular and morphological selection
- Field evaluation; Randomized complete block design
- Determination of qualitative and quantitative parameters
- Statistical, correlation and cluster analysis

Murashige and Skoog, 1962
Yasmeen et al., 2013
Callus Culture in Sugarcane

A) Explant
B) Callus
C) Regeneration
D) Rooted plantlets
E) Plantlets in earthen pot
F) Plants in the field
Molecular Selection of Low Water Requiring Somaclones

- Random Amplified Polymorphism (RAPD) markers - to confirm genetic diversity in somaclones
- Target Region Amplification Polymorphism (TRAP) and Sequence-Tagged Site (STS) markers - to assess the sucrose content and low water requirement
- TRAP markers - genetic polymorphism for sucrose gene
- Dehydration-responsive element-binding protein (DREB) STS Marker - determination of drought tolerance
Results of RAPD-PCR with primer C-02; M=DNA marker, 1=Parent, 2=SC2, 3=SC3, 4=SC6, 5=SC7, 6=SC8, 7=SC11, 8=SC12, 9=SC13, 10=SC14, B= Blank

Results of RAPD-PCR with primer B-02; M=DNA marker, 1=Parent, 2=SC2, 3=SC3, 4=SC6, 5=SC7, 6=SC8, 7=SC11, 8=SC12, 9=SC13, 10=SC14, B= Blank
STS profile of sugarcane genotype using DREB sequence; M=DNA marker, 1=Parent, 2=SC2, 3=SC3, 4=SC6, 5=SC7, 6=SC8, 7=SC11, 8=SC12, 9=SC13, 10=SC14, B= Blank

TRAP profile of sugarcane genotype using Sucrose Synthase; M=DNA marker, M=DNA marker, 1=Parent, 2=SC2, 3=SC3, 4=SC6, 5=SC7, 6=SC8, 7=SC11, 8=SC12, 9=SC13, 10=SC14, B= Blank
## Range of Parameters of Tissue Culture Derived Somaclones against the Parent

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parent</th>
<th>Range in Somaclones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Height</td>
<td>303.67</td>
<td>95.2 - 385.7</td>
</tr>
<tr>
<td>Girth</td>
<td>2.43</td>
<td>2.0 - 3.3</td>
</tr>
<tr>
<td>Tillers per Plant</td>
<td>6.76</td>
<td>3.3 - 7.2</td>
</tr>
<tr>
<td>Number of Internodes</td>
<td>30.00</td>
<td>8.7 - 29.0</td>
</tr>
<tr>
<td>Internodes Length</td>
<td>15.89</td>
<td>4.7 - 19.1</td>
</tr>
<tr>
<td>Stool Weight</td>
<td>6.79</td>
<td>2.2 – 6.9</td>
</tr>
<tr>
<td>Cane Yield</td>
<td>66.96</td>
<td>24.3 - 71.2</td>
</tr>
<tr>
<td>CCS %</td>
<td>8.08</td>
<td>4.9 - 11.33</td>
</tr>
<tr>
<td>Brix %</td>
<td>16.01</td>
<td>12.8 – 21.6</td>
</tr>
<tr>
<td>Sucrose %</td>
<td>13.18</td>
<td>8.0 - 15.9</td>
</tr>
<tr>
<td>Fiber %</td>
<td>14.52</td>
<td>9.1 - 17.0</td>
</tr>
<tr>
<td>Purity</td>
<td>70.2</td>
<td>59.0 - 91.1</td>
</tr>
<tr>
<td>Sugar Recovery</td>
<td>8.12</td>
<td>5.1 - 11.9</td>
</tr>
<tr>
<td>Sugar Yield</td>
<td>4.63</td>
<td>3.0 – 6.89</td>
</tr>
</tbody>
</table>
Number of Significant Variants

Number of Significant Variations

- Height
- Girth
- No. of... (likely another variable, cut off)
- Internode...
- Tillers per...
- Can Yield
- Brix %
- CCS %
- Purity %
- Recovery %
- Sugar %
- Fiber %
- Sugar Yield

- Increased
- Equal
- Decreased

- No. of internodes
- Interode length
- Brix %
- Sucrose %
- Girth
- Cane Weight (t/ha)
- Cane Yield
- Recovery %
- Sugar Yield
# Pearson Correlation Analysis

<table>
<thead>
<tr>
<th></th>
<th>Height</th>
<th>Girth</th>
<th>Tillers per Plant</th>
<th>No. of Internodes</th>
<th>Internodes Length</th>
<th>Stool Weight</th>
<th>Cane Yield</th>
<th>CCS %</th>
<th>Brix %</th>
<th>Sucrose %</th>
<th>Fiber %</th>
<th>Purity</th>
<th>Sugar Recovery</th>
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<tbody>
<tr>
<td>Girth</td>
<td></td>
<td>0.342**</td>
<td></td>
<td></td>
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<tr>
<td>Tillers per Plant</td>
<td>0.025</td>
<td>0.162</td>
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<tr>
<td>No. of Internodes</td>
<td>0.704**</td>
<td>0.228</td>
<td>0.098</td>
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<tr>
<td>Internodes Length</td>
<td>0.878**</td>
<td>0.279*</td>
<td>0.098</td>
<td>0.487*</td>
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<tr>
<td>Stool Weight</td>
<td>0.287*</td>
<td>0.507**</td>
<td>0.604**</td>
<td>0.292*</td>
<td>0.228</td>
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</tr>
<tr>
<td>Cane Yield</td>
<td>0.287*</td>
<td>0.507**</td>
<td>0.604**</td>
<td>0.292*</td>
<td>0.227</td>
<td>1**</td>
<td></td>
<td></td>
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<tr>
<td>CCS %</td>
<td>-0.243</td>
<td>-0.013</td>
<td>-0.230</td>
<td>-0.188</td>
<td>-0.111</td>
<td>-0.183</td>
<td>-0.183</td>
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<td></td>
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<tr>
<td>Brix %</td>
<td>0.003</td>
<td>0.294*</td>
<td>0.119</td>
<td>-0.065</td>
<td>0.150</td>
<td>0.146</td>
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<tr>
<td>Sucrose %</td>
<td>-0.1823</td>
<td>0.115</td>
<td>-0.066</td>
<td>-0.147</td>
<td>-0.043</td>
<td>-0.048</td>
<td>-0.048</td>
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</tr>
<tr>
<td>Fiber %</td>
<td>0.0451</td>
<td>0.147</td>
<td>0.412**</td>
<td>0.274*</td>
<td>-0.070</td>
<td>0.25</td>
<td>0.250</td>
<td>-0.436**</td>
<td>-0.183</td>
<td>-0.274*</td>
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<tr>
<td>Purity</td>
<td>-0.362**</td>
<td>-0.297*</td>
<td>-0.422**</td>
<td>-0.143</td>
<td>-0.318*</td>
<td>-0.426**</td>
<td>0.757**</td>
<td>0.224</td>
<td>0.588**</td>
<td>-0.292*</td>
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<tr>
<td>Sugar Recovery</td>
<td>-0.212</td>
<td>-0.010</td>
<td>-0.210</td>
<td>-0.135</td>
<td>-0.067</td>
<td>-0.157</td>
<td>-0.157</td>
<td>0.992**</td>
<td>0.788**</td>
<td>0.956**</td>
<td>-0.425**</td>
<td>0.744**</td>
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<tr>
<td>Sugar Yield</td>
<td>0.364**</td>
<td>0.344**</td>
<td>0.347**</td>
<td>0.106</td>
<td>0.075</td>
<td>0.667**</td>
<td>0.667**</td>
<td>0.586**</td>
<td>0.665**</td>
<td>0.657**</td>
<td>-0.096</td>
<td>0.25</td>
<td>0.711**</td>
</tr>
</tbody>
</table>
Cluster Analysis, Ward’s Linkage

Parent grouped with just one somaclone

- Good quality, low quantitative parameters
- Excellent qualitative parameters
- Low parameters
- Low qualitative, average quantitative
- Low parameters, good fiber %
- Good stool weight, and fiber %

Quantitative & qualitative parameters
In vitro Culture Studies in Sugarcane

Callus Culture

Micropropagation

Direct Regeneration
Sugarcane Fields, NIA
Sugarcane Improvement Against Climate Change

- Stress Resistance
- High Cane /Sugar Yield
- Early Sugar Recovery
- Erect Stand
25
The Global Goals 2030, UN Sustainable Development
Conclusions

Climate change effects sugarcane production
Solution lies in stress tolerant genotypes
Tissue culture technology can serve the purpose of getting genetic diversity in sugarcane
Stress tolerant varieties need to be adopted
Thank You!
Presented at Annual Meeting of Pakistan Society of Sugar Technologists, 2016
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