From genes to yield: A cross institution and discipline initiative to improve postrainy sorghum productivity and quality

An ACIAR-funded project

V Vadez, J Kholova, S Deshpande, CT Hash, HS Talwar, R Madhusudhana, M Blummel, A Borrell, E van Oosterom, GL Hammer

ICRISAT – ILRI – IIMR - UQ

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Postrainy sorghum growing area and profile

**Definition:** Post-rainy sorghum

**Target agro-ecology:** Residual moisture - Rainfall <50mm

**Geography:** SW India – 5M ha

**Market:** grain, stover around cities

**Producers:** small-holder farms (0.5-1.0 ha), Staple / cash crop

**Customers:** white seed, large grains,

**Existing variety:** M35-1

**Product development goal:** Replace M35-1 – Yield > 10% M35-1

**Traits:** Yield potential, drought adaptation, shoot fly resistance

**Market traits:** Seed size, colour, stover quantity/quality
Strategy: Targeting the staygreen phenotype

Staygreen improves seed filling (Water available)
Grain quality – Stover quality
Project objectives (Phase 1, 2008-12 – Phase 2, 2013-17)

(i) “Breeding efficiently in a value-chain mindset”
• Breeding staygreen QTLs (proof of concept, introgression in cultivars, markers for QTL region)
• Test introgressions (grain / fodder yield/quality - traits underlying staygreen)
• Ex-ante assessment of potential impact

(ii) “Predicting and expanding the scope”
• Characterize stress scenarios / Analyze trait effects across scenarios / Expand this work to Africa
• Test GxExM packages
• Screen variants for key staygreen underlying traits in diverse germplasm
Staygreen introgression: Proof of concept / Development of cultivars

Trait analysis / screening of germplasm

Environmental characterization and trait modelling

Value chain aspects – Stg effect on stover quality and on grain nutritional quality

Ex-ante analysis
**Introgression Scheme**

**B35 as QTL donor**

**Rabi 14-15:**
- 80 BC1F1s were sown in pots. (C1-80)
- Genotyping of 80 BC1F1s was done with 15 (Stg3a and Stg 3b) markers
- 11 selected plants were back crossed to develop BC2F1s.

**BC2F1 KH15:**
- 59 BC1F2s were advanced to BC1F3s

**Kharif 15:**
- 98 BC2F1 s from backcrossed progenies (C7, C41 and C47) were grown in pots.
- FS: Genotyping completed with 15 Stg3a and Stg3b markers
- 11 plants based on genotyping data selected and back crossed to develop BC3F1s.

**BC1F2 Rabi 15-16:**
- 90 BC3F1s of C41-28 were grown in pots.
- FS: Genotyping completed with 15 Stg3a and Stg3b markers
- 27 BC4F1s were developed in CRS4 ground.
- Background selection of BC3F1 plants (76); 839 markers tested.

**Kharif 16:**
- 25 BC1F3s of C41-28 are grown in pots.
- FS: Genotyping –going on

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**Type (3A & 3B)**

<table>
<thead>
<tr>
<th>Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB</td>
</tr>
<tr>
<td>BA</td>
</tr>
<tr>
<td>A B</td>
</tr>
</tbody>
</table>
Developing more / better markers for key QTLs

A set of 69 SNP markers developed for the introgression of Stg3A and Stg3B

Marker name – SSRs
Marker name – marker within QTL interval of stg3A;
Marker name – marker within QTL interval of stg3B
### Introgression in 6 cultivated backgrounds

<table>
<thead>
<tr>
<th>Recurrent parent</th>
<th>Target QTL</th>
<th>Generation</th>
<th>Families</th>
<th>Population evaluated for marker genotype</th>
<th>Projected individuals selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phule Vasudha</td>
<td>stg3A</td>
<td>BC3F2:F3</td>
<td>16</td>
<td>358</td>
<td>20</td>
</tr>
<tr>
<td>Phule Vasudha</td>
<td>stg3B</td>
<td>BC3F2:F3</td>
<td>12</td>
<td>319</td>
<td>20</td>
</tr>
<tr>
<td>CRS1</td>
<td>stg3A</td>
<td>BC3F2:F3</td>
<td>5</td>
<td>121</td>
<td>10-15</td>
</tr>
<tr>
<td>CRS1</td>
<td>stg3B</td>
<td>BC3F2:F3</td>
<td>8</td>
<td>165</td>
<td>10-15</td>
</tr>
<tr>
<td>M 35-1</td>
<td>stg3A</td>
<td>BC3F2:F3</td>
<td>5</td>
<td>127</td>
<td>10-15</td>
</tr>
<tr>
<td>M 35-1</td>
<td>stg3B</td>
<td>BC3F2:F3</td>
<td>8</td>
<td>207</td>
<td>20</td>
</tr>
<tr>
<td>Parbhani Moti</td>
<td>stg3A+3B</td>
<td>BC2F2</td>
<td>1</td>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td>CRS4</td>
<td>Stg3A/3B</td>
<td>BC3F4 / BC4F3</td>
<td>510/201</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSLG262</td>
<td>Stg3A/3B</td>
<td>BC3F4 / BC4F3</td>
<td>111/192</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Staygreen introgression: Proof of concept / Development of cultivars

Trait analysis / screening of germplasm

Environmental characterization and trait modelling

Value chain aspects – Stg effect on stover quality and on grain nutritional quality

Ex-ante analysis
Transpiration efficiency: Stg Introgressions

Stg QTL effect on TE is background-dependent

Vadez et al., 2011 FPB
Transpiration efficiency: Germplasm

VPD-sensitive lines have high TE

VPD-insensitive lines have low TE
Transpiration response to VPD in Sorghum
1 - Introgression lines in R16

Staygreen ILs (Stg3A – Stg 3B) are VPD-sensitive
Transpiration response to VPD in Sorghum 2 - Introgression lines in S35

No effect of Stg QTL in a different background
Effect of staygreen QTL introgression on the leaf area development

Inflection coefficient used in crop modelling
Trait effect summary in different introgressions

**R16 (senescent line)**

**S35 (senescent line)**
- 7001 - stgB - small leaves, H₂O extraction
- 6008 – stgA – growth dynamics, tillering
- 6040 - stg1 - growth dynamics

Vadez et al. 2011
Phenotype at different level of organization

Phenotyping pipeline

Genetics of Key traits

1000’s

TE - T
Grain yield

100’s

Yield Quality

10’s

Strategic crosses

LeasyScan

Lysimetry

Accelerated selection

Field

genotyping

phenotyping

DO NOT COPY
Preliminary testing of BC4F3’s:
Green leaf area retention (GLAR)

Water stress

Fully irrigated

All QTL lines improved over recipient parents under both WS & WW
More improvement with RSLG 262 than CRS 4 under WS, vice-versa under WW
Most improved lines under WS- CRS 4: C1, C3 & C7, RSLG 262- R5 & R3
Five QTL lines improved in CRS 4, three lines in RSLG 262 under WS
More improvement with CRS 4 (51%) than RSLG 262 (23%) under WS
Most improved lines under WS- CRS 4: C3 & C7 RSLG 262- R5, R1 & R3
Preliminary testing of BC4F3’s: Stover productivity

Water stress

Fully irrigated

Three QTL lines improved in both CRS 4 & RSLG 262 under WS
More improvement with CRS 4 (66%) than RSLG 262 (62%) under WS
Most improved lines under WS- CRS 4: C3 & C7, RSLG 262: R5 & R2
Staygreen introgression: Proof of concept / Development of cultivars

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Ex-ante analysis
Characterizing stress scenarios in a target region

- Different stress scenarios
- Different breeding needs
- A careful choice of testing sites

From Kholova et al 2013
Water stress patterns in Mali for two leading cultivars

Diancoumba, Kholova, Adam, et al.; in prep
Simulating the effect of a smaller leaf Area in S35 introgressions of Stg3A / Stg3B QTL

Trade-off between grain and stover yield

Kholová et al. 2014 (FPB)
Simulating the effects of TR limitation under high VPD in R16 introgressions of Stg3A / Stg3B QTL.

No trade-off in this case.
Staygreen introgression: Proof of concept / Development of cultivars

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Ex-ante analysis
Sorghum stover in India

Stover value: About 60% of grain value
QTL effects on stover quality

Stover in vitro digestibility (%)

\[ y = -4.9 + 0.17x; R^2 = 0.75; P = 0.03 \]

Stover quality gets a price premium

Some stay-green QTLs improve stover quality

(Chandalawada et al., in prep)
QTL effects on stover quality

QTL effect is background-dependent

Staygreen QTL associated stover digestibility across 2 years and 2 treatments

QTL effect is background-dependent
PCA of drought response phenotype and stover quality attributes

Senescence and stover quality (IvoDM) have opposite weighings.
Relationship between stover quality and quantity

Limited trade-off between digestibility & quantity of stover
Sufficient genetic variation at given stover yield
Staygreen introgression: Proof of concept / Development of cultivars

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Ex-ante analysis
Ex-ante Assessment – Phase 1

- questionnaire circulated among the scientists involved in the project
- Based on survey responses of scientists, three scenarios were generated
- Economic surplus model was used

**Conservative scenario**

**Optimistic scenario**

**Likely scenario**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Conservative</th>
<th>Optimistic</th>
<th>Likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in grain yields (Research station)</td>
<td>Percent</td>
<td>2</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>Increase in grain yields (farmer's field)</td>
<td>Percent</td>
<td>1</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Increase in fodder yields (Research station)</td>
<td>Percent</td>
<td>5</td>
<td>30</td>
<td>18</td>
</tr>
<tr>
<td>Increase in fodder yields (farmer's field)</td>
<td>Percent</td>
<td>2</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Increase in fodder digestibility</td>
<td>Percent</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Reduction in yield variability</td>
<td>Percent</td>
<td>10</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Probability of success</td>
<td>Probability</td>
<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>Max level of adoption</td>
<td>Percent</td>
<td>30</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>Revised max levels of adoption</td>
<td>Percent</td>
<td>7</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Adoption lag</td>
<td>Years</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Note: Figures highlighted in blue have been revised to reflect farmers’ field conditions.
## Return to Research Investment

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Conservative</th>
<th>Optimistic</th>
<th>Likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRR (%)</td>
<td>20</td>
<td>56</td>
<td>40</td>
</tr>
<tr>
<td>BC ratio</td>
<td>7</td>
<td>53.8</td>
<td>16.4</td>
</tr>
<tr>
<td>Net Present Value of Net Benefits (Rs. million)</td>
<td>98.4</td>
<td>3,032.1</td>
<td>883.2</td>
</tr>
<tr>
<td>Net Present Value of Net Benefits (AUS$ million)</td>
<td>2.4</td>
<td>60.1</td>
<td>20.1</td>
</tr>
<tr>
<td>Payback period after release</td>
<td>4 years</td>
<td>1 Year 6 months</td>
<td>2 Years</td>
</tr>
</tbody>
</table>

- In the grain markets, the consumers gain more than the grain producers; in the stover markets, the producers gain more than the consumers.
- Conservative estimates for adoption rates and yield increases were used = real net benefits might be higher.
Ex-ante Assessment – Phase 2

Livestock per capita

“GRAIN type” Sorghum bread

“STOVER type” Livestock feed

Vikraman et al., in prep
2. Projected benefits of stay-green technology for rabi sorghum in India

Table 1. Summary Of Results From Ex-ante analysis of Returns to Investment for Staygreen Sorghum Technology, by case, by scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Case</th>
<th>Description of scenario</th>
<th>IRR (%)</th>
<th>NPV ( Million Rs)</th>
<th>BC Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>One case only</td>
<td>Single SG technology (with a Grain: Stover ratio of 1:2) across all regions and population using actual data on area and production</td>
<td>46</td>
<td>1766</td>
<td>31.74</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Case 1</td>
<td>SG1 with a Grain: Stover ratio of 1:2.5 for region with high livestock intensity using actual data on area and production</td>
<td>34</td>
<td>588</td>
<td>11.24</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>SG2 with a Grain: Stover ratio of 1.5:2 for region with low livestock intensity using actual data on area and production</td>
<td>43</td>
<td>1397</td>
<td>25.32</td>
</tr>
</tbody>
</table>

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Key messages...

A breeding product developed by a breeding team

Value chain perspective

Importance of water at critical times

Importance of nutrition value (feed but also food)

Key role of crop simulation to guide breeding/agronomic targets
Thank you

Collaborators:
JF Rami / D Luquet / A Audebert (CIRAD)
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C Messina, M Cooper / A Pandravada (Pioneer)
H Anderberg (Lund Univ.)
F. Chaumont (Univ. Louvain)
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Students:
M Tharanya
S Sakthi
S Medina
M Diancoumba

Technicians / Data analyst:
Srikanth Malayee
Rekha Badham
M Anjaiah
N Pentaiah

Colleagues at ICRISAT:
KK Sharma / T Shah / F Hamidou
HD Upadhyaya / Bhasker Raj