Development of new sorghum ideotypes to meet the increasing demand of bioethanol

S. Braconnier, G. Trouche, S. Gutjahr, D. Luquet, M. Dingkhun
Global oil production is rapidly approaching its peak.

Actual CO₂ atmospheric concentration = 381.2 ppm (WMO source)

Oil is now being consumed four times faster than it is being discovered, and the situation is becoming critical.

It is urgent to find alternative and sustainable energies.

Biofuels or agrofuels, defined as solid, liquid or gas fuels derived from biomass, are today the only direct substitute for oil on a significant scale particularly in the transport sector.
poorest countries will be lead to grow biofuel crops

Less arable surfaces available for food production

Increasing staple food world market prices
(good for producers, bad for urban consumers)

Instability of the staple food market

Increase of food insecurity
Which plant for producing bioethanol?

In the tropics
- Sugar Cane
- Sweet Sorghum
  + almost any staple food crops

In temperate area
- Mayze
  + sugar beet and other promising biomass crops (switchgrass, miscanthus, alfalfa...)
- Sorghum
Why producing ethanol from sorghum?

<table>
<thead>
<tr>
<th>Tropical zone</th>
<th>Temperate zone</th>
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<tbody>
<tr>
<td><strong>VS</strong></td>
<td><strong>VS</strong></td>
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<tr>
<td>Propagation</td>
<td>Intra needs</td>
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<tr>
<td>Cuttings</td>
<td>sorghum</td>
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<tr>
<td>seeds</td>
<td>maize</td>
</tr>
<tr>
<td><strong>Length of cycle</strong></td>
<td><strong>Water requirement</strong></td>
</tr>
<tr>
<td>12-16 months</td>
<td>1/3 less than maize</td>
</tr>
<tr>
<td>4-5 months</td>
<td></td>
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<tr>
<td><strong>Water requirements</strong></td>
<td><strong>Nitrogen Use Efficiency</strong></td>
</tr>
<tr>
<td>36 000 m³</td>
<td>sorghum</td>
</tr>
<tr>
<td>8000 m³</td>
<td>maize</td>
</tr>
<tr>
<td><strong>Adaptation to dry zones</strong></td>
<td><strong>Adaptation to dry environments</strong></td>
</tr>
<tr>
<td>Irrigation</td>
<td>sorghum</td>
</tr>
<tr>
<td>yes</td>
<td>maize</td>
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<tr>
<td><strong>Adaptation to marginal soils</strong></td>
<td><strong>Adaptation to marginal soils</strong></td>
</tr>
<tr>
<td>cane</td>
<td>sorghum</td>
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<tr>
<td>&lt;&lt; sorghum</td>
<td>&gt;&gt; maize</td>
</tr>
<tr>
<td>Grain production</td>
<td><strong>Ethanol production (l ha⁻¹)</strong></td>
</tr>
<tr>
<td>0 &lt;&lt; up to 6T / ha (2 cycles)</td>
<td>6500</td>
</tr>
<tr>
<td>6500</td>
<td>5600 (2 cycles)</td>
</tr>
<tr>
<td><strong>Biomass</strong></td>
<td><strong>Hudge potential of improvement and adaptation</strong></td>
</tr>
<tr>
<td>sorghum ↔ maize</td>
<td>Development of rural zones</td>
</tr>
<tr>
<td>(25 to 40T DM ha⁻¹)</td>
<td>Low competition with food crop</td>
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<td></td>
<td>Better sustainability of the production system</td>
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<tr>
<td><strong>Uses</strong></td>
<td><strong>Uses</strong></td>
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<tr>
<td>Fuel</td>
<td>Food, Feed, Fuel</td>
</tr>
</tbody>
</table>
What is the bottleneck for sorghum development?

Among different reasons, the lack of varieties adapted to the different environments was identified as the main bottleneck.

**Development of a FP7 project: SWEETFUEL**

**Sweet sorghum: an alternative energy crop**

**Overall objective:** development of ethanol production from sweet sorghum in temperate and tropical area through genetic enhancement and improvement of harvest and cultural practices.

**Scientific consortium:** 10 partners from 7 countries and 3 continents
- Cirad, Icrisat, Embrapa, KWS, Ifeu, UniBO, UCSC, ARC-GCI, UANL, WIP

**Target area:** temperate and tropical area (particularly semi arid tropics)

**Duration:** 5 years (01/2009 – 12/2013)

**Budget:** 5 millions € including 3 millions contribution from EC
**Definition of the new sorghum ideotypes**

**Temperate area**
- EtOH 2\textsuperscript{e} generation
- Centralized system

**New sorghum ideotype**
« Biomass » sorghum (sweet or not, with or without grains)

**Essential traits**
- High biomass production with a good quality and homogeneity (low lignin content = \textit{bmr} trait and good digestibility)
- Adaptation to low temperature to enlarge sowing (and thus harvesting) window
- Drought tolerant / high WUE
- Photosensitivity for increasing cycle duration
Develoment of new sorghum ideotypes

Temperate area

106 accessions

Possible combination of + high stalk biomass
+ low lignin content
+ good digestibility of fibres

(Source: Grassbiofuel project / 2009 report)
Development of new sorghum ideotypes

In Brazil

Centralized system
Centralized system
Decentralized system
Decentralized system

In 2nd G

Target ideotype
Triple purpose

Essential traits

Decentralized

Grain yield, juicy, sugar °Brix%, Al toxicity tolerant, P deficiency tolerant, bmr, biomass

Decentralized system
Objective: develop production systems to provide village or cooperative with food and fuel
Development of new sorghum ideotypes

106 accessions

46 lines

\[ y = 0.8502x + 11.472 \]

\[ R^2 = 0.0267 \]

Possible combination

°Brix% + juice
°Brix% + stalks biomass

(source Grassbiofuel 2008)

(source Nataima Colombia 2007)
Development of new sorghum ideotypes

Identification of the gene for tolerance to aluminum toxicity: $A_{ltSB}$

and incorporation in the best lines in EMBRAPA
Development of new sorghum ideotypes

In India

- Centralized system
- Decentralized system

Target ideotype: Triple purpose sorghum

Essential traits

- Grain yield, juicy, sugar, °Brix%, adaptation to rainy and post rainy seasons, stay green, bmr, biomass

Centralized system

Objective:
Production of ethanol through syrup partnership with industrial sector

Decentralized system

Objective:
Develop syrup production systems to provide village or cooperative with additional income
Development of new sorghum ideotypes

There is a competition °Brix% / grain, but also a great diversity

Source: Sweetfuel project / PhD S. Gutjahr
Development of new sorghum ideotypes

Identification of the best lines combining sugar and biomass

1.63 to 2.36 t ha\(^{-1}\)  
8.25 to 72.43 t ha\(^{-1}\)

Identification 2 stay-green QTL lines S 35 SG 06002 and 19-S35 SG 06019 having °Brix% >15
**Development of new sorghum ideotypes**

**Case of Haïti**

**Target ideotype:** triple purpose sorghum: grains + ethanol + fodder

**ANR project**

**S3F for Haïti**

Adapted phenology is essential
Development of a new sorghum model

SAMARA model is a new model for cereals (simulator of morpho-physiological adaptability to abiotic stresses, and of annual graminaeae yield).

Objectives:

• identification of TPE, study the adaptation to CC and CV as well as interaction variety x cultural practice x environment...
• + conception of ideotypes and their adaptation to the environment
• (at plant canopy scale)

Main characteristics:

• based on ECOTROP software
• based on hydric balance and phenology module from SARRAH
• trophic relationships and competitions between organs are inspired by ECOMERISTEM
Development of a new sorghum model

Biomasses

Stem (sheath internode reserves)

Leaf

Panicle

Grain

Root

Reserves

Sowing

Above-ground

Simulation software used: Siemens 2.2 - Modèle Siemens - http://www.cs.lri.fr/
Development of new sorghum model

Sensitivity analysis were done by:

- Modifying varietal parameters (plant height, cycle duration, stay green...)
  - or
  - agronomic practices (irrigation, plant density...)
  - or
  - combining 2 parameters (i.e. height + duration)

- Analyzing evolution of output values (panicule and grain yield, total and above ground biomass, sugar yield, LAI, tillering, plant height etc...)

International Conference on Crop Improvement, Ideotyping and Modeling for African Cropping Systems under Climate Change (CIMAC), 2011/02/07-09, Stuttgart-Hohenheim, Germany
Development of a new sorghum model

Effect of terminal drought

« Wild Type », irrigated
High yielding, dwarf, early, sweet, stay-green (like Kouressy's V3)
Plant Height 2.0 m

Rainfed condition (terminal drought)
Biomass - 19%
Grain yield – 16%
Final sugar reserves – 50%

CIMAC Conference, Hohenheim University - Stuttgart, 7-9 February 2011
Development of a new sorghum model

Effect of lateness (photosensitivity)

« Wild Type »
High yielding, dwarf, early, sweet type
(like Kouressy’s V3)
Plant Height 2.0 m

Cycle 40 d longer due to longer PSP
(PSP longer : photoperiodism)
Plant Height + 40% (2.8m)
Biomass + 34%
Grain yield – 30%
Higher Tiller No., more motality
LAI max+200%
Sugar reserves much smaller

CIMAC Conference, Hohenheim University - Stuttgart, 7-9 February 2011
Development of new sorghum model

Calibration of SAMARA for sorghum is possible in many different environments.

Results from sensitivity analysis are quite conform to the reality on a qualitative basis.

We must now conduct some specific trials to validate this model.
Thank you for your attention

Contact:
serge.braconnier@cirad.fr
www.sweetfuel-project.eu