SWEET SORGHUM – AN ALTERNATIVE ENERGY CROP

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ABSTRACT: The energy crop sweet sorghum (*Sorghum bicolor* L. Moench) is raising considerable interest as a source of either fermentable free sugars or lignocellulosic feedstock with the potential to produce fuel, food, feed and a variety of other products. Sweet sorghum is a C4 plant with many potential advantages, including high water, nitrogen and radiation use efficiency, broad agro-ecological adaptation as well as a rich genetic diversity for useful traits. For developing countries sweet sorghum provides opportunities for the simultaneous production of food and bioenergy (e.g. bio-ethanol), thereby contributing to improved food security as well as increased access to affordable and renewable energy sources. In temperate regions (e.g. in Europe) sweet sorghum is seen as promising crop for the production of raw material for 2nd generation bio-ethanol. The project SWEETFUEL (Sweet Sorghum: An alternative energy crop) is supported by the European Commission in the 7th Framework Programme to exploit the advantages of sweet sorghum as potential energy crop for bio-ethanol production. Thereby, the main objective of SWEETFUEL is to optimize yields in temperate and semi-arid regions by genetic enhancement and the improvement of cultural and harvest practices.

Keywords: sweet sorghum, energy crops, liquid biofuel, bioethanol, developing countries

1 INTRODUCTION

Historically, sweet sorghum has been used for nearly 150 years to produce concentrated syrup as well as forage and silage for animal feed [1]. After a decline of sweet sorghum use, the oil crisis of 1973 and 1976 renewed efforts in the commercial production of sweet sorghum for biological transformation into ethyl alcohol for use as fuel or fuel additive [2].

During the past years sweet sorghum (scientific name: *Sorghum bicolor* L. Moench) has gained considerable interest as a source of either fermentable free sugars or lignocellulosic feedstock with the potential to produce fuel, food, feed and a variety of other products in various combinations thereby reconciling energy and food security issues [3]. Sweet sorghum is considered one of the most efficient crops to convert atmospheric CO_2 into sugar with large advantages compared to sugarcane production in some areas of the tropics, making it a promising crop for bioenergy while meeting food and fodder needs.

Figure 1: *Sorghum bicolor* grains [Source: CIRAD]

Sweet sorghum is a C4 plant with the following interesting characteristics: (i) its growth cycle is short (about four months) facilitating double cropping, (ii) it can be easily grown from seeds, (iii) its production can be completely mechanized, (iv) it produces sugar in the stalk, and starch in the grain, (v) it has a high water and nutrient use efficiency, (vi) the bagasse produced from sweet sorghum has high biological value when used as forage and (vii) it has a wide adaptability to different environments [4, 5, 6].

However, unlike sugarcane and maize, sweet sorghum has little breeding history. The potential of production improvement through genetic enhancement is thus very high.

Originated from Africa (see Figure 2), today sweet sorghum is cultivated in semi-arid to humid climates in several African countries, India, Southeast Asia, the USA and Europe.

Figure 2: Centres of origin of selected crops [7]

The main parts of sweet sorghum (grains, juice, bagasse, leaves) can be used in a variety of applications as summarised in Table 1.

Table 1: Use options of sweet sorghum crop parts, adapted from [8]

Crop part	Use option
Grains	Feed, food, first generation bioethanol
Juice	Sugar, first generation bioethanol
Bagasse	Feed, pulp, bioenergy, fertiliser, second generation bioethanol
Leaves	Feed, bioenergy, fertiliser, second generation bioethanol

2 THE SWEETFUEL PROJECT

2.1 SWEETFUEL objective

The project SWEETFUEL (Sweet Sorghum: An alternative energy crop) is supported by the European Commission in the 7th Framework Programme to exploit the advantages of sweet sorghum as potential energy crop for bioethanol production. Thereby, the main objective of SWEETFUEL is to optimize yields in temperate and semi-arid regions by genetic enhancement and the improvement of cultural and harvest practices.

The duration of the SWEETFUEL project is from January 2009 until December 2013.

More information on the project is available at the website **www.sweetfuel-project.eu**.

2.2 SWEETFUEL activities

In order to achieve abovementioned objective, the SWEETFUEL project will deliver a matrix of multi-disciplinary and cross-sectoral work packages to:

- Breed sweet sorghum ideotypes specially adapted to temperate climates, drought prone environments and poor soils
- Improve knowledge on the relationships among traits for sugar accumulation, plant phenology, stay-green and terminal drought tolerance
- Understand the agronomic determinants of optimized yield and recommend cultural and harvest techniques
- Provide a multi-criteria (social, economic and environmental) sustainability evaluation of resulting commodity chains
- Promote the exchanges between RTD experts, stakeholders and key actors
- Identify and monitor ethical risks resulting from ethanol production from sweet sorghum and to propose guidelines for policy makers

Figure 3 presents a schematic overview of the work packages (WP) along which the activities of the SWEETFUEL project will be implemented. Specifically, 3 work packages will be dedicated to sweet sorghum breeding efforts:

- WP1: Breeding for temperate environments
- WP2: Breeding for drought prone environments
- WP3: Breeding for low-fertility soil environments

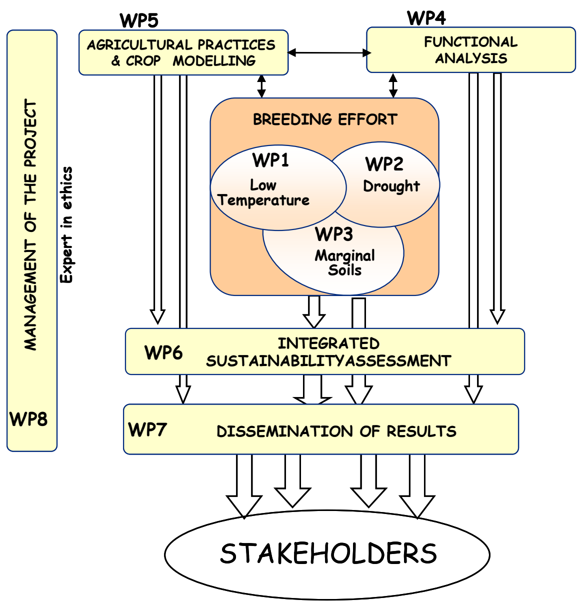

Figure 3: Schematic overview of SWEETFUEL project activities

The specific objectives of SWEETFUEL breeding programmes are to **develop new sorghum lines or hybrids**. Thereby, the target ideotypes depend on the target environment and on the biofuel conversion process.

a) *Target ideotype for* ***temperate climates:*** Sorghum with high biomass, good adaptation to low temperature and good digestibility (low content of lignin, *bmr* trait)**,** suitable for **2nd generation bioethanol** (see chapter 3)

b) *Target ideotype for* ***semi-arid tropics/subtropics:*** Double purpose sorghum (grain + sugars) suitable for humane and/or animal feeding, with a good drought adaptation, juicy stalks with high sugar content and good digestibility**,** suitable for **1st generation bioethanol** (see chapter 4)

c) *Target ideotype for* ***tropical savannas with acid soils:*** Double purpose sorghum (grain + sugars) suitable for humane and/or animal feeding, with a good adaptation to marginal soils (acidity, high Al, low P) and good digestibility**,** suitable for **1st generation bioethanol** (see chapter 5)

2.3 SWEETFUEL partnership

The SWEETFUEL partnership is coordinated by the Centre International en Recherche Agronomique pour le Développement (CIRAD) from France and comprises the following 10 partners from research, academia and industry:

- CIRAD (coordinator) France
- ICRISAT - International Crops Research Institute for Semi-Arid Tropics, India
- EMBRAPA Maize and Sorghum, Brazil
- KWS SAAT AG, Germany
- IFEU Institute, Germany
- Universita di Bologna, Italy
- Universita Cattolica del Sacro Cuore, Italy
- Agricultural Research Council – Grain Crop Institute, South Africa
- Universidad Autónoma de Nuevo León, Mexico
- WIP Renewable Energies, Germany

Figure 4: SWEETFUEL logo

3 BREEDING FOR TEMPERATE CLIMATES

In temperate regions, sweet sorghum has large advantages over maize, the currently prevalent 1st generation bio-ethanol crop, because it can produce digestible substrate both in stalks (soluble sugars and starch) and grain (starch). The residue (bagasse) can be used as high-grade forage or for co-generation [9].

Its low water and nutrient (particularly nitrogen) requirements improve the energy balance of produced bio-ethanol and the amount of GHG savings by reducing N_2O emissions. Sweet sorghum is well adapted as summer crop to southern European environments where it benefits from high radiation and expresses its high water use efficiency (WUE) [10]. Potential for sugar/ethanol yield is fairly high on land marginal for food production [11], but limited by low temperatures in north and central Europe [12].

Breeding activities in the framework of the SWEETFUEL project have the prime objective of adaptation of sweet sorghum to low temperatures.

Specific breeding objectives include an increased biomass yield (enhanced productivity), improved standability, fast seedling development (increase of cold tolerance, fast and homogeneous germination), and increased disease resistance.

In order to benefit from envisaged advantages of 2nd over 1st generation bio-ethanol production technologies, focus will be placed on the entire aboveground biomass of sorghum for 2nd generation bio-ethanol production. Breeding will therefore not only target sweet sorghum genotypes but also, particularly for the cooler environments, high-biomass types.

SWEETFUEL breeding activities for temperate climates are coordinated by KWS SAAT AG (Germany). Partners involved include CIRAD, Universita di Bologna, and the Agricultural Research Council (South Africa). Breeding and varietal testing is performed at locations in Germany, Italy and Southern France. Furthermore, testing will be done in high-altitude, temperate environments in South Africa to evaluate possible adaptation of such technologies to temperate tropics. During the 2009 growing season breeding activities were launched by KWS SAAT AG at testing sites in Germany. Figures 5 to 7 show initial results on the evaluation and selection of germplasm with the aim to improve the cold tolerance of sweet sorghum varieties.

Figure 5: Evaluation of cold tolerance – Bonitur: 2 (Range 1-9) [Source: KWS]

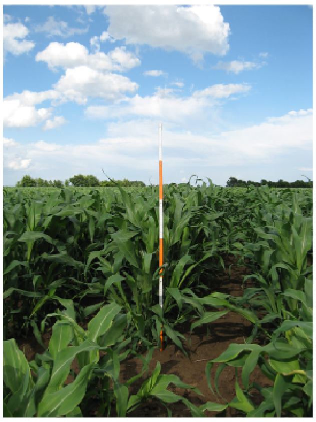

Figure 6: Evaluation of cold tolerance – Bonitur: 4 (Range 1-9) [Source: KWS]

Figure 7: Evaluation of cold tolerance – Bonitur: 6 (Range 1-9) [Source: KWS]

Results of the SWEETFUEL project with respect to breeding of sweet sorghum for temperate climates in the growing seasons 2010-2012 will be made available at the project website.

4 BREEDING FOR SEMI-ARID (SUB)TROPICS

Sorghum breeding for semi-arid tropics or sub-tropics will generally target sweet sorghum types for 1^{st} generation bio-ethanol, as limitations with respect to technological maturity and infrastructure for large-scale biomass transport are currently seen as major obstacles for the introduction of 2^{nd} generation technologies. Furthermore, non-energy uses for biomass residues (cattle feed) and grain (human consumption and poultry) will continue to play an important role in these environments.

In semi-arid environments in West and Southern Africa and South Asia, rainfall and the duration of the rainy season are the main limiting factors. In semi-arid savannahs, cultivation of sugarcane will increasingly become limited by the availability of irrigation water [13]. Sweet sorghum is a suitable crop option as a complementary system to sugar cane since it grows with less water [14].

An important advantage of sweet sorghum cultivation in semi-arid regions, where food security is a major issue, is the possibility to limit fuel/food trade-offs [15]. Sweet sorghum is similar to grain sorghum but in addition, accumulates soluble sugars in the internodes of the stems. There seems to be little physiological competition between grain and sugar production, at least at the low grain yields commonly observed in traditional African sorghum systems [16].

Thus, sweet sorghum based bio-ethanol production shows the potential for decentralized pre-processing (juice pressing, fermentation, low-grade distillation, production of pellets for animal feed) and reducing transport costs of farm-gate products (low-grade bio-ethanol) while creating additional sources of revenue for smallholder farmers.

Breeding activities in the framework of the SWEETFUEL project address dual purpose (energy/food) sorghum crops and aim to fully exploit the duration of the mono-modal rainy season in the target environments.

Additional breeding objectives include the improvement of traits such as stay-green (for maintenance of stem juiciness and for tolerance to terminal drought), increased sugar content, as well as the feed quality of biomass residues.

SWEETFUEL breeding activities for semi-arid tropics or sub-tropics are coordinated by ICRISAT (India). Partners involved include the Universidad Autónoma de Nuevo León (Mexico) and the Agricultural Research Council (South Africa). Breeding and varietal testing is performed at locations in India, Mexico and South Africa.

During the 2009/2010 growing season breeding activities were launched by ICRISAT at testing sites in India. Initial results presented in Figures 8 to 11 address the selection of genotypes with the aim to improve drought tolerance of sweet sorghum varieties with respect to mid-season and terminal stress.

Figure 8: Genotypes with varied drought tolerance (mid-season stress) [Source: ICRISAT]

Figure 9: Productive genotypes under drought (mid-season stress) [Source: ICRISAT]

Figure 10: Susceptive genotypes under terminal stress [Source: ICRISAT]

Figure 11: Tolerant genotypes under terminal stress [Source: ICRISAT]

Results of the SWEETFUEL project with respect to breeding of sweet sorghum for semi-arid tropics or sub-tropics in the growing seasons 2010-2012 will be made available at the project website.

5 BREEDING FOR MOIST TROPICAL SAVANNAHS WITH ACID SOILS

As described in chapter 4, sorghum breeding for moist tropical savannahs will target sweet sorghum types for 1st generation bio-ethanol. In moist savannahs (e.g. in Brazil and the West African Guinea savannah), soil acidity often is the most important abiotic constraint.

In moist savannahs with highly acid and aluminium toxic soils, less emphasis will be given on grain production and phenology, and the focus is placed on acid soil tolerance (using available genes and donor materials), maximal stalk juice and sugar content, stay-green and animal-feed quality of the residual cake.

Previous research in Brazil demonstrated that such plants can be bred comparatively easily and have large economic potential in semi-intensified systems in Brazil. Sweet sorghum can be included in or associated with existing sugar cane based systems [5, 14]. Genetic donor materials will be different from that for semi-arid environments and mainly based on improved, short to medium tall *Sorghum bicolor* germplasm.

SWEETFUEL breeding activities for moist savannahs with highly acid and aluminium toxic soils are coordinated by EMBRAPA (Brazil). Partners involved include CIRAD and the Agricultural Research Council (South Africa). Breeding and varietal testing is performed at locations in Brazil and South Africa.

During the 2009/2010 growing season breeding activities launched by EMBRAPA at testing sites in Brazil address the evaluation of sweet sorghum varieties with respect to improved aluminium tolerance (see Figure 12) and to increased lignocellulose yield (Figure 13).

Figure 12: Identification of Al-tolerant sweet sorghum genotypes [Source: EMBRAPA]

Figure 13: Breeding of lignocellulose sorghum hybrids [Source: EMBRAPA]

Results of the SWEETFUEL project with respect to breeding of sweet sorghum for moist savannahs with highly acid and aluminium toxic soils in the growing seasons 2010-2012 will be made available at the project website.

6 SOCIAL IMPACTS OF SWEET SORGHUM

Today, it is commonly agreed upon that the production of biofuels such as bio-ethanol can potentially generate additional income for rural communities and thus contribute to development in a variety of developing countries [17]. However, current systems for the production of ethanol from starch and sugar crops can also cause negative environmental and social impacts, such as food shortages and food price increases, deforestation, biodiversity loss, soil erosion, and conflicts over the use of water and land.

The implementation of large-scale bio-ethanol production schemes poses the threat of displacement and marginalisation of local communities and smallholders. Issues of poor working conditions with health and safety risks, forced and child labour mainly concern large-scale projects, especially in developing countries. Further concerns exist about the insecurity of land ownership and tenure rights for rural and indigenous communities. Furthermore, the production of bio-ethanol based on traditional food crops may lead to increases of agricultural commodity prices which negatively affect access to food, particularly in net food importing, developing countries and for the poorest therein. Significant price increases have already occurred in major bio-ethanol feedstock markets such as corn and sugar.

According to FAO, food security is influenced by four main aspects: availability, access, stability and utilisation [18]. Thereby, food availability can be threatened by bio-ethanol production through competition with food production over land, water and other productive resources. This resource competition concerns present sugar and starch feedstock and will be reduced for 2nd generation technologies based on lignocellulosic biomass. Access to food (the ability of households to buy food) is affected if food prices rise faster than real incomes, leading to food insecurity.

In comparison with current sugar and starch crops for bio-ethanol production, sweet sorghum offers important benefits with respect to food security. In **temperate climates** sweet sorghum has great advantages over maize due to its low water and nutrient (e.g. nitrogen) requirements. Furthermore, high yields of sweet sorghum on marginal lands unsuitable for food production and high-biomass types of sweet sorghum serving as feedstock for future 2nd generation biofuel technologies will reduce potential competition for land in temperate climates.

In **water-limited tropical and subtropical environments** (typically 600-1000 mm rainfall/a), sweet sorghum can serve as multiple purpose crop for food, energy and high-value feed production and contribute significantly to enhancing food supply and improving food security, especially in rural areas of developing countries prone to food insecurity. In addition to the grain used for human or animal consumption, sweet sorghum accumulates sugars with little competition between grain and sugar production. A major problem in such innovative systems will be transport costs of biomass to processing facilities, as well as the perishable nature of the fresh biomass. This problem may be solved by decentralised, local pre-processing using low cost equipment, permitting village level juice extraction and low-grade distillation, resulting in low-grade alcohol which can be stored and transported inexpensively to industrial facilities that perform the fuel-grade processing. Such systems also contribute to revenue generation in rural areas, through decentralized production and commercialization of pre-processed bio-fuel feedstock, grain and high-value fodder production from pressing residues (cake).

For the use of sweet sorghum varieties on **acid soils in tropical, moist savannahs** (typically, 800-1600 mm/a), emphasis will be placed on crop genetic tolerance to acid soils and aluminium toxicity. These soils, abundant in sub-saharan Africa (SSA), are of limited suitability for intensified food production unless subject to major investments, as described for the Brazilian Cerrados. Acid-soil tolerance genes are expected to dramatically enhance productivity of sweet sorghum on tropical acid soils, and will reduce the need for expensive lime and P inputs.

In order to contribute to improved food security and to avoid potential negative social impacts in developing countries, the SWEETFUEL project will employ participatory approaches for the development of improved sweet sorghum varieties and maintain a close dialogue with stakeholders during the full duration of the project. Thereby, it will be guaranteed that social risks associated with bio-ethanol production in common production systems, such as poor working conditions with health and safety risks as well as insecurity of land ownership and tenure rights, are minimised.

On the contrary, this project has the potential to significantly enhance social welfare, especially in rural areas of developing countries, through the development of integrated technology packages for sweet sorghum cultivation leading to increased revenue generation as well as enhanced food supply. Finally, sweet sorghum can be associated with existing agricultural (e.g. sugar cane) systems, thereby increasing (energy, food and feed) productivity and leading to a re-vitalisation of agricultural production which is currently suffering from low investment and low productivity, especially in rural areas of developing countries [17].

7 SWEETFUEL ASSOCIATE PARTNERSHIP

In the framework of the SWEETFUEL project an associate partnership has been established to provide opportunities for cooperation and knowledge exchange with international stakeholders.

SWEETFUEL Associate Partners will be regularly informed about events, activities, and results of the SWEETFUEL project. Associate Partners are invited to make use of the dissemination platforms established in the framework of the project. Associate Partners are requested to notify the project coordinator about the use of information and documents gained through the SWEETFUEL project.

Interested stakeholders are invited to join the SWEETFUEL partnership by signing an application form available at the website www.sweetfuel-project.eu.

8 ACKNOWLEDGMENT

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