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Characterization of Improved Sweet Sorghum Cultivars

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Editors
P. Srinivasa Rao
Sorghum Breeding—ICRISAT
Patancheru, Andhra Pradesh
India

C. Ganesh Kumar
Chemical Biology Laboratory
CSIR-Indian Institute of Chemical Technology
Hyderabad, Andhra Pradesh
India

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Preface

Food and energy security are the most critical subjects for the sustenance of modern civilization. In view of the depleting oil resources and negative environmental impacts associated with the use of fossil fuels, there is a renewed interest in renewable biofuels, which can form the swivel for sustainable development in terms of socio-economic and environmental considerations. As it is a locally available resource, and there is a possible utilization at the local level, the developing nations are set to gain. Biofuel production and consumption in many developing countries like India, Philippines, Indonesia, Argentina, Nigeria, and Mozambique is at the nascent stage and are evolving. For example, India approved the National Policy on Biofuels on December 24, 2009, which envisaged the use of renewable energy resources as an alternate fuel to supplement transport fuels and proposed an indicative target of 20 % blending of biofuels by 2017. The bioethanol blending programme followed in India has two major bottlenecks; first, there is lack of sufficient ethanol for blending, and second, the purchase price of ethanol is low. It is anticipated that sooner these two issues will be addressed. The biofuel policy also identified sweet sorghum as a unique biofuel feedstock due to its potential to supply food, feed, and fodder simultaneously.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has a BioPower initiative that aims to empower the dryland poor to benefit from, rather than be marginalized by, the biofuels revolution. The Institute has developed diverse and improved sweet sorghum varieties, female hybrid parents, and hybrids that can be used as feedstock sources for bioethanol production. The fodder quality is good and nutritious for livestock. The Indian National Agricultural Research System (NARS) started working on sweet sorghum to produce sugar in mid-1980s to augment sugar production. However, this effort could not succeed due to crystallization problems with sweet sorghum juice. Since then many varieties like SSV 74, SSV 84, and RSSV 9 and also a hybrid, CSH 22SS were released to explore for bioethanol production as well as for fodder use.

This book on the characterization of tropical sweet sorghum chronicles sweet sorghum history, comparative performance with other competing feedstocks, breeding efforts, morpho-biochemical traits of rainy and post-rainy season adapted cultivars (supported by colored photographs for easy identification) besides the status of commercialization which is described in five distinct chapters.

Written by highly experienced scientists from ICRISAT and CSIR-Indian Institute of Chemical Technology (CSIR-IICT), this lucid and comprehensive publication is a valuable source of information on the genesis and progress of sweet sorghum research and morpho-biochemical traits of tropical sweet sorghums. It will serve as an important source of reference to researchers, students, entrepreneurs, policymakers, and other stakeholders in India and in many developing countries as well.

P. Srinivasa Rao
C. Ganesh Kumar

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About the Book

A number of driving forces, including the soaring global crude oil prices and environmental concerns in both developed and developing nations has triggered a renewed interest in the recent years on the R&D of biofuel crops. In this regard, many countries across the globe are investing heavily in the bioenergy sector for R&D to increase their energy security and reduce their dependence on imported fossil fuels. Currently, most of the biofuel requirement is met by sugarcane in Brazil and corn in the United States, while biodiesel from rapeseed oil in Europe. Sweet sorghum has been identified as a unique biofuel feedstock in India since it is well adapted to Indian agro-climatic conditions and more importantly it does not jeopardize food security at the cost of fuel.

Sweet sorghum [*Sorghum bicolor* (L.) Moench] is considered as a SMART new generation energy crop as it can accumulate sugars in its stalks similar to sugarcane, but without food-fuel trade-offs and can be cultivated in almost all temperate and tropical climatic conditions and has many other advantages. The grain can be harvested from the panicles at maturity. There is no single publication detailing the agronomic and biochemical traits of tropical sweet sorghum cultivars and hybrid parents. Hence, an attempt is made in this publication—"Characterization of improved sweet sorghum cultivars" to detail the complete description of cultivars. This book serves as a ready reference on the detailed characterization of different improved sweet sorghum genotypes following the PPVFRA guidelines for the researchers, entrepreneurs, farmers, and other stakeholders to identify the available sweet sorghum cultivars and understand their yield potential in tropics.

Sweet Sorghum: From Theory to Practice

P. Srinivasa Rao, C. Ganesh Kumar and Belum V. S. Reddy

Abstract Sweet sorghum [*Sorghum bicolor* (L.) Moench] is a multipurpose crop (food, feed, fodder and fuel) that has the potential as an alternative biofuel feedstock without impacting food and fodder security. This chapter entitled "Sweet sorghum: From theory to practice" discusses on the historical developments in sweet sorghum and immense range of genetic variability that was available in major sorghum regions of the world. The candidate feedstock characteristic traits of sweet sorghum *vis-a-vis* other major biofuel feedstocks like sugarcane, corn and sugar beet were compared. Sweet sorghum fares well in many aspects as it is a C_4 species with greater resilience to diverse agro-ecologies, low fertilizer and water requirement besides short lifecycle. Hence, many consider it as climate change ready crop; some consider it as miracle crop and few term it as a smart crop. A quantitative insight into the production-ecological sustainability of sweet sorghum biofuel feedstock production systems has been discussed. The ongoing R&D efforts at ICRISAT as well as in National Agricultural Research System (NARS) on sweet sorghum value chain were highlighted. The breeding efforts in Brazil, USA and China on this crop are briefly narrated.

Keywords Sweet sorghum · Biofuels · Semi-arid tropics · C_4 plant · Jowar · Agronomy · Taxonomy, food—fuel trade off

P. Srinivasa Rao (✉) · B. V. S. Reddy
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT),
Patancheru 502324, India
e-mail: psrao72@gmail.com

C. Ganesh Kumar
Chemical Biology Laboratory, CSIR-Indian Institute of Chemical Technology (CSIR-IICT),
Uppal Road, Hyderabad 500607, India

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1 Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a C_4 herbaceous annual grass that is cultivated from the seed, and is known by various names like great millet and guinea corn in West Africa, kafir corn in South Africa, durra in Sudan, mtama in Eastern Africa, jowar in India, kaoliang in China and milo or milo-maize in the United States (Purseglove 1972). It has wide flat leaves and a round or elliptical panicle with full of grain at maturity. The plant accumulates high concentrations of soluble sugars (10–15 %) in the plant stalk sap or juice. It is a crop of high universal value since it can be cultivated in tropical, subtropical, temperate, and semi-arid regions as well as in poor quality soils of the world. It is termed as "the sugarcane of the desert" or "the camel among crops" due to its drought hardy characteristics (Sanderson et al. 1992).

The name "sweet sorghum" is used to identify those varieties of sorghum, *Sorghum bicolor* (L.) Moench, which has juicy and sweet stalks. Sweet sorghum is mainly cultivated for syrup production or forage, whereas other sorghum varieties such as kafirs and milos are cultivated for grain. Other sorghum-types include the broomcorn-type sorghum (*Sorghum dochna* var. *technicum* (Koern.) Snowden), whose head/panicle is used for making brooms and brushes; while johnsongrass, *Sorghum halepense* (L.) Pers. and sudangrass, *Sorghum sudanense* (Piper) Stapf. are grown primarily for forage purpose.

2 History

Sorghum is a grass of Old World origin and *Sorghum vulgare* Pers. is a native wild plant of Africa that is drought-resistant and heat-tolerant member of the grass family and many of the varieties under cultivation in the recent history have originated from that continent. Documented evidence indicated that sorghum was grown in Assyria as early as 700 BC (Ziggers 2006). Wide varieties in the genus *Sorghum* were observed in the North Eastern regions of Africa comprising of Ethiopia and Sudan in Eastern Africa (Doggett 1988). Around 200 AD or even earlier, sorghum made its way into Eastern Africa from Ethiopia via the local tribes, who cultivated this crop mainly for grain and the sweet cane was chewed for pleasure and nutrition. Later, the Bantu tribe carried this crop with them to the Savannah regions of Western and Southern Africa who used the grain mainly for making beer. The Bantu tribe later moved this crop during their expansion from Southern Cameroon region around first century AD, and the southern border of the Congo forest belt. The present-day sorghums of Central and Southern Africa bear close relationship with those of the Tanzania and are more distantly related to those of West African varieties, since the equatorial forests were an effective barrier to their spread (FAO 1995).

During the first millennium BC, sorghum was probably carried to India from Eastern Africa in ships as food by the chow traffic which operated for about

3000 years between East Africa (the Azanean Coast) and India via the Sebaean Lane in Southern Arabia. The sorghum varieties of India bear relationship to those existing in Northeastern Africa and the coast between Cape Guardafui and Mozambique. This crop might have spread along the coast of Southeast Asia and around China around the beginning of Christian era; however, a possibility that cannot be denied is that sorghum might have arrived much earlier in China by the silk trade routes (FAO 1995). Later it made its way to Western parts of the World via Asia. This plant was mentioned in European botanical literature in 1542 and was referred to as Sorghi, the name similar to that used in India.

Sorghum was introduced in the Caribbean Islands and other Latin American countries from West Africa through the slave trade and by navigators plying the Europe-Africa-Latin America trade route in the early 17th century as another source for sugar production. The case is similar for Australia. These early varieties were established as "guinea corn" (also called as Rural Branching Durra). However, the guinea corn in course of time disappeared from production. The tropical adapted varieties were introduced via slave trader ships as broomcorn variety by Benjamin Franklin in the United States in 1725, while Johnson grass was introduced as forage grass variety in South Carolina in 1830. These varieties were cultivated extensively in the US after 1850s, when sweet sorghum was introduced in 1853 by William Prince, a New York nurseryman who received some seed from France via China and cultivated the sorghum crop in New York. He claimed that sweet sorghum was a potential new sugar crop and sold the seed to farmers around Northern America for mass cultivation. In a parallel effort, J.D. Browne, a United States patent agent, traveled to France and noticed French efforts on sweet sorghum cultivation for sugar production from the sweet canes, which grew in places having similar climatic conditions favoring corn cultivation. Based on these observations, Browne collected seed from France and sent them back to the US Patent office and advised that this crop can act as a new sugar source and could be cultivated in America's Corn Belt like American North and Midwest regions.

The sweet sorghum varieties introduced by William Prince and J.D. Browne were termed as "Black amber" or "Chinese sugarcane" since they arrived in America though France via China. The Chinese sugar cane variety was also known as Eusorghum. Since then many sweet and forage varieties were introduced in the US from China, Africa and Australia and were domesticated (Vinall et al. 1936; Ziggers 2006). Subsequently, sorghum production was established in the United States to a larger extent with the introduction of grain sorghum variety in California in 1874 and the milo variety's introduction by the Colombian missionary H.B. Pratt in 1879. In the early 1900s, grain sorghum was identified as a drought-tolerant crop and its production surpassed corn in the arid regions of the Southern Great Plains. Scientists from various agricultural experiment stations and USDA scientists from Texas, Oklahoma and Kansas recorded the sorghum's drought tolerance and with the help of seed production farmers selected improved phenotypes. Many local land laces of sweet stalked sorghum found in Western and Central Africa (Mali, Niger and Tanzania) are used for staple purpose.

3 Sweet Sorghum and its Utilization

Characteristics: The term sweet sorghum is used to distinguish varieties of sorghum with high concentrations of soluble sugars in the plant stalk sap or juice compared to grain sorghum which has relatively less sugar and juice in the stalks. Sweet sorghum is a C_4 plant species having wide flat leaves and a round or elliptical head with full of grain at the stage of maturity. It is, like grain sorghum, traditionally under cultivation for nearly 3000 years. It can be grown successfully in semi-arid tropics, where other crops fail to thrive and are highly suitable for cultivation in harsh dryland growing areas. With irrigation, it can produce very high yields. During very dry periods, sweet sorghum can go into dormancy, with growth resuming when sufficient moisture levels return (Gnansounou et al. 2005). It can be grown easily on all continents, in tropical, sub-tropical, temperate, semi-arid regions as well as in poor quality soils. It is known as the sugarcane of the desert and also "the camel among crops" for its drought hardy characteristics (Sanderson et al. 1992). It has higher drought tolerance and water use efficiency (WUE) compared to maize, and yields, like those of *Miscanthus*, ranging from 18 to 36 dry t ha^{-1} of biomass per year on low-quality soils with minimal inputs of fertilizer and water. In Indiana, studies showed that sweet sorghum cultivars produced 25–40 tons of dry mass per hectare with 0–60 kg ha^{-1} of nitrogen fertilizer. The high WUE and low N requirements of sorghum also provide significant advantages to the growers, because sorghum fits into a normal rotation scheme with corn and soybeans, yet has lower production costs and employs similar production equipment. Its ratooning ability enables multiple harvests per season, a feature that could expand the geographical range of sorghum cultivation. The grain, stalk juice and bagasse (the fibrous residue that remains after juice extraction) can be used to produce food, fodder, ethanol and power. Owing to these favorable attributes, William D Dar, refers to it as a **SMART** crop (Fig. 1). It's candidate traits *vis-a-vis* utilizable options are listed in Table 1.

These important characteristics, along with its suitability for seed propagation, mechanized crop production, and comparable ethanol production capacity *vis-a-vis* sugarcane and sugarbeet makes sweet sorghum a viable alternative source for ethanol production (Table 2).

The sweet sorghum value chain basically involves four critical areas i.e. feed stock supply, sugars conversion, bioenergy (ethanol blended gasoline) distribution and use (Fig. 2). In a feedstock like sweet sorghum, whole plant, its products and byproducts are used for diverse purposes.

4 Sorghum Distribution and Climatic Conditions

Sorghum (*Sorghum bicolor* (L) Moench) is the fifth important cereal crop in the world in production and fifth in acreage after wheat, rice, maize and barley. It is mostly grown in the semi-arid tropics (SAT) of the world wherein the production

Fig. 1 An ICRISAT improved sweet sorghum variety, ICSV 25274

system is constrained by poor soils, low and erratic rainfall and low inputs resulting in low productivity. In terms of area, India (7.5 m ha) is the largest sorghum grower in the world followed by Nigeria (7.6 m ha) and Sudan (6.6 m ha). India is the third largest producer after USA and Nigeria. Sorghum is well adapted to the SAT and is one of the most efficient dryland crops to convert atmospheric CO_2 into sugar (Srinivasa Rao et al. 2009). The crop can be grown in a wide range of climatic conditions as given below.

Latitude: Sorghum is grown between 45°N and 45°S latitude on either side of the equator.

Altitude: Sorghum can be found at elevations between mean sea level and 1,500 m. Most East African sorghum is grown between the altitudes of 900–1,500 m, and cold-tolerant varieties are grown between 1,600 and 2,500 m in Mexico.

Temperature: Sweet sorghum can be grown in the temperature range of 12–37 °C and optimum temperature for growth and photosynthesis is 32–34 °C, day length is 10–14 h, optimum rainfall ranges from 550 to 800 mm and relative humidity ranges between 15 to 50 %.

Soils: Alfisols (red) or vertisols (black clay loamy) with pH ranging between 6.5 to 7.5, organic matter >0.6 %, depth >80 cm, bulk density <1.4 gcc, water holding capacity >50 % field capacity, N $\geq$ 260 kg ha^{-1} (available), P $\geq$ 12 kg ha^{-1} (available), K $\geq$ 120 kg ha^{-1} (available).

Water: Sorghum will survive with a supply of less than 300 mm over the season of 100 days, while it responds favorably with additional rainfall or

Table 1 Candidate traits of sweet sorghum as biofuel feedstock (Reddy et al. 2005; Srinivasa rao et al. 2009, 2010)

As crop	As ethanol source	As bagasse	As raw material for industrial products
Short duration (3–4 months)	Amenable to eco-friendly processing	High biological value	Cost-effective source of pulp for paper making
C_4 dryland crop Good tolerance of biotic and abiotic constraints	Less sulphur in ethanol High octane rating	Rich in micronutrients Use as feed, for power co-generation or bio-compost	Dry ice, acetic acid, fusel oil and methane can be produced from the co-products of fermentation
Meets fodder and food needs Non-invasive species Low soil N_2O and CO_2 emission Seed propagated	Automobile friendly (up to 25 % of ethanol-petrol mixture without engine modification)	Good for silage making	Butanol, lactic acid, acetic acid and beverages can be manufactured

irrigation water. Typically, sweet sorghum needs between 500 to 1000 mm of water (rain and/or irrigation) to achieve good yields, i.e., 50–100 t ha^{-1} total above ground biomass (fresh weight). Though sorghum is a dryland crop, sufficient moisture availability for plant growth is critically important for high yields. The major advantage of sorghum is that it can become dormant especially in vegetative phase under adverse conditions and can resume growth after relatively severe drought. Early drought stops growth before panicle initiation and the plant remains vegetative; it will resume leaf production and flower when conditions again become favorable for growth. Mid-season drought stops leaf development. Sorghum is susceptible to sustained flooding, but will survive temporary water logging much better than maize.

Radiation: Being a C_4-plant, sweet sorghum has high radiation use efficiency (RUE, about 1.3–1.7 g M J^{-1}). It has been shown that taller sorghum types possess higher RUE, because of a better light penetration in the leaf canopy.

Photoperiodism: Most hybrids of sweet sorghum are relatively less photoperiod-sensitive. Traditional farmers, particularly in West Africa, use photoperiod-sensitive varieties. With photoperiod-sensitive types, flowering and grain maturity occur almost during the same calendar days regardless of planting date, so that even with delayed sowing, plants mature before soil moisture is depleted at the end of the season.

5 Taxonomy

The name *Sorghum bicolor* (L.) Moench was proposed by Clayton in 1961 as the correct name for the cultivated sorghum which is currently in use (Spangler 2003). The genus *Sorghum* is a variable complex genus belonging to the tribe