Exploring the Gold Mine of Genetic Resources to Improve Abiotic Stress Tolerance in Sugarcane

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ARTICLE ID: 28

Introduction

Sugarcane is the second most important industrial crop in India after cotton. It is the major source of sugar, alsoused for the production of ethanol, electricity and fiber products (paper, cardboard and fiberboard). Sugarcane is a member of the Andropogoneae tribe in the grass family Poaceae. The subtribe Saccharine includes the genus *Saccharum*and related genera such as *Erianthus*and *Miscanthus*. Genus *Saccharum*includes six species three cultivated species *viz*., *Saccharumofficinarum*, *S. barberi* and *S. sinense* and three wild species *viz*., *S. robustum*,*S. spontaneum* and *S. edule*. These six species along with the related genera *Erianthus*, *Miscanthus*, *Narenga* and *Sclerostachya* form the basic genetic resources of sugarcane. They form a closely related interbreeding group involved in the evolution of the cultivated sugarcane referred to as the 'Saccharum Complex'.

Wild relatives are an important component of plant breeding programs as they are the sources of valuable genes for high productivity and adaptability. In the case of sugarcane, wide hybridization is one of the important crop improvement strategies. The first interspecific hybrid variety of sugarcane, Co 205 was derived from the cross between the *S. officinarum*clone Vellai and *S. spontaneum*clone Coimbatore local which led to the stabilization of sugarcane agriculture worldwide. Modern sugarcane cultivars are complex aneupolyploids derived from the crosses involving *S. officinarum*, *S. spontaneum*, *S. barberi*, *S. sinense* and *S. robustum*.

The sugarcane genetic resources are conserved in two world repositories; one in India at the ICAR-Sugarcane Breeding Institute Regional Centre (SBIRC), Kannur, Kerala and the other in the USA at the World Collection of Sugarcane and Related Grasses (WCSRG), Miami, Florida. The ICAR-SBIRC repository is the world's largest *in situ* germplasm collection, with 3377 accessions of different *Saccharum* sp., allied genera and man-made historical and commercial hybrids. Yet another collection consisting of 1709 *S. spontaneum*, 406 *Erianthus* sp. and 63 allied genera collected across India, and exotic clones from different parts of the world are conserved in the field gene bank of ICAR-SBI, Coimbatore. Few *S. spontaneum* clones collected from Arunachal Pradesh, *Erianthus*sp. and *Mischanthus* sp. clones collected from Meghalaya are maintained at ICAR-Indian Agricultural Research Institute (IARI) Regional Station, Wellington, Tamil Nadu. Apart from this, an active germplasm collection comprising 230 *S. officinarum* is maintained at ICAR-SBI Research Centre, Agali, Kerala for the utilization in National Distant Hybridization Facility. Wild germplasm sources impart genes for high biomass producing ability, resistance to pests and diseases and adaptability for growth under different stress conditions in the modern cultivars. Despite the availability of large germplasm collections, the extensive use of wild resources are restricted due to the lack of elaborate diversity studies and trait specific characterization. A brief description of the different species and related genera is detailed below.

S. officinarum(Noble canes; 2n = 80)

Noble canes are the cultivated species and form the secondary gene pool of modern sugarcane cultivars. The characteristics of this species are thick juicy stalks with low fibre content, broad leaves, shy tilleringwith moderately tall stature. The stalks are variously coloured like red, pink, purple, greenor yellow, being either striped or marked. They grow well under favourable conditions and are susceptible to many diseases. This species originated in New Guinea and spread throughout the tropics and subtropics. The noble canes were the source of sugar for centuries but now have been replaced by improved hybrid varieties. Currently, some clones are cultivated only for chewing purpose. This species is the major contributor (~75-80%) to the genome of modern sugarcane hybrids, as the main source of sugar genes in breeding programs.

S. barberi(North Indian canes; 2n = 111 to 120)

The species was grown in Northern India and were indigenous subtropical forms. The clones are characterized by profuse tillering, intermediate thick stalks with low sucrose and high fibre content and narrow tomedium leaves. They are hardy with tolerance to unfavourable environmental conditions and resistance to pests and diseases. Barber classified the canes into four groups *viz.*,Mungo, Saretha, Sunnabile and Nargoribased on

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morphological traits. The clones in Saretha group have been used in breeding programs in Barbados, Java and India.

S. sinense(Chinese canes; 2n = 81to 124)

This species is under Pansahi group according to Barber's classification. The clones are vigorous and widely adaptable with narrow leaves. The stalks are thin with high fibre content and poor juicequality. The best-known clone of this species 'Uba' was in cultivation for many years on a worldwide scale but none is in cultivation presently. Resistant to some diseases but susceptible to red rot, rust and streak diseases.

S. robustum(2n = 60, 80)

The clones of this species are vigorous and luxuriant. High tillering, tall medium thick stalks with high fibre content and low juicequality. This species is considered as the progenitor of the cultivated canes *S. officinarum*.

S. spontaneum(2n = 40to 128)

It is an extremely variable and widely distributed species. The clones are adaptable to drought, cold, disease or other poor growing conditions. Vigorous growth habit with profuse tillering, thin fibrous stalks with low sucrose content and rhizomatous. They vary enormously in appearance, some are short, bushy plants growing in clumps; others are very tall and spreading. *S. spontaneum*contributed the genes for vigour, ratooning ability, resistance to pests and diseases and adaptability for growth under different stress conditions in modern sugarcane varieties.

S. edule(2n = 60to 80)

Grown for edible inflorescence in New Guinea to Fiji. The inflorescence is sterile, aborted and edible. Morphologically similar to *S. robustum*except that the inflorescence is compact.

Genus *Miscanthus*(2n = 38to 114)

This genus includes small, wiry-leaved plants with little stalks to large reeds. It is found on the sides of hills and the banks of sloping watercourses in its natural habitat. *Miscanthus*has been revised into four sections: *Trierrhena, Eumiscanthus, Kariyasua* and *Diandra*. Section *Diandra*is endemic to north India, Nepal, and southwest China and quite different from others with chromosome number n= 20 and two stamens. The four species in

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*Diandra*include *M. nepalensis*, *M. nudipes*, *M. brevipilus*and *M. szechuanensis*. The tenacious nature of rachis and paired pedicellatespikelets are the differentiating traits of *Miscanthus*from *Saccharum* and *Erianthus*. It is distinguished from *Sclerostachya*by having awned fourth glume and longer callus hairs.

Genus *Erianthus*

This genus has the highest number of species in *Saccharum*complex. The stem formation is poor and the nodes and internodes are not prominent except in *E. arundinaceus.* The most distinctive trait is the absence of an auricle. The root zone has only one row of root eyes. The important species are listed below.

- ***E. ravennae*** (2n = 20): characterized by erect dark green leaves, spiny leaf sheath, brownish panicle and a distinct awn on the fourth glume, which is exerted.
- ***E. elephantinus*** (2n = 20): characterised by light green broader leaves and glabrous leaf sheath. It has a limited distribution, only occurring insubmontane areas (terai) of Assam and Nepal.
- ***E. hostii*** (2n = 20): distinguished by creeping rhizomes and very short callus hairs.
- ***E. bengalense***(2n = 20, 30, 40, 60): has very small, virtually non-existent vegetative stalks that elongate on flowering. Commonly called 'Munja grass' in North India. More adaptable and is often found under sub-optimalmoisture conditions.
- ***E. procerus*** (2n = 40):it resembles *E. arundinaceus*and *E. kanashiroi*, but lacks a vegetative cane and has large droopy silky panicles.
- ***E. arundinaceus*** (2n = 30, 40, 60):is closely related to *E. procerus*, but with a vegetative cane and broad leaves. The inflorescence is a much looser panicle with longer rachis joints and pedicels.
- ***E. kanashiroi*** (2n = 60): is a genuine *Erianthus* species closely related to *E. arundinaceus* and *E. procerus*.

The genus *Sclerostachya*(2n=30)

Characterized by hollow stalks, no root eyes, poorly developed buds, glabrous sheath and leaves and copper brown panicle. In *Sclerostachya*,both spikelets of apair have pedicels, while in *Saccharum*and *Erianthus* one spikelet is pedicellate and the other sessile. Three species are recognized: *Sclerostachyafusca*, *Sclerostachyamilroyi* and *Sclerostachyaridleyi*.

The genus *Narenga*(2n=30)

*Narenga*is a small genus closely related to *Sclerostachya* but differentiated by the presence of nearly sessile spikelet in the pair, bearded nodes, pubescent sheath and leaf, and a deep yellow to deep copper coloured inflorescence. There are two species: *Narengafallax* and *Narengaporphyrocoma*, which are readily distinguished by their spikelet length, 4.0 to 5.0 mm and 2.5 to 3.0 mm, respectively.

Abiotic stress is defined as the negative effect of non-living factors on living organisms in a particular environment. It may act independently or in multiples and cause adverse effects across the sectors of agriculture. Abiotic stress such as drought, salinity, heat, cold, oxidative stress and heavy metal toxicity are the common adverse environmental conditions that affect and limit crop productivity worldwide. India being a tropical country is more challenged by a multitude of abiotic stresses. Sugarcane being an annual crop is more vulnerable to abiotic stresses. Recently, floods and droughts have become increasingly common in many regions in India and it may lead to reduced productivity of crops. Drought is the major abiotic stress in sugarcane affecting plant vigour, yield, millable quality and sucrose content.

S. officinarum and *S. spontaneum* are the genetic resources widely used in sugarcane improvement programs. *S. officinarum*forms the secondary gene pool of sugarcane and contributed to the sucrose genes ofmodern sugar cane cultivars. Many *S. officinarum*clones have been identified as drought and saline tolerant. Six drought responsive candidate genes *viz*., *DREB1A*, *NAC2*, *Snac1*, *SHN1*, *SIZ1* and *PIN3* involved in the ABA independent pathway of drought stress response were identified in *S. officinarum* clones. The other two cultivated species *S. sinense*and *S. barberi*also constitute the secondary gene pool of sugarcane. These two species are hardy and adapted to unfavourable conditions. Eleven drought responsive candidate genes *viz*., *DRF1*, *NIT1*, *NAC2*, *Wrky 38 factor*, *Snac1*, *Hep2*, *HRD*, *SHN1*, *PIN3*, *DREB1A*, and *SIZ1* of the ABA independent pathway were reported to be present in *S. barberi* clones Kewaliand Khatuia and *S. sinense* clone Ikhri. It was reported that ten drought responsive candidate genes belonging to ABA dependent pathways were present in *S. barberi* clone Pathri. Out of the eleven drought responsive candidate genes of ABA dependent pathway, six genes *viz., ABF 3, CDPK 18, TPS 2, LEA 3, RGS 1 and RD 28* were found to be present in *S. barberi* clones Saretha, Pathri, Kewali, Khautu and *S. sinense*

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clones Chuckche, Uba white and Ikhri. The presence of majority of the drought responsive candidate genes makes these sugar rich species potential donor of abiotic stress tolerance in breeding programs. Some clones of *S. barberi*have been identified as salinity stress tolerant. In India, many successful early varieties like Co 213, Co 244, Co 312 and Co 313 have been derived from *S. barberi*and their success can be attributed to their high adaptability which resultedfrom the indigenous cane of India,*S. barberi*.At present the pre breeding materials originated from the crosses of S.*officinarum* with *S. barberi*, *S. sinense*and *S. robustum* are being screened for drought tolerance at ICAR-SBI, Coimbatore.

The two wild related species *S. spontaneum*and *S. robustum*constitutes the tertiary gene pool of sugarcane. *S. spontaneum* is known for its ability to withstand severe adverse conditions including cold, salinity, drought and waterlogging. It had been widely used in improving the adaptability of present-day sugarcane cultivars. The hardiness of modern cultivars is mainly imparted from the *S. spontaneum*genes. Even though a comprehensive study is lacking, different attempts were made atthe physiological and molecular characterization of drought and salinity tolerance in this species and many genotypes were identified as drought or salinity tolerance. In different studies, eleven drought responsive candidate genes belonging to ABA independent pathway and ten drought responsive candidate genes belonging to ABA dependent pathway were identified from *S. spontaneum* clones. However, only two clones of *S. spontaneum*, namely 'Coimbatore' and 'Glagah', were prominently used in the development of many Indian hybrids. The immediate progenitor of cultivated cane, *S. robustum*, is considered agood source of fibre, biomass, drought and waterlogging resistance. It is reported that the *S. robustum*clone'NG 77-59' harboured eleven drought responsive candidate genes of the ABA independent pathway. Similarly, nine drought responsive candidate genes of ABA dependent pathway were reported to be present in *S. robustum*clones NG 77-59, NG 77-122 and IJ 76-336.*S. robustum* clones have been screened for salinity stress tolerance and few of them were identified as potential donors.

The related genera including *Erianthus*, *Mischanthus*, *Narenga*and *Sclerostachya* constitute the distant gene pool of sugarcane. In the genus *Erianthus*, *E. arundinaceus* and *E. procerus* are being used in pre breeding programs. There is now renewed interest in the use of *Erianthus*because of its high biomass potential, multiple pest resistance and tolerance to most of theabiotic stresses. *E. arundinaceus* along with *S. spontaneum*hasbeen identified as the most potent wild sources for the varietal improvement of sugarcane. Eleven drought responsive candidate genes of ABA independent pathway and six drought responsive candidate genes of ABA dependent pathway were reported to be present in five *Erianthus* sp. clones *viz.*, IK 76-48, IK 76-62, IK 76-91, IK 76-99 and IND 84-863. It is also reported that in *E. arundinaceus*, the increased expression of EaHSP70 under moisture stress resulted in better survival through enhanced cell membrane stability, relative water content, gas exchange parameters, chlorophyll content and photosynthetic efficiency.*Miscanthus*had been used as a source for cold tolerance while *Sclerostachyafusca* provides tolerance to waterlogging.

A B

Fig 1: The cultivated species A) *Saccharumofficinarum*B) *Saccharumbarberi*

A B

Fig 2: The two important wild species for abiotic stress tolerance A) *Saccharumspontaneum*B) *Erianthusarundinaceus*

A B

Fig 3: Allied genera of *Saccharum*complex A) *Sclerostachya*spp. B) *Narenga*spp.

Conclusion

The sugarcane germplasm available today is large and diverse, representing the variability present in native habitats. The world collection in India has been well characterized and documented for agro-morphological traits and disease resistance. However, further efforts are needed to identify trait specific germplasm to optimize its utilization to meet the growing sugar and energy needs. The advances in biotechnological and genome sequencing tools may provide more insight into the existing biodiversity and their utilization in sugarcane improvement. The utilization of germplasm needs to be accelerated to ensure a broader genetic base and improve the productivity and adaptability of future varieties in view of the scenario of climate change. The large genetic variability represented across the *Saccharum*species and related genera, and the absence of any compatibility barriers within the *Saccharum* complex offer enormous possibilities to create genetic recombination that will meet the future varietal needs for sugar and energy sectors.