REVIEW

SUGARCANE GENETIC RESOURCES - STATUS, POTENTIAL AND ROLE IN SUGARCANE IMPROVEMENT

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Abstract

The basic genetic resources of sugarcane comprise the five species of Saccharum and the related genera Erianthus, Miscanthus, Narenga and Sclerostachya, together forming the Saccharum complex (Mukherjee 1957; Daniels et al 1975). Attempts to collect Saccharum germplasm began in the later parts of the 19th century, initially for the collection of noble canes for introduction as new cultivars. Later, with the successful use of the wild species in sugarcane breeding, particularly S. spontaneum, efforts were made to collect the wild species of Saccharum and related genera as well. The major areas of diversity for Saccharum germplasm are the Indonesia- New Guinea region for S. officinarum and S. robustum, and the Indian sub-continent for S. spontaneum and related genera. Explorations were carried out periodically during the past 120 years in the centres of diversity and numerous collections representing the different species of Saccharum and the related genera have been accumulated. The two world collections of Saccharum germplasm are currently maintained in India and USA; at the Sugarcane Breeding Institute Research Centre, Kannur, and the Subtropical Horticulture Research Station, Miami, respectively. The Indian collection had been characterized for agro-morphological traits and disease and pest resistance. Part of the collection had also been characterized for tolerance to abiotic stress. Among the wild germplasm, S. spontaneum had been widely used in base broadening programmes as a source for high productivity and better adaptability. There is now renewed interest in the use of Erianthus in view of its high biomass potential, multiple pest resistance and tolerance to most of the abiotic stresses. Miscanthus had also been used as a source for high productivity, cold tolerance and disease resistance. Intraspecific improvement of the Saccharum species had been attempted in West Indies and India to develop improved species-clones to be utilized in interspecific hybridization. Attempts are also being made to diversify the cytoplasmic base of the new varieties by deploying the cytoplasm of S. spontaneum, S. barberi and Erianthus. The future varietal needs are varied in terms of productivity, adaptation and product diversification, and the large genetic variability present in the Saccharum species and the related genera offer scope for meeting these demands through their optimized use.

Key words : *Sugarcane, genetic resources, germplasm collection*

Introduction

The six species of *Saccharum* and the related genera comprising *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 sugarcanes referred to as '*Saccharum* Complex' (Mukherjee 1957, Daniels et al. 1975). *Saccharum officinarum* (noble canes), *S. barberi* (the North Indian canes) and *S. sinense* (Chinese sugarcanes) are the cultivated species of *Saccharum* while *S. robustum, S. spontaneum* and *S. edule* represent the wild species. While the Indonesia-New Guinea region is the major centre of diversity for *S. officinarum* and *S. robustum*, diversity of *S.*

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spontaneum, *Erianthus*, *Narenga* and *Sclerostachya* is abundant in the North eastern states of India. The Indian (*S. barberi*) and the Chinese (*S. sinense*) sugarcanes have been totally replaced from cultivation, following the introduction of the new hybrid varieties in 1920s, and can be found only in field gene banks. Apart from the basic germplasm described above, several historical and commercial hybrids developed over the years at different cane breeding stations also form a potential gene pool for sugarcane improvement. This category also includes natural and induced mutants, aneuploids, somaclones, etc. with specific attributes of importance in cane breeding.

Germplasm collection and conservation

Attempts to collect *Saccharum* germplasm from the areas of diversity began in the later part of the 19th Century. Initially the objective was to collect the noble canes for introduction as new cultivars, but with the successful use of *S. spontaneum* in cane breeding programmes in India and Java, due attention was given for the collection of *S. spontaneum* and other wild species also. The major collection efforts were centered on the Indian subcontinent and the Indonesia-New Guinea region, which are the major centres of diversity.

The Indonesia–New Guinea region is considered to be the Centre of origin of the cultivated sugarcanes, *S. officinarum*. The sugar industry in its early stages was sustained by the introductions from New Guinea. The closely related wild species *S. robustum* also had exclusive presence in the region. There had been considerable interest in the collection of *Saccharum* germplasm from the New Guinea region right from 1892. The earlier explorations focused on collecting *S. officinarum* clones for introduction as cultivars whereas explorations conducted after 1921 endeavored to collect both cultivated and wild species of *Saccharum*. Collections were made from New Guinea during 1892, 1895, 1921, 1928, 1951, 1957 and 1977. Indonesia was explored for *Saccharum* germplasm collection during 1976 and 1984. Besides these major explorations, efforts were also made to collect germplasm from Thailand (1982 and 1983), Taiwan (1957-1958, 1966), Philippines (1984, 1985). *Saccharum* germplasm has also been collected from China and Japan over a period of time.

India is a major centre of diversity for *Saccharum* and related genera. India is the centre of origin of *S. spontaneum* which is distributed almost throughout the country from the Southern Peninsula to the sub-Himalayan regions. The species shows wide variation in morphology, adaptation and chromosome number. Over 25 cytotypes of *S. spontaneum* have been reported from India including the lowest chromosome form of 2n= 40. North East India has the maximum distribution of *Saccharum* and its wild relatives. Besides *S. spontaneum*, other related genera like *Erianthus*, *Miscanthus*, *Narenga* and *Sclerostachya* are widely distributed in the North-eastern States. The genus *Erianthus* includes both old world and new world species. The predominant species occurring in India is *Erianthus arundinaceus*, which is found in the southern peninsula, east coast and in some of the North-eastern states. This is the only cane-forming type among *Erianthus* and is viewed as a donor for important agronomic traits and adaptability. Other species found in the country include *E. bengalense*, *E. procerus*, *E. ravennae* and *E. rufipilus*, which are largely confined to the North Eastern States. *Narenga* and *Sclerostachya* are the two primitive genera in the *Saccharum* complex, the latter reported to be a source for waterlogging resistance.

The history of sugarcane germplasm collection in India dates back to 1912, following the establishment of the Sugarcane Breeding station at Coimbatore. The Spontaneum Expedition Scheme was launched in 1947 by the Sugarcane Breeding Institute for the collection of *Saccharum* germplasm from India and other Asian countries. During 1947-56, over 500 clones were collected from the distributional areas of India under this scheme. Efforts were renewed during 1981-1990 to collect *Saccharum* germplasm from the North East India. During this period, six explorations were organized and over 800 clones were collected. Collection efforts were revived in 1999 and nearly 750 clones were collected from the states of Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Arunachal Pradesh, Orissa, Mizoram, Tripura, Rajasthan, Himachal Pradesh, West Bengal and the Andaman Nicobar Islands. These explorations resulted in the collection of a large number of accessions representing the wide range of variability for *Saccharum* and related genera present in the country.

Conservation of germplasm

Consequent to the sustained efforts by several national agencies and the ISSCT, a large collection of sugarcane germplasm is available today representing the native variability available in the *Saccharum* complex. These collections have been conserved in the two World collections in USA and India. The USDA-World Collection of Sugarcane Germplasm maintained at the Subtropical Horticulture Research Station, Miami, Florida, includes nearly 1100 accessions. The World collection in India comprising nearly 1800 accessions is maintained at the Sugarcane Breeding Institute-Research Centre, Kannur, which was established in 1962 specifically for disease and pest-free maintenance of the sugarcane germplasm. Part of the germplasm is also being maintained *in vitro* under medium term storage. Most of the USDA collections are also maintained by the Cana Vialis Research Station (Monzanto) in Brazil. Apart from this, working collections of smaller size are available with most of the sugarcane research stations in different countries.

Wild species as sources for important characters

A major breakthrough in sugarcane improvement was achieved through the use of the wild species, *viz*. *S. spontaneum* in breeding. The modern sugarcane varieties are complex interspecific hybrids involving two or more species of *Saccharum* and the high productivity and adaptability of the varieties have been attributed to the *S. spontaneum* component of the genome. The wild germplasm available in India had been characterized over the years for various attributes and potential sources for important traits have been identified. *S. spontaneum* and *E. arundinaceus* have been identified as the most potent wild sources for the varietal improvement of sugarcane. *S. spontaneum* is considered a source for high productivity, adaptability and tolerance to pests and diseases. It is also endowed with the natural ability to withstand severe adverse conditions including cold, salinity, drought and waterlogging. *S. robustum*, the immediate progenitor of *S. officinarum*, is a source for fibre, yield and waterlogging resistance. *Erianthus* spp. is characterized by high biomass production, multiple pest resistance and tolerance to drought, waterlogging and salinity. Besides, *E. arundinaceus* is also an important source for fiber and now being used as a substitute for wood pulp in the paper industry. The species is being introduced for large-scale cultivation in Tamil Nadu, India, as a raw material for paper manufacture.

Trait specific germplasm

The germplasm available had been screened for agronomic traits and tolerance to some of the biotic and abiotic stresses. Potential sources among the species and hybrid germplasm are listed in Table 1.

Evidently the sugarcane germplasm available today is highly diverse and variable. The genetic variability required for the improvement of the crop in terms of productivity, stress tolerance and product diversification is readily available in the germplasm represented by the *Saccharum* species, derived hybrids and the related genera. In the absence of any serious crossability barrier among the members of *Saccharum* complex, interspecific and intergeneric gene transfer is a distinct possibility in sugarcane through conventional breeding. Precise characterisation of the germplasm is essential to optimize their utilization. The World Collection has largely been characterised for agro-morphological traits in India and the information has been documented. In the context of the latest developments in plant molecular biology, it will be appropriate to carry out allele mining in *Saccharum* species and the related wild genera with respect to important traits like high productivity, biotic and abiotic stress tolerance, biomass production, sucrose accumulation, etc. The wild germplasm also holds promise for locating sugarcane specific genes and promoters for developing sugarcane transgenics.

Utilization of *Saccharum* germplasm

The initial breeding efforts in sugarcane involved intercrossing among the *S. officinarum* cultivars (nobles). Some of the prominent early varieties like Buke, B147, B156, B208 in Barbados, POJ 100 in Java, Q813 and HQ 409 in Australia, Diamond 10,

Table 1. Potential sources for important traits

Trait	Germplasm: Species	Germplasm: Hybrids
Yield	***S. officinarum***: NG 77-171, 51 NG 097, 57 NG 116 Yellow, 51 NG 115 G, 28 NG 266, NG 77 42	H 382915, Q50, B43337, B 45116, H 507000, B45116, CP 49-50
Sucrose	***S. officinarum***: Creoula rayada, 57 NG 174, Saipan G, Seleri, Selemi Bali, Striped Mauritius, Chrystalina,, Chittan	PR1095, PR1085, PR1056, PR 905, B45285, B 54142, CP62251, CP 63384. CoC 671, Co 94012, CoJ 64, Co 62126, Co 888, Co 887, Co 62118,
Early sucrose (7 months)	***S. officinarum:*** 57NG 174, Azul de Caza, Oramboo, 57NG 155 ***S. barberi / S. sinense:*** Lalri, Kansor, Kavangiri	CP 62251, PR 1080, H482094 CoC 671, Co 94012, Co 281, Co 840, Co 385, Co 675 Co 725
Tolerance to water logging	***S. barberi***: Khari, Khajri	Co 62175, Co 785,Co 513, Co 805, Co 958, Co 1290, Co 8231, Co 62100, Co 8371, Co 99006, B54-142, CB 4013, CP 49-50, CP 63-361, H63-361, H50-7209, H52-3689, H53-263, H59-3775, H49-3553, PT 4352
Drought tolerance	***S. officinarum*** Gungera, 57 NG 73, IJ76-412, IS 76-564, Caledonia ribbon ***S. barberi / sinense:*** Nargori, Lalri, Mangwa sic, Matna Shaj, Pararia Shaj, Mcilkrum, Reha, Lalkhadi, kalkya, Kheli ***S. robustum:***NG77-79, 57NG 19, NG77 146, NG77 23, 57 NG 27	Co 7336, Co 8367, Co 99008, Co 94008, Co 8368, Co 8371, Co 8372, Co 87016, Co 955, Co 99004, ISH 100
Cold tolerance	***S. barberi / S. sinense***: Kalkya, Manjuria, Pararia Shaj ***S. spontaneum:*** SES114, SES234A, IND81-144, IND81-165, IND81-80	Q63, PR1016B44-130, Co 8339, Co 1148
Red rot resistance	***S. officinarum***: Baragua, Seleri, Saipan G ***S. spontaneum:*** many clones ***Erianthus:*** IJ 76-332, IJ 76-365, IJ76-383, IJ76-384, IJ76-400, IK 76-78, IK76- 88, IK76-99	BO 91, Co 62175, Co 7314, Co 94008, Co 62198, Co 86249,
Smut resistance	***S. officinarum:*** Awela Green Sport, Bamboo, Fiji 64, Hitam Broewang, Timor Riet, Vellai, NC 17, NC 92, 28 NG 57, 57 NG 186, 57 NG 251, IJ 76 504	Several clones
Resistance to multiple pests	***S. barberi / sinense:*** Katara barah, Mangwa sic, Rekha, Hemja, Maneria IMP 1552, Khadya ***S. robustum:*** IJ76-444, IJ 76-36, IJ76496, IS76-121, IJ76-422, NG77-108, NG77-235, NG77-73, NG77-23 ***Erianthus:*** IJ76-92, IK 76-84, IJ76-347, IS76-169, IJ76-408,IK76-78, IJ76-364, NG77-182	B44-130, CP 29-116, CP33-409, TUC 472, CP33-425, LF65-4233, KM724, P72-4

D109, D145 and D625 in Demerara, and H109 in Hawaii were from intraspecifc hybridization involving *S. officinarum* clones. Later, sugarcane breeding largely focussed on interspecific hybridization involving *S. officinarum* and *S. spontaneum* followed by backcrossing of the hybrids to the nobles. Improving the species themselves prior to using them in interspecific hybridization was considered a potential approach to develop superior interspecific hybrids by some of the research stations. Population improvement of *S. officinarum* and *S. spontaneum* for developing broad based parental lines was initiated in Barbados in 1960s. This involved successive hybridization and selection within each species to develop intraspecifc hybrid populations with enhanced expression for desirable traits. Nobles were specifically selected for high sugar content, low fibre and thick stalks while *S. spontaneum* was selected based on adaptability, since these clones were collected from a wide range of latitudes and ecological conditions. Walker (1982) reported significant gains from this programme and after three cycles of intercrossing and selection a range of improved nobles were developed which represent a superior and broader genetic base than the original species-clones. In India, intraspecific improvement of *S. officinarum*, *S. robustum* and *S. spontaneum* was initiated at Sugarcane Breeding Institute (SBI) in 1988. Two cycles of intraspecific hybridization and selection had been completed and significant improvement in important traits could be achieved (Nair et al. 1998). Improved *S. officinarum* populations with nearly 40% improvement in cane yield over the base population and improved intrapsecific population of *S. robustum* with more than 11% juice sucrose could be developed under this programme. A number of commercial varieties have been developed using these intraspecifc hybrids in breeding programmes.

The earliest attempt to utilize the wild germplasm in sugarcane improvement was in Java and India. The interspecific hybridization involving *S. officinarum*, *S. spontaneum* and to a limited extent *S. barberi* and the subsequent back crossing of the hybrids to *S. officinarum* and thereafter the intercrossing among the nobilised products resulted in a number of outstanding commercial varieties. Interest on interspecific hybridization was revived in 1960s following the realization that the cultivated varieties have a narrow genetic base drawn from a limited number of original species-clones. As such interspecific hybridization remains the backbone of sugarcane breeding programmes to improve and sustain sugarcane productivity. The nobilisation programmes carried out in India, USA, Australia, West Indies and many other countries suggest that maintaining a high level of genetic diversity in the breeding pool through pre-breeding involving the basic species is essential to achieve progressive gains through breeding programmes. In many countries, significant progress has been achieved through the use wild species, particularly *S. spontaneum*, in imparting higher productivity, resistance to mosaic disease, borer resistance, red rot and smut resistance, cold tolerance, drought and salinity tolerance to commercial varieties. In India, base broadening programmes were initiated during 1980s. New cycles of interspecific and intergeneric crosses were made utilizing the hitherto unutilized germplasm and the hybrids were screened for yield and quality potential. These hybrids were intercrossed, back crossed and crossed with commercial varieties. A comparison of the different mating groups showed that hybrids from (*S. officinarum* x commercial hybrid) x commercial and (*S. officinarum* x commercial) x *S. officinarum,* showed better performance with respect to juice sucrose% and CCS/plot. Evaluation of the hybrids involving *S. robustum* showed that BC2 x double cross hybrids were superior for CCS/ plot. This programme resulted in the development of an elite gene pool of more than 300 hybrids representing different combinations and different stages of hybridization. These hybrids (designated as ISH clones) were evaluated at different agroclimatic zones of the country and location specific genetic stocks were identified and inducted into the commercial breeding programmes. The success of the base broadening programmes in India is adequately reflected in the recent release of a number of 'Co' varieties like Co 95017, Co 97007, Co 97010, Co 97015, Co 97016, Co 97017, Co 98003, Co 99007, Co 99016 and Co 200005 with ISH parentage.

The use of genetic resources in sugarcane breeding has largely been confined to *S. officinarum* and *S. spontaneum*. The indigenous canes of India, *viz. S.*

barberi grown for centuries in the country are highly adapted to the harsh climatic conditions of subtropical India, be it high or low temperature, drought or waterlogging. The use of *S. barberi* proved successful during the early years of breeding research in India. Many of the successful early varieties like Co 213, Co 244, Co 312 and Co 313 have *S. barberi* derivation and their success can be attributed to the contribution of the highly adaptable *S. barberi* to their genetic makeup. Utilization of this species was revived during 1980s after proper characterization at different locations in India. Potential clones of *S. barberi* were crossed to *S. officinarum* and commercial varieties. The hybrids showed potential as commercial varieties and better adaptability to the abiotic stresses. However, the utilization of *S. barberi* was to a limited extent in other countries.

S. robustum had been extensively used in the Hawaiian breeding programme and many commercial varieties like H37-1933 have *S. robustum* genealogy. However, the utilization of the species had been to a limited extent in other countries. The species has been evaluated in India for agronomic traits and disease/pest tolerance. The species shows better tolerance to waterlogging, besides being resistant to major pests and thus holds promise as potential germplasm. In India, intraspecific hybridization and selection within the species resulted in the development of *S. robustum* clones with better sucrose (>11%). These clones were crossed to *S. officinarum* and commercial varieties and the progenies expressed advantage in sucrose and other agronomic traits.

Use of related genera

Saccharum is crossable with other members of *Saccharum* complex and a large number of hybrids involving different species of *Saccharum* and allied genera had been developed over the years (Janakiammal and Singh 1936; Janakiammal 1938; Janakiammal 1941; Li et al. 1948; Kandasami 1964; Nair 1999). Serious efforts to utilize *Erianthus spp.*, which is an important source for higher biomass production and pest and disease resistance, are currently underway in many countries including India. *Erianthus* was crossed with *S. officinarum*, *S. robustum* and *S. spontaneum* and hybrids were obtained and characterized for their agronomic potential. Crosses were made with *Erianthus* as male as well as female parent. Juice sucrose was found to be significantly higher in *S. officinarum* x *Erianthus* crosses compared to the reciprocal combination. The hybrids were backcrossed to commercial varieties and there was progressive improvement in sucrose content in the back crosses. Molecular markers were found useful in following the introgression of *Erianthus* genome in the hybrids and their back crosses (Nair et al. 2006). Among the related genera, *Miscanthus* holds promises as a source for high biomass, disease resistance and cold tolerance.

Sorghum is viewed as a source for earliness and *Saccharum* x Sorghum hybrids were produced to meet this objective (Thomas and Venkatraman 1930; Janakiammal and Singh 1936). *Saccharum officinarum* x Sorghum hybrids showed an early build up of sucrose content. Some of the recent Sugarcane x Sorghum hybrids developed at SBI showed HR brix up to 19.90% at six months as against 15.6% brix in the popular cultivar. HR brix at eighth month was 23.2% compared to 20.4% in the best standard. Sorghum x *Saccharum officinarum* hybrids also have been developed which are unique in having sorghum cytoplasm (Nair 1999).

Diversification of cytoplasmic base

Most of the present day commercial varieties have *S. officinarum* cytoplasm. To diversify this cytoplasmic base crosses were carried out at SBI using *S. spontaneum* and *S. barberi* as pistil parents and *S. officinarum* / commercial varieties as pollen parents. The hybrids were evaluated for yield and quality attributes and for smut and red rot resistance. A new generation of hybrids with *S. spontaneum*, *S. sinense* and *S. barberi* cytoplasm has been thus developed with desirable agronomic traits and disease resistance for utilization in breeding programmes. These hybrids and their back cross derivatives also had been tested at different locations for agronomic performance and also disease resistance. Similarly, hybrids with *Erianthus* and Sorghum cytoplasm have also been developed and characterized. They form a potential group of genetic stocks for base broadening programmes in sugarcane.

Wild species as potential source for biomass and bioenergy

Genetic improvement in sugarcane had largely been focused on improving sugar yield and stress tolerance. However, the potential of sugarcane and related grasses as feedstock for biofuel and energy generation is seriously considered now in view of the huge biomass potential of sugarcane and related grasses. Sugarcane can produce nearly 100t/ha biomass which is twice or more than that any other crop can produce. The capacity of related grasses like *Erianthus* and *S. spontaneum* to produce high biomass is equally high. *Erianthus* yields nearly 100 t/ha biomass and can be grown under sub-optimal conditions and is adapted to drought and waterlogging. *Erianthus* has 25-30% fibre and can yield 60 t/ha of wet bagasse as against 32 t/ha wet bagasse yield of sugarcane. Multi ratoonability, tolerance to biotic and abiotic stress and high fibre content make *Erianthus* an ideal energy crop. *Miscanthus* is already grown in Europe as an energy crop while switch grass is popular in USA for energy generation. *Erianthus*, essentially a tropical grass, has significantly higher potential as an energy crop in view of its higher biomass yield and better adaptability. The *Erianthus* germplasm at SBI had been screened for biomass potential and superior clones have been identified. Some of them had been introduced for large scale cultivation as a raw material for paper industry. Attempts were also made to further improve the fibre content of *Erianthus* by selfing the high fibre *Erianthus* clones and progenies with 30% fibre could be identified. Energy canes with high biomass potential have also been developed by introgressing *S. spontaneum* and *Erianthus* into commercial varieties. Type I energy canes with >20% fibre and >15% sucrose and type II energy canes with >25% fibre and <15% sucrose have been developed and are currently under trials in factory locations for feasibility to be grown as energy plantations. High biomass potential of *Erianthus* also renders it an ideal candidate for the production of cellulosic ethanol.

Conclusions

The sugarcane germplasm available today is large, diverse and represents the variability present in the native habitats. While the World collections are maintained in India and USA, sufficiently large collections are also available with the sugarcane breeding stations located in different countries. The World collection in India has been well characterized and documented with respect to 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 utilization of germplasm needs to be accelerated to ensure a broader genetic base and improve productivity and adaptability of the future varieties. The large genetic variability represented across the *Saccharum* species and related genera and the absence of any serious crossability barriers within the *Saccharum* complex offer enormous possibilities to create genetic recombinations that will meet the future varietal needs for sugar and energy sectors.

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