**RESEARCH ARTICLE**

# EXPLORATION AND GENETIC DIVERSITY ANALYSIS OF *SACCHARUM SPONTANEUM* IN MAHARASHTRA STATE, INDIA

**P. Govindaraj*, S. Karthigeyan and Adhini S. Pazhany**

**Abstract**

Exploration, collection, characterization and utilization of new wild germplasm in breeding programmes are the essential components of varietal development programmes. An exploration for the collection of species in *Saccharum* complex conducted in Maharashtra state, India, during 2015 led to the collection of 41 *Saccharum spontaneum* clones. This species was occurring in large populations as well as isolated individuals. Most of the collections were found in agricultural or fallow lands. *Saccharum spontaneum* (L.) had restricted distribution and out of the 29 districts surveyed only 13 districts had this wild species. High variations for leaf and stem characters were observed among the collections. Plant height varied from 46 cm to 215 cm, stalk diameter from 0.15 cm to 0.80 cm and leaf width from 0.15 cm to 0.75 cm. In addition to *S. spontaneum*, one *Saccharum officinarum* (L.) was also collected from Akola which had medium height, thick cane with few tillers and was commercially cultivated in small areas for chewing purpose. Two *Erianthus bengalense* clones were collected from Thane and Kolhapur, both being tall, vigorous in growth and in flowering stage. Most of the *S. spontaneum* clones were short in stature with narrow leaves of less than 3 mm width, such reduced plant height and leaf lamina apparently being mechanisms of adaptation for drought tolerance. Statistical analysis of altitude of the collection sites with plant characters showed no significant association. However, plant height had significant positive association with stalk diameter (0.669), internode length (0.459), leaf width (0.517) and arrow length (0.481). Peduncle length had significant positive association only with arrow length (0.411). Clustering of the new clones resulted in six distinct groups based on the geographical locations. Cluster III consisted of five clones collected from the western coastal districts of Rajgad and Ratnagiri. Cluster IV had four genotypes collected from the high rainfall eastern districts of Chandrapur and Gadchiroli. Eleven clones collected form Amravathi, Wardha, Nagpur and Bhandra were grouped into cluster VI. Since Maharashtra was not explored earlier, the collection of 41 *S. spontaneum* clones, besides one *S. officinarum* and two *Erianthus bengalense* clones, would add greater diversity to the germplasm conserved.

**Keywords:** *Su*garcane, germplasm, *Saccharum spontaneum*, exploration, distribution, diversity

## Introduction

*Saccharum spontaneum* L. (family: Poaceae), a wild relative of cultivated sugarcane, is a polyploid and polymorphic species which is believed to have evolved in India (Mukherjee 1957). Among the six species in *Saccharum* complex, *S. spontaneum* has wider adaptability that grows in diverse habitats across southern Asia and East Africa to the Mediterranean, spanning the tropics to temperate regions from latitudes 8° S to 40° N (Daniels and Roach 1987; Tai and Miller 2001). *Saccharum officinarum* (L.) was the cultivated cane in tropical India and *Saccharum barberi* (Jeswiet) was the main sugarcane species under cultivation in northern India before the introduction of sugarcane hybrids. Although *S. officinarum* displays tall stature, thick canes and high sucrose content, the species is highly

P. Govindaraj*, S. Karthigeyan and Adhini S. Pazhany
ICAR - Sugarcane Breeding Institute, Coimbatore – 641007, Tamil Nadu, India
*Email: govindsbi1912@gmail.com

sensitive to biotic and abiotic stresses and has low cane yield. The first interspecific hybrid between *S. officinarum* (Vellai; 2n=80) and *S. spontaneum* (Coimbatore local; 2n=64) was made and first generation interspecific hybrid Co 205 with wide adaptability was released for cultivation in subtropical India. Several such combination crosses followed by back crosses with noble canes made subsequently had led to the development of an array of varieties for cultivation in different agro-climatic conditions. The success of these varieties was primarily due to high tillering, wider adaptability to various agro-climatic conditions and resistance to biotic and abiotic stresses contributed mainly by *S. spontaneum* (D'hont et al. 1996). Although other species/genera of *Saccharum* complex, namely *S. robustum*, *S. barberi* and *Erianthus* were introduced later in breeding programmes, their contribution to varietal development is very minimal. The present day cultivars have around 15% *S. spontaneum* genome in their genetic constitution (D'hont et al. 1995). The contribution of this species to red rot resistance was demonstrated by Natarajan et al. (2001), as the vertical resistance was positively and significantly correlated with the number of *S. spontaneum* chromosomes present in their genome. Recently, cold tolerant clones were identified in *S. spontaneum* (Hale et al. 2014) which can be used for imparting winter hardiness and winter ratoonability in sugarcane cultivars. This species also showed the potential to be used in improving vegetation and restoration programmes (Pandey et al. 2015). *Saccharum spontaneum* had become an integral part of the sugarcane varietal development programmes (Panje 1972; Roach 1978; Mary et al. 2006) due the contribution of several agronomically important traits.

*Saccharum spontaneum* as a proven donor for the improvement of fibre content in cane and biomass production has generated interest in the development of sugarcane as a multipurpose crop that provides raw materials for sugar, electric power and alcohol generation. Improving the biomass of sugarcane has significant implication for the availability of cheap fibre for cogeneration. Studies indicated that progeny of a cross with *S. spontaneum* as a parent showed higher mean cane fibre than those from crosses involving other species or Co canes (Govindaraj et al. 2012). Energy cane breeding programmes initiated by several countries for use in cogeneration of power and lignocellulosic routed ethanol production had extensively used *S. spontaneum* as one of the parents. A dual purpose type I energy cane (SBIEC 11002) developed from *S. spontaneum* x Co cane cross recorded more than 100 t/ha of dry biomass and around 300 t/ha of harvestable biomass (Govindaraj and Nair 2014). Consequently, *S. spontaneum* has generated a lot of interest among sugarcane breeders in sugarcane and energy cane breeding programmes (Cosentino et al. 2015). This has led to the exploration of new genetic resources in *Saccharum* complex, especially of *S. spontaneum*, and introgression of new alleles for economically important traits in genetic enhancement programmes (Mary et al. 2006).

ICAR-Sugarcane Breeding Institute (ICAR-SBI), Coimbatore, India, has conducted several explorations in different parts of the country for *S. spontaneum* and is maintaining a collection of nearly 1,410 clones. While major parts of the Indian subcontinent were covered in the earlier explorations, Maharashtra state, which represents diverse agro-climatic conditions, was not explored so far. In this paper, the results of an exploration

conducted in September 2015 for sugarcane germplasm and the diversity analysis of the data are presented.

## Materials and Methods

The study material consisted of 41 new clones collected during the exploration in Maharastra state representing nine major agroclimatic zones: (I) Very High Rainfall Zone with Laterite Soils, (II) Very High Rainfall Zone with Non-lateritic soils, (III) Western Ghats Zone, (IV) Sub Montane Zone, (V) Western Maharashtra Plain Zone, (VI) Western Maharashtra Scarcity Zone, (VII) Central Maharashtra Plateau Zone, (VIII) Central Vidarbha Zone (Moderate Rainfall) and (IX) Eastern Vidharbha Zone/High Rainfall Zone ("Dept. of Agriculture, Govt. of Maharashtra", n.d.). Duplicate collection was avoided by allowing 5 km distance between two adjacent collections and avoiding collection of morphologically similar looking types.

Three representative clumps were taken at the site of collection for recording observations on quantitative characters, viz. plant height, leaf length, leaf width, internode length, stem diameter, peduncle length and arrow length and the average of the parameters was worked out. The altitude and latitude of the germplasm collection sites were determined with a 12 channel receiver Gramin GPS12 personal navigator instrument. Pearson Correlation coefficients were worked out in Microsoft Excel. Euclidean distances between pairs of clones were estimated, clustering was done and dendrogram was constructed using complete cluster method in R package GGE biplot GUI (Interactive GGE Biplots in R version 1.0-9), with distance function euclidean and the complete cluster method developed by Frutos et al. (2014).

## Results and discussion

Periodical collection and characterization of the new germplasm has been routinely carried out to preserve and harness new variability in breeding programmes. India was considered the primary centre of origin for *S. spontaneum* (Mukherjee 1957, Roach 1978) because the collections starting from Andaman and Nicobar to Himachal Pradesh and Gujarat to Arunachal Pradesh had shown huge variation in terms of morphological, cytological and molecular aspects (Kandasami et al. 1983; Sreenivasan et al. 2001; Mary et al. 2006). Indian *Saccharum* germplasm collection has around 1,410 *S. spontaneum* entries which were characterized for important morphological and agronomic traits. The world repository of *S. spontaneum* maintained in the field gene bank at ICAR-SBI and its Research Centre at Kannur, Kerala, is highly diverse in terms of morphological and geographical variation.

A total of 29 districts, viz. Pune, Thane, Mumbai, Rajgad, Ratnagiri, Kolhapur, Sangli, Satara, Ahmednagar, Nashik, Aurangabad, Jalgaon, Dhule, Nandurpur, Buldhana, Akola, Amravathi, Wardha, Nagpur, Bhandar, Chandrapur, Gadchiroli, Yavatmal, Nandad, Parbhani, Beed, Latur, Osmanabad and Solapur were surveyed during the exploration (Fig. 1). Out of these 29 districts, *S. spontaneum* was distributed only in 13 districts mainly in the western and Vidarbha regions. Two *Erianthus bengalense* clones, one each from Kolhapur and Thane, occurring as single clumps were also collected. One *S. officinarum* was collected from Akola which was cultivated for commercial chewing purpose. The major rivers surveyed were Bhima, Manjri, Visava, Koina, Tarli, Urmodi, Indrayini, Pravara, Mehlingi,

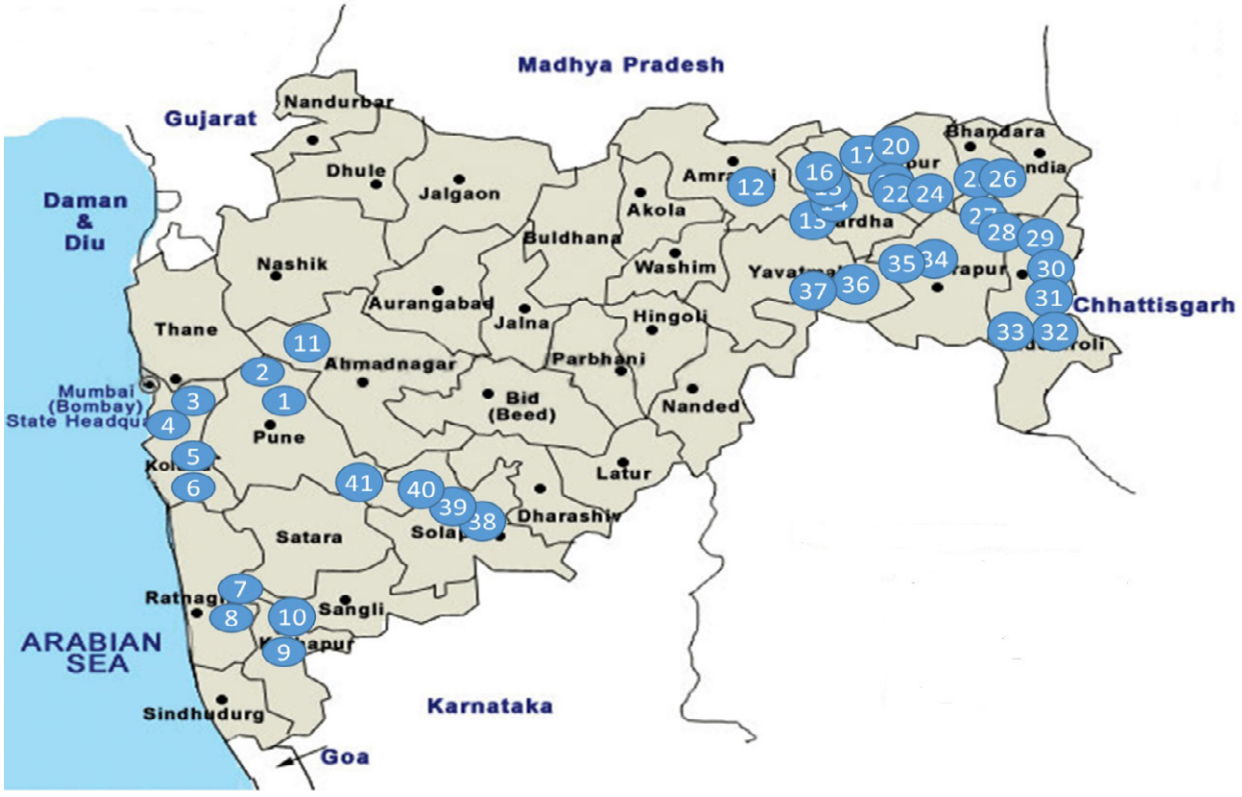


**Fig. 1.** Distribution of *Saccharum spontaneum* collections in different parts of Maharashtra state; 1-41: collection sites of 41 clones

Godawari, Panch Ganga, Ghod, Kandwa, Girna, Kordi, Amravathi, Asli, Tapi, Mula, Pan Ganga, Wardha, Tirina and Purna. It was also observed that most of the *S. spontaneum* collections were from agricultural field bunds or fallow lands and river banks but western hilly areas were devoid of these wild species.

## Distribution of *S. spontaneum*

Most of the collections were from Konkan Coastal Zone (Thane, Raigad, Ratnagiri and Sindhudurg districts), Western Ghats zone (hilly high lying terrains of Kolahapur, Satara, Pune, Ahmednagar and Nasik districts) and Eastern Vidharba region (Bhandara and Gadchiroli and parts of Chandrapur and Nagpur districts). Surprisingly, no *S. spontaneum* was found even after extensive survey in the assured rainfall zone (Aurangabad, Jalna, Beed and Osmanabad districts, major parts of Parbhani, Nanded and Latur, and parts of Akola, Amravati, Yavatmal, Jalgaon, Dhule and Solapur) (Fig. 1).

Maximum number of seven collections was from Nagpur district followed by five collections from Gadchirolli. Four collections each were made from Chandrapur, Wardha and Rajgad. One *S. spontaneum* each was collected from Ahmednagar, Amravathi and Ratnagiri districts. The first *S. spontaneum* clone (IND 15-1704), a medium tall, narrow leaved and high tillering clone, was collected from the bank of a small water stream. The clone was of late flowering type and the young inflorescence had not yet

emerged out. A high tillering, profusely flowering and tall clone IND 15-1709 occurred as a large population next to a paddy field. IND 15-1710, another medium tall clone located from Rajgad, was also of late flowering type and it occurred as a small population located nearer to a small water pond. From Ratnagiri, one clone (IND 15-1712) was collected at 87 MASL. In the western hilly and coastal areas, five collections were made. Three collections of *S. spontaneum* were made from Kolhapur, a high rainfall and water logging area, and three more were collected from Solapur district which experiences low rainfall.

Eastern Vidharbha Zone/High Rainfall Zone consisted of Bhandra and Gadchiroli districts and a total of eight collections were made from this zone. Most of the collections were distributed in agriculture fields, fallow lands, canals and river banks. Except IND 15-1735, a clone collected on the river side, all the clones were profusely flowering. They were tall (202 cm), erect and heavy tillering types. One of the tallest collections (IND 15-1738) was from Gadchiroli district. This was an erect high tillering one with long leaves and lengthy arrows. IND 15-1740 was an early flowering type collected from a soybean field in Chandrapur district. It was a small population wherein flowering was almost complete. The last collection (IND 15-1747) occurred as a large population on both banks of river Bhima. It was a tall, erect and heavy tillering clone with lengthy peduncle (58 cm) and long arrows (56 cm).

**Variability in *S. spontaneum***

The most dwarf type IND 15-1724 (46 cm) was collected from Nagpur district which also had very short (62 cm) and narrow leaf (0.2 cm), thin cane (0.2 cm stem diameter) and very short peduncle (10 cm) (Table 1). The tallest collection (IND 15-1714) was from Kolhapur district (215 cm) and it was found on the bund of a paddy field. It had the widest leaf (0.75 cm) and comparatively thicker cane (0.7 cm cane diameter). IND 15-1716 was collected in Ahmednagar from a running water stream with excess moisture in the clay and muddy soil. It was a tall, erect clone with heavy tillering and profuse flowering. IND 15-1719, a non-flowering clone, was collected on the roadside at Wardha which recorded the shortest internode length of 5.60 cm. IND 15-1716, IND 15-1735, IND 15-1711, IND 15-1738 and IND 15-1710 recorded more than 6 ft long canes. Among these six tall clones, two were collected from Kolhapur district. *Saccharum spontaneum* was distributed between 27 MASL (IND 15-1709) collected at Rajgad to 636 MASL (IND 15-1716) spotted at Ahmednagar. Two more *S. spontaneum*, viz. IND 15-1710 (28 MASL) and IND 15-1706 (30 MASL) were also collected from low altitude.

High variability was recorded for all the quantitative characters, especially for plant height which ranged from 46 cm (IND 15-7124) to 215 cm (IND 15-7114) (Table 1) and among them five were of very short types (< 60 cm). While the leaf length varied from 40 cm (IND 15-7142) to 103 cm (IND 15-7139), leaf width ranged from 0.15 cm (IND 15-7133) to 0.75 cm (IND 15-7114). Significant variation for leaf characters was reported with the *S. spontaneum* collections from North West India (Govindaraj et al. 2014) and Arunachal Pradesh (Mary et al. 2006). High variability among *S. spontaneum* collections was also reported based on agronomical traits, morphological characters and molecular markers (Zhang et al. 2006; Yang et al. 2008; Qi et al.

**Table 1. Details of the altitude of collection sites and quantitative traits of *Saccharum spontaneum* germplasm**

| District | Collection No. | Altitude (m) | Plant height (cm) | Leaf length (cm) | Leaf width (cm) | Internode length (cm) | Stalk diameter (mm) | Peduncle length (cm) | Arrow length (cm) |
|---|---|---|---|---|---|---|---|---|---|
| Pune | IND 15-1704 | 552 | 139 | 74 | 0.70 | 10.50 | 0.50 | NF* | NF |
| | IND 15-1705 | 625 | 152 | 76 | 0.60 | 10.40 | 0.40 | 46 | 39 |
| | IND 15-1747 | 486 | 165 | 46 | 0.40 | 12.00 | 0.35 | 58 | 56 |
| Rajgad | IND 15-1706 | 30 | 168 | 57 | 0.50 | 6.50 | 0.40 | 15 | 20 |
| | IND 15-1708 | 57 | 102 | 47 | 0.75 | 10.00 | 0.55 | 56 | 60 |
| | IND 15-1709 | 27 | 167 | 76 | 0.50 | 19.50 | 0.50 | 21 | 42 |
| | IND 15-1710 | 28 | 212 | 51 | 0.70 | 14.00 | 0.80 | 38 | 42 |
| Kolhapur | IND 15-1711 | 557 | 190 | 63 | 0.30 | 6.00 | 0.30 | 52 | 40 |
| | IND 15-1713 | 558 | 112 | 87 | 0.50 | 8.50 | 0.45 | NF | NF |
| | IND 15-1714 | 545 | 215 | 56 | 0.75 | 11.50 | 0.70 | 35 | 22 |
| Ratnagiri | IND 15-1712 | 87 | 104 | 98 | 0.50 | 11.20 | 0.60 | 45 | 48 |
| Ahmednagar | IND 15-1716 | 636 | 187 | 68 | 0.30 | 16.00 | 0.60 | 35 | 28 |
| Amravathi | IND 15-1718 | 338 | 98 | 98 | 0.30 | 13.80 | 0.40 | 38 | 31 |
| Wardha | IND 15-1719 | 318 | 47 | 69 | 0.40 | 5.60 | 0.25 | NF | NF |
| | IND 15-1720 | 476 | 62 | 69 | 0.30 | 6.00 | 0.20 | 28 | 23 |
| | IND 15-1721 | 462 | 72 | 84 | 0.20 | 9.80 | 0.30 | 12 | 24 |
| | IND 15-1722 | 441 | 78 | 93 | 0.30 | 7.50 | 0.30 | 41 | 24 |
| Nagpur | IND 15-1723 | 450 | 113 | 73 | 0.20 | 7.50 | 0.30 | 51 | 23 |
| | IND 15-1724 | 347 | 46 | 62 | 0.20 | 8.00 | 0.20 | 10 | 25 |
| | IND 15-1725 | 289 | 58 | 63 | 0.15 | 7.00 | 0.30 | 46 | 22 |
| | IND 15-1726 | 283 | 86 | 71 | 0.20 | 8.00 | 0.30 | 37 | 19 |
| | IND 15-1727 | 349 | 90 | 63 | 0.20 | 10.00 | 0.20 | 29 | 29 |
| | IND 15-1728 | 302 | 93 | 55 | 0.20 | 6.70 | 0.30 | 46 | 22 |
| | IND 15-1729 | 310 | 113 | 88 | 0.30 | 7.50 | 0.30 | 51 | 37 |

**Cont'd**

**Table 1. Cont'd**

| District | Collection No. | Altitude (m) | Plant height (cm) | Leaf length (cm) | Leaf width (cm) | Internode length (cm) | Stalk diameter (mm) | Peduncle length (cm) | Arrow length (cm) |
|---|---|---|---|---|---|---|---|---|---|
| Bhandara | IND 15-1730 | 271 | 67 | 64 | 0.15 | 11.00 | 0.25 | 42 | 13 |
| | IND 15-1731 | 264 | 79 | 63 | 0.30 | 7.50 | 0.40 | 49 | 33 |
| | IND 15-1732 | 285 | 73 | 79 | 0.20 | 9.50 | 0.30 | 29 | 21 |
| Chandrapur | IND 15-1733 | 258 | 48 | 51 | 0.15 | 7.00 | 0.35 | 23 | 15 |
| | IND 15-1734 | 239 | 153 | 75 | 0.30 | 12.00 | 0.40 | 51 | 42 |
| | IND 15-1740 | 214 | 68 | 93 | 0.20 | 6.00 | 0.30 | 35 | 20 |
| | IND 15-1741 | 221 | 82 | 52 | 0.20 | 6.00 | 0.30 | 46 | 29 |
| Gadchiroli | IND 15-1735 | 236 | 187 | 72 | 0.40 | 9.00 | 0.70 | NF | NF |
| | IND 15-1736 | 227 | 105 | 78 | 0.20 | 7.50 | 0.30 | 52 | 24 |
| | IND 15-1737 | 227 | 143 | 41 | 0.15 | 6.30 | 0.30 | 52 | 23 |
| | IND 15-1738 | 216 | 202 | 72 | 0.40 | 8.50 | 0.30 | 47 | 36 |
| | IND 15-1739 | 216 | 113 | 103 | 0.40 | 13.00 | 0.30 | 36 | 39 |
| Yavatmal | IND 15-1742 | 208 | 53 | 40 | 0.20 | 7.20 | 0.15 | 19 | 20 |
| | IND 15-1743 | 225 | 116 | 72 | 0.30 | 11.20 | 0.35 | 46 | 37 |
| Solapur | IND 15-1744 | 475 | 160 | 63 | 0.30 | 10.20 | 0.35 | 36 | 32 |
| | IND 15-1745 | 477 | 178 | 82 | 0.30 | 10.50 | 0.70 | 32 | 53 |
| | IND 15-1746 | 477 | 111 | 58 | 0.70 | 10.20 | 0.30 | NF | NF |
| Average | | 324.1 | 117.2 | 69.39 | 0.35 | 9.42 | 0.38 | 38.65 | 31.16 |
| Maximum | | 636.0 | 215.0 | 103.0 | 0.75 | 19.50 | 0.80 | 58.00 | 60.00 |
| Minimum | | 27.0 | 46.00 | 40.00 | 0.15 | 5.60 | 0.15 | 10.00 | 13.00 |
| SD | | 133.7 | 41.92 | 12.50 | 0.14 | 2.34 | 0.12 | 10.14 | 9.59 |

* Not flowered

2009; Chang et al. 2012; Liu et al. 2012; Zhou et al. 2012; Govindaraj et al. 2014; Praneetha and Nair 2014). Variability for genome size based on flow cytometry studies within *S. spontaneum* was also reported by Zhang et al. (2012). *Saccharum officinarum* accessions had a narrow genome size range (7.50 - 8.55 Gb) with an average of 7.88 Gb whereas *S. robustum* (7.65 to 11.78 Gb) and *S. spontaneum* (3.36 to 12.64 Gb) showed a high genome size range due to variation of ploidy level.

**Correlation analysis**

Altitude is likely to exert considerable influence on plant traits due to the significant variations in climatic conditions. However, in the present study, correlation analysis indicated that altitude had no significant influence on any of the plant traits but showed non-significant negative trend with traits like stalk diameter and internode length (Table 2). The non-significant association may be due to the minimal variation in climatic factors among the collection sites whose altitude ranged from 27 to 623 MASL. However, altitude was negatively related to yield and sugar related traits in Chinese populations (Liu et al. 2012). Correlation analysis among plant characters showed the highest correlation coefficient between plant height and stalk diameter (0.669). Besides, plant height had significant positive association with leaf width (0.517), arrow length (0.481) and internode length (0.459). Leaf width showed significant correlations with internode length, stalk diameter and arrow length. Peduncle length had significant positive association only with arrow length (0.411).

**Diversity analysis**

Efficiency of breeding programmes for the development of varieties depends upon the total variability present in the population on which selection is exercised. Diversity analysis among the available germplasm gives an opportunity for the breeders to select appropriate diverse parents for creation of more variability and select elite segregants. Traditionally, morphological markers and agronomical traits are employed for assessing the variability (Stevenson 1965; Skinner et al. 1987; Govindaraj et al. 2014). Clustering of germplasm carried out through complete linkage clustering using Euclidean distances (GGE Biplot package of R statistics) led to six clear clusters of the germplasm (Fig. 2). Cluster III consisted of five clones collected from the western coastal districts of Rajgad and Ratnagiri, all being from low altitude sites of 30 - 87 MASL (Table 3). The

**Table 2. Correlations among different quantitative traits of *Saccharum spontaneum* clones**

| Parameter | Plant height | Leaf length | Leaf width | Peduncle length | Arrow length | Stalk diameter | Internode length |
|---|---|---|---|---|---|---|---|
| Altitude | 0.114 | 0.103 | 0.025 | 0.073 | -0.052 | -0.061 | -0.042 |
| Plant height | | -0.088 | 0.517** | 0.244 | 0.481** | 0.669** | 0.459** |
| Leaf length | | | -0.040 | -0.030 | 0.095 | 0.052 | 0.203 |
| Leaf width | | | | 0.136 | 0.578** | 0.610** | 0.395** |
| Peduncle length | | | | | 0.411** | 0.106 | -0.092 |
| Arrow length | | | | | | 0.509** | 0.442** |
| Stalk diameter | | | | | | | 0.307* |

* $P<0.05$; ** $P<0.01$

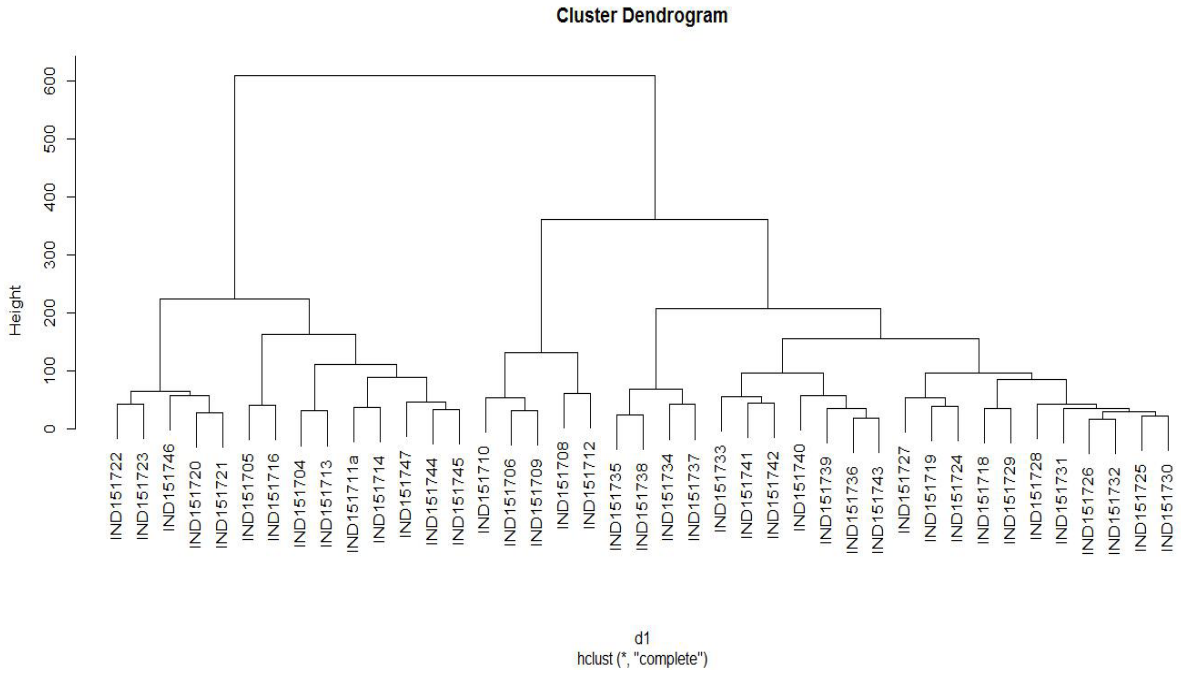


**Fig. 2.** Dendrogram of *Saccharum spontaneum* clones collected based on Euclidean distances

average altitude of 46 MASL was the lowest among all other clusters. They had the highest mean stem diameter (0.57 cm) and internode length (12.24 cm). In contrast, Cluster II grouped all the nine clones collected from relatively higher altitudes with the range of 486 - 636 MASL in the districts of Pune, Kolhapur, Ahmednagar and Solapur districts. The average altitude was 546 MASL and the collections from Southern Maharashtra were grouped in this cluster. Cluster IV had four clones collected from the high rainfall eastern districts of Chandrapur and Gadchiroli. The germplasm collected from these regions had high mean plant height (171 cm) and peduncle length (50 cm). Eleven clones collected form Amravathi, Wardha, Nagpur and Bhandara grouped into cluster VI. Narrow leaf width (0.23 cm) and thin canes (0.29 cm stem diameter), known to be drought adaptation mechanisms in sugarcane (Davies et al. 2002; Lopez et al. 2008), observed among the clones in this cluster indicated that they may possess drought tolerant genes. Grouping of genotypes with short internode length, narrowest stalk diameter, lowest single cane weight, narrowest leaf width and lowest leaf area was reported by Tena et al. (2016). While cluster I had five clones collected from Wardha, Nagpur and Solapur districts, cluster V had seven collections. The clones were also grouped according to the geographic location and agro-climatic conditions as reported in an earlier study with a different set of clones (Mary et al. 2006). Grouping of germplasm in to six clusters clearly indicated that the germplasm collected had good genetic diversity. Utilization of *S. spontaneum* representing different clusters in breeding programs will ensure greater variability required for effective selection in relation to economic traits.

**Table 3. Grouping of new *Saccharum spontaneum* germplasm based on Euclidean distances**

| Clusters | Germplasm | District of collection | Average values of the group | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Altitude (m) | Plant height (cm) | Leaf length (cm) | Leaf width (cm) | Stalk diameter (mm) | Internode length (cm) | Peduncle length (cm) | Arrow length (cm) |
| I | IND 15-1720<br>IND 15-1721<br>IND 15-1722<br>IND 15-1723<br>IND 15-1746 | Wardha<br>Nagpur<br>Solapur | 461 | 87 | 75 | 0.34 | 0.28 | 8.2 | 33 | 23 |
| II | IND 15-1704<br>IND 15-1705<br>IND 15-1711<br>IND 15-1713<br>IND 15-1714<br>IND 15-1716<br>IND 15-1744<br>IND 15-1745<br>IND 15-1747 | Pune<br>Kolhapur<br>Ahmednagar<br>Solapur | 546 | 166 | 68 | 0.46 | 0.48 | 10.62 | 42 | 39 |
| III | IND 15-1706<br>IND 15-1708<br>IND 15-1709<br>IND 15-1710<br>IND 15-1712 | Rajgad<br>Ratnagiri | 46 | 151 | 66 | 0.59 | 0.57 | 12.24 | 35 | 42 |
| IV | IND 15-1734<br>IND 15-1735<br>IND 15-1737<br>IND 15-1738 | Chandrapur<br>Gadchiroli | 230 | 171 | 65 | 0.31 | 0.42 | 8.95 | 50 | 34 |
| V | IND 15-1733<br>IND 15-1736<br>IND 15-1739<br>IND 15-1740<br>IND 15-1741<br>IND 15-1742<br>IND 15-1743 | Chandrapur<br>Gadchiroli<br>Yavatmal | 224 | 84 | 70 | 0.23 | 0.29 | 8.27 | 37 | 26 |

**Table 3 Cont'd**

| Clusters | Germplasm | District of collection | Average values of the group | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Altitude (m) | Plant height (cm) | Leaf length (cm) | Leaf width (cm) | Stalk diameter (mm) | Internode length (cm) | Peduncle length (cm) | Arrow length (cm) |
| VI | IND 15-1718 | Amravathi | 305 | 77 | 70 | 0.23 | 0.29 | 8.6 | 37 | 25 |
| | IND 15-1719 | Wardha | | | | | | | | |
| | IND 15-1724 | Nagpur | | | | | | | | |
| | IND 15-1725 | Bhandara | | | | | | | | |
| | IND 15-1726 | | | | | | | | | |
| | IND 15-1727 | | | | | | | | | |
| | IND 15-1728 | | | | | | | | | |
| | IND 15-1729 | | | | | | | | | |
| | IND 15-1730 | | | | | | | | | |
| | IND 15-1731 | | | | | | | | | |
| | IND 15-1732 | | | | | | | | | |

The present exploration resulted in the collection of 41 *S. spontaneum*, one *S. officinarum* and two *Erianthus bengalense* germplasm representing total variability available in the state of Maharashtra. The new collections showed considerable morphological and agronomical variability. Clustering of these germplasm also indicated the preferential grouping based on geographical location and climatological variations. Characterization of the germplasm for agronomical and climate resilient traits may identify useful clones for utilization in targeted breeding programmes.

## References

Chang D, Yan JJ, Bai SQ, Liang XZ (2012) Evaluation of production performance for wild *Saccharum spontaneum L.* germplasm. Chinese Agric Sci Bull 3:039.

Cosentino SL, Copani V, Testa G, Scordia D (2015) *Saccharum spontaneum L.* ssp. aegyptiacum (Willd.) Hack. a potential perennial grass for biomass production in marginal land in semi-arid Mediterranean environment. Ind Crops Products 75:93-102.

Daniels J, Roach BT (1987) Taxonomy and evolution. In: D Heinz (Ed) Sugarcane improvement through breeding, pp.7-84. Elsevier Science Publishers, B.V. (Amsterdam).

Davies WJ, Wilkinson *S,* Loveys B (2002) Stomatal control by chemical signaling and the exploitation of this mechanism to increase water use efficiency in agriculture. New Phytol 153:449-460.

Dept. of Agriculture, Govt. of Maharastra. Agro Climatic Zones in Maharastra (n.d.). Retrieved from http:/www.mahaagri.gov.in /Crop Weather/AgroClimaticZone.html.

D'hont A, Rao P, Feldmann P, Grivet L, Islam-Faridi N (1995) Identification and characterisation of sugarcane intergeneric

hybrids, *Saccharum officinarum* x *Erianthus* arundinaceus, with molecular markers and DNA in situ hybridisation. Theor Appl Genet 91:320-326.

D'hont A, Grivet L, Feldmann P, Rao *S,* Berding N, Glaszmann JC (1996) Characterisation of the double genome structure of modern sugarcane cultivars (*Saccharum* spp.) by molecular cytogenetics. Mol Gen Genet 250(4):405-413.

Frutos E, Galindo MP, Leiva V (2014) An interactive biplot implementation in R for modeling genotype-by-environment interaction. Stoch Environ Res Risk Assess 28:1629-1641.

Govindaraj P, Nair NV (2014). Energy canes as feedstock for bioenergy industries in India–potential and challenges. International Conclave on Sugar Crops 2014, February 15 - 17, 2014. Indian Institute of Sugarcane Research, Lucknow.

Govindaraj P, Nair NV, Suganya A, Sreenivasa V (2012) Development and biomsss characterization of new energy canes in India. Proceedings of the International Symposium on New Paradigms in Sugarcane Research, October 15-18, 2012, pp.335-337. Sugarcane Breeding Institute, Coimbatore, India.

Govindaraj P, Amalraj VA, Mohanraj K, Nair N V (2014) Collection, characterization and phenotypic diversity of *Saccharum spontaneum L.* from arid and semi-arid zones of northwestern India. Sugar Tech 16(1):36-43.

Hale AL, Viator RP, Veremis JC (2014) Identification of freeze tolerant *Saccharum spontaneum* accessions through a pot-based study for use in sugarcane germplasm enhancement for adaptation to temperate climates. Biomass and Bioenergy 61:53-57.

Kandasami PA, Sreenivasan TV, RamanaRao TV, Palanichami K, Natarajan BV, Alexander KC, Rao MM, Mohanraj D (1983) *Catalogue on sugarcane genetic resources I. Saccharum spontaneum L*. Sugarcane Breeding Institute, Coimbatore. 48p.

Liu XL, Su HS*,* Ying XM, Ma L, Lu X, Liu HB, Deng ZH (2012) Phenotypic correlation and genetic diversity of decaploids of *Saccharum spontaneum*. J Hunan Agric Univ (Nat Sci) 38:574–579.

Lopez FB, Chauhan YS, Johansen C (2008) Effects of timing of drought stress on leaf area development and canopy light interception of short-duration pigeonpea. J Agron Crop Sci 178:1-7.

Mary S, Nair NV, Chaturvedi PK, Selvi A (2006) Analysis of genetic diversity among *Saccharum spontaneum L.* from four geographical regions of India using molecular markers. Genet Resour Crop Evol 53(6):1221-1231.

Mukherjee SK (1957) Origin and distribution of *Saccharum*. Bot Gaz 119:55–61.

Natarajan US*,* Balasundaram N, Ramana Rao TC, Padmanaban P, Mohanraj D, Karthigeyan S, Damodaran S (2001) Role of *Saccharum spontaneum* in imparting stable resistance against sugarcane red rot. Sugarcane Int 10:17-20.

Pandey VC, Bajpai O, Pandey DN, Singh N (2015) *Saccharum spontaneum*: an underutilized tall grass for revegetation and restoration programs. Genet Resour Crop Evol 62(3):443-450.

Panje RR (1972) The role of *Saccharum spontaneum* in sugarcane breeding. Proc Int Soc Sugarcane Technol 14:217-223.

Praneetha M, Nair NV (2014) Cytological studies on *Saccharum spontaneum L.* from Andhra Pradesh, India. J Sugarcane Res 4(1):40-47.

Qi YW, Fan LN, He HY, Chen YS, Ao JH, Deng HH (2009) Genetic diversity assessment of *Saccharum spontaneum L.* native to Guangdong area with agronomic traits. Sugarcane and Canesugar 3:7–10.

Roach BT (1978) Utilization of *Saccharum spontaneum* in sugarcane breeding. Proc Int Soc Sugarcane Technol 16:43-57.

Skinner J, Hogarth DM, Wu KK (1987) Selection methods, criteria and indices. In: DJ Heinz (ed) Sugarcane improvement through breeding, pp.409–453. Elsevier, Amsterdam.

Sreenivasan TV, Amalraj VA, Jebadhas AW (2001) *S.garcane Genetic Resources V. Saccharum spontaneum L., Vol.2*. Sugarcane Breeding Institute, Coimbatore. 125p.

Stevenson GC (1965) Genetics and breeding of sugarcane. Longmans, London.

Tai PYP, Miller JD (2001) A core collection for *Saccharum spontaneum L.* from the world collection of sugarcane. Crop Sci 41:879–885.

Tena E, Mekbib F, Ayana A (2016) Genetic diversity of quantitative traits of sugarcane genotypes in Ethiopia. Am J Pl Sci 7:1498-1520.

Yang SC, Li YH, Yang QH, Li FS, Xiao GL (2008) Relations between photosynthesis characteristics of *Saccharum spontaneum* and altitude of its native area. Sugar Crops of China 1:003.

Zhang GM, Yang RZ, Liu HB, Fang WK (2006) Principal component analysis for 7 quantitative traits and cluster analysis based on 7 quantitative traits of *Saccharum spontaneum L.* SW China J Agric Sci 19(6):1127–1131.

Zhang J, Nagai C, Yu Q, Pan YB, Silva TA, Schnell RJ, Comstock JC, Arumuganathan AK, Ming R (2012) Genome size variation in three *Saccharum* species. Euphytica 185(3):511–519.

Zhou MM, Suman A, Kimbeng C (2012) Molecular markers associated with starch content and implications for sugarcane introgression breeding using *Saccharum spontaneum*. J Agric Sci Technol B 2(11B):1127-1137.

Received : 22 August 2016; Revised & Accepted : 25 January 2017