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RESEARCH ARTICLE

Variation in the flowering behaviour of *Saccharum spontaneum L.* world collection at Coimbatore

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Abstract

An assessment of the influence of weather parameters on flowering of 1459 world germplasm collections of *Saccharum spontaneum* L. collected over a century (1916-2016) and maintained in the field germplasm at Coimbatore during 2017 to 2019 flowering seasons was undertaken. The collections were from 23 states of India and exotic regions belonging to various latitudes. Accessions from Karnataka, Kerala, Andhra Pradesh, and Tamil Nadu recorded profuse flowering along with Madhya Pradesh, Maharashtra, Rajasthan, Odisha and Tripura accessions in all the three seasons even though they are latitudinally displaced. Inherent limited latitudinal tolerance was noticed in these clones. Maximum number of accessions was found to be in flowering during October month irrespective of the planting date. Statistical analysis has been carried out by calculating correlation coefficients between different pairs of weather parameters and t- test for finding out the significance. Relative humidity in the forenoon as well in the afternoon had a significant positive correlation and solar radiation had a highly negative correlation on flowering. Rainfall and rainy days had positive correlation on flowering during season I of flowering. Ideal temperature condition for *S. spontaneum* panicle development and pollen fertility under Coimbatore condition was found to be 30° C during day and 22° C at night. Utilization of these new flowering accessions and late flowering germplasm in the future breeding programme will enhance the commercial cultivars in sugarcane and aid in the development of improved varieties.

Keywords: Sugarcane; *Saccharum spontaneum*; Germplasm accessions; Flowering behaviour; Environmental factors; Pollen fertility.

Introduction

Along with the increasing demand for improved varieties that suit various agro-ecologies, there exist a continuous demand for broad genetic base sugarcane varieties that are high yielding and stable under abiotic and biotic stresses. The development of high yielding and stable varieties requires an overarching supply of novel germplasm as a source of desirable genes and/or gene complexes. The primary sources of such genes are land races, introductions, weedy, and wild relatives of crop plants (Harlan, 1992; Allard, 1999). Exploration and collection of natural diversity present in the crop gene pool in search of novel genes and alleles has always fascinated the researchers. Wild relatives of crop plants constitute a part of crop gene pool which possesses genes that have great potential for their utilization programs. The collection of plant genetic resources primarily aims at tapping germplasm variability in different agri-horticultural plants, their wild relatives and related species. The Indian gene centre harbours about 166 species of native cultivated plants (Vavilov 1949–1950; Zeven and de Wet 1982) and over 320 wild relatives (Arora and Nayar 1984; Arora 1991, 2000). The wild relatives of crop plants by and large occur as components of disturbed habitats within the major vegetation types with distribution in the warm humid tropical, sub-tropical regions and in the Western Himalaya with low representation in the drier parts of North-Western region (Arora and Nayar 1984; Arora and Pandey 1996; Arora 2000). Over 100 wild relatives and related taxa and endemic/rare/endangered species occur predominantly in the hot spot / micro-centres of India (Nayar 1996; Pandey and Arora 2004; Pandey et al. 2005). The germplasm so collected reveals the nature and extent of variability in different species, within species, cultigens, etc. as also their agro-ecological/phyto-geographical distribution. It gives an opportunity to acquire knowledge on diversity in crop plants vis-a-vis its distribution to tap target areas and/or target species and the variability contained thereof. The genetic variability provided by the wild species and weed races is a source of resistance to diseases and insects, controlled mainly by major genes, tolerance for extreme environments such as salinity, desiccation, water logging, and frost and high vegetative vigour.

Sugarcane (*Saccharum* spp.) is the second most important industrial crop of India with a production area of 5 Mha. India is also the centre of origin of (*Saccharum spontaneum* L.); the wild relative of cultivated sugarcane. The wild related species *S. spontaneum* has contributed immensely in the development of modern sugarcane hybrids and are a valuable source of novel alleles for disease resistance and climate resilience. *Saccharum* germplasm is widely distributed across the country, across the geographical locations starting from below sea level to the foothills of Himalaya. The collection, conservation and utilization of *Saccharum* diversity has been the mandate of ICAR Sugarcane Breeding Institute ever since its inception. Since then several explorations conducted by the Institute for the collection of *Saccharum* germplasm from different geographical and climatic regimes of the country (Nair et al., 1991, 1993; Nair and Somarajan, 2003, Nair and Vigneswaran, 2005; Nair et al. 2006, Nair and Sekharan, 2009; Sreenivasan et al., 1985, 1986).

Flowering in sugarcane is a complex physiological process consisting of various stages of development and each of them has its unique physiological and environmental requirements (Araldi et al., 2010). According to Moore and Nuss (1987) sugarcane being a short day plant, is found to flower in Coimbatore (India), Barbados (West Indies), Canal point, Florida and Louisiana (USA), Taiwan, Natal (South Africa), Java (Indonesia), Brisbane (Australia) at some locations in the world. Poor flowering in tropical sugarcane breeding programs possess a considerable impediment to genetic improvement of the crop (Berding et al. 2004) and major limitations are imposed by environmental parameters *viz.,* temperature, photoperiod, humidity, altitude and latitude (McIntyre and Jackson, 2001). Coleman (1959, 1963, 1968) is of the opinion that, optimum photoperiod for flower induction is 12 hours and 35 minutes and flowering decline with any decrease in day length by ±5 min. Clements and Awada (1964) reported that the extent that flowering is decreased depends on the clone, age of the crop, and availability of water. Flowering is inhibited where night temperature drops below 18°C. A night period of 11 hours 32 minutes is very conducive for flowering. Ten continuous nights with temperature below 18°C prevent flowering induction. The factors that influence flowering are the sensitivity of the variety to flowering besides age of the plant some varieties that are very sensitive to flowering may be induced at six months (Araldi et al. 2010). Among the several listed factors affecting flowering including photoperiod, temperature, moisture, age and nutrition, photoperiod is the most important factor as reported by Glassop et al. (2014). Rao et al. (1973) reported that the optimum period of 11:30 to 12:00 hours occurs from the last week of September to mid-October. The successful crossing depends upon the genotypes which are known to flower at the same time. Annadurai et al. (2014) studied the flowering behaviour of parental clones from the National Hybridization Garden at ICAR Sugarcane Breeding Institute, Coimbatore; both subtropical and tropical parents and grouped them into regular flowerers, frequent flowerers, timid flowerers and rare flowerers. Altitudinal difference in the parental clones did not appear to have influence on flowering. Most germplasm need to be evaluated for flowering response with viable fuzz production to identify the best parents for future hybridization program (Ahmed and Gardezi (2017).

S. spontaneum is highly polymorphic, disease resistant, vigorous species with high fibre content. It has variable chromosome numbers ranging from 2n=40 to 128 and is a complex polyploid with a possible basic chromosome number x = 8-10 (Panje and Babu, 1960, Srinivasan et al., 1987; D'Hont et al. 1996). It can be distinguished from the cultivated *Saccharum* by thinner canes and narrow inflorescence (Purseglove 1972). Interspecific hybridization of *S. officinarum* x *S. spontaneum* and the interspecific hybrid derivative with wide adaptability was released as commercial cane variety Co 205 in 1918. Several earlier breeding programmes with *S. spontaneum* as male parent followed by nobilization process yielded an array of varieties for cultivation in different agro-climatic conditions. The present day cultivars have around 15% of *S. spontaneum* genome in their genetic constitution (D'Hont et al. 1995). In the Indian varieties, the genetic base is still very narrow with only 11 *S. officinarum* and two clones of *S. spontaneum* (Natarajan 1994) and the contribution of red rot resistance by *S. spontaneum* chromosome was correlated with the number of *S. spontaneum* chromosomes present in the genome (Natarajan et al 2001). Zhang et al., (2018) identified 361 sequences putatively encoding nucleotide-binding site (NBS) proteins, including 22 N-type, 169 NL-type, 68 CN-type and 102 CNL-type. The number of NBS-encoding genes found to be larger than that in sorghum due to the species-specific tandem duplication in *S. spontaneum.* The present study was carried out to assess flowering behaviour of all the *S. spontaneum* germplasm collections (1916 - 2016) at Coimbatore, Tamil Nadu, India under natural flowering condition to monitor the effect of weather parameter on flowering and to identify the germplasm with synchronized flowering and pollen fertility with the commercial clones.

Materials and Methods

A total of 1459 *S. spontaneum* germplasm accessions collected from different locations of the states of the country (1916 - 2016) along with exotic collections imported from various countries through germplasm exchange programme during 1956-1958 were used as the study material. Most of the clones have been maintained by re-propagation every year except for the new accessions collected during 2015 and 2016 (Table 1). These clones were planted between October to January, every year, in a plot size of single row of 3m x 0.9m with four clumps in each row with 0.50m gap between each clump in our experimental farm at Coimbatore located at 110 N latitude and 770 E longitude. During the year 2017 (season I), planting was carried out during 13.10.2016 to 28.10.2016 (Planting in Oct. 2016), for 2018 season (season II) planting was initiated on 10.01.2018 and completed during 22.01.2018 and for the 2019 season (season III), the date of planting was from 27.12.2018 to 18.01.2019. Regular field operations were carried out and gaps of the non-established clones were filled within one month time from completion of the planting in respective seasons.

Table 1. Collection details of *Saccharum spontaneum* germplasm accessions

S. No.	Place of collection	Year of collection
1	Tamil Nadu	1916, ,1931,1935,1936, 1948, 1999 & 2004
2	Andhra Pradesh	1937, 1948, 1949, 1954, 1955, 2002 & 2003
3	Karnataka	1948, 1949, 1954, 1955 & 2003
4	Kerala	1934, 1937, 1940, 1948, 1949, 1952 & 1999
5	Maharashtra	1954, 1955 & 2015
6	Madhya Pradesh	1955
7	Gujarat	2007
8	Rajasthan	1952 & 2008
9	Punjab & Haryana	1951, 1952 & 2016
10	Uttarakhand	1916 & 2009
11	Uttar Pradesh	1937, 1950 & 1951
12	Bihar	1933, 1936, 1950 & 1981
13	Sikkim	1982
14	Odessa	1937, 1949 & 2001
15	West Bengal	1949, 2001 & 2010
16	Assam	1933, 1935, 1937 & 1951
17	Nagaland	1951
18	Manipur	1951 & 1989
19	Meghalaya	1989 & 2006
20	Mizoram	2004
21	Tripura	2005
22	Arunachal Pradesh	1984, 1985, 1990 & 2000
23	Exotic collections	1929, 1932, 1940, 1951, 1952, 1976 & 1977

Data on flowering based on the appearance of first short blade or flag leaf stage of the parental clones by visual observation of the arrows starting from 1st week of April upto 4th week of December at weekly intervals were recorded. Flowering data for the three consecutive flowering seasons during 2017, 2018 and 2019 were recorded (Table 2). Pollen fertility (%) was assessed by collecting the matured but unopened spikelets and stained with standard acetocarmine staining technique during first flowering season (Table 7) using Olympus compound microscope. Based on pollen fertility, germplasm accessions were grouped into non-fertile (0% fertility), low fertile (1%-40%), medium fertile (41% to 70%) and highly fertile (>70%). Weather data *viz.,* maximum – minimum temperature (°C), solar radiation (Cal./cm2/Day), rainfall (mm), number of rainy days (no.), relative humidity (%) in the forenoon and afternoon were recorded on day to day basis and monthly average were calculated. Pearson correlation co-efficients were worked out using OP-STAT package developed by HAU, Hissar, Haryana.

Results and Discussion

Overall effect of weather parameters on flowering during all three flowering seasons

In the overall effect of weather parameters on flowering, during the 1st year (season I), among the 1459 germplasm accessions planted and established in the field, 437 accessions (33.77 per cent) flowered (Table 2). A considerable impediment existed. Flowering was variable, with a standard deviation of 28.34%. In the 2nd year (season II) also, only 690 accessions flowered with a standard deviation of 29.16%. Improvement in flowering tendency was noticed during the II season flowering because of more number of germplasm clones from southern states flowered *viz;* Tamil Nadu (87.61%), Andhra Pradesh (88.46%), Kerala (88.24%) and from the North eastern states of Sikkim (62.96%), Meghalaya (30.43%), Mizoram (55.17%), Arunachal Pradesh (13.53%). The exotic collections also showed improved flowering (74.83%). There was improvement in flowering during 3rd year (season III) with 60.54% of germplasm accessions flowered with a standard deviation of 26.62%. Latitudinal displacement for these accessions was found to be less and hence consistent flowering noticed in them. However, this could be observed because of the profuse flowering in southern state accessions along with additional accessions from the states of Maharastra (70.45%), Rajasthan (76.47%), Odisha (69.62%) and Tripura (56.25%). Madhya Pradesh accessions (77.78%), followed by Karnataka (77.42%), Kerala (63.24%), Andhra Pradesh (55.77%) and Tamil Nadu accessions (49.56%) showed maximum flowering in all the three seasons with overall mean of 23.65%. This result is in concurrence with the earlier finding by Panje and Srinivasan (1959) that, the behaviour of the successive populations resembles the expected reaction of a single clone when transplanted at various latitudes and is clearly a reflection on mass behaviour of the varying but sharp tolerance limits possessed by each individual. These clones possess to have control over photoperiodic response and or limited level of tolerance. Few of the far off collections *viz.,* Uttar Pradesh and exotic collections in this all season flowering group may tend to possess this kind of mechanism operated in this genotype. The extreme non flowering nature was also noticed in highly displaced locations like Sikkim, Nagaland, Manipur and Meghalaya accessions. As stated by Panje and Srinivasan (1959) that the tendency in most clones is either to flower or not to flower; that is, the transition from a complete readiness to flower to a complete inhibition of flowering is not gradual but somewhat abrupt.

Monthly effect of weather parameter on flowering season during all three seasons

Flowering initiation was observed to be from the fourth month after planting (Table 3). Maximum flowering of 24.55% was observed in October in season I followed by September (21.50%), November (17.75%), December (12.07%) and August (11.23%). The standard deviation was less with 8.71%. During April, increased flowering of 7.49 (%) was observed in this season because of the early planting of the accessions during October 2016. Early period of two months has enhanced crop growth. The older and more vigorous stems in a stool are the most likely to initiate flowering (More and Nuss 1987). In season II, maximum flowering percentage was observed during October (31.35%) followed by November (22.34%), September (16.50%), August (13.96%) and December months (13.71%). The standard deviation was 11.33%. During season III, maximum flowering was recorded during December with 31.89% accessions. Minimum flowering was noticed in all the three seasons during May. As intensity of *Saccharum* sp.

Table 2. Details of *Saccharum spontaneum* accessions flowered during three (2017 to 2019) flowering seasons

S. No.	Collection source	Accn. No.	Season I		Season II		Season III		All three Seasons		Overall mean	Mean min.	Mean max.	SE	SD	CV
			(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(%)					
1	Andhra Pradesh	104	71	68.27	92	88.46	97	93.27	58	55.77	83.33	68.27	93.27	7.66	13.27	15.92
2	Arunachal Pradesh	266	4	1.50	36	13.53	45	16.92	4	1.50	10.65	1.50	16.92	4.68	8.10	76.09
3	Assam	14	10	71.43	12	85.71	13	92.86	3	21.43	83.33	71.43	92.86	6.30	10.91	13.09
4	Bihar	148	20	13.51	55	37.16	68	45.95	18	12.16	32.21	13.51	45.95	9.69	16.78	52.09
5	Exotic collections	151	58	38.41	113	74.83	105	69.54	46	30.46	60.93	38.41	74.83	11.36	19.68	32.30
6	Gujarat	34	25	73.53	11	32.35	26	76.47	8	23.53	60.78	32.35	76.47	14.24	24.67	40.58
7	Karnataka	62	52	83.87	53	85.48	58	93.55	48	77.42	87.63	83.87	93.55	2.99	5.19	5.92
8	Kerala	68	46	67.65	60	88.24	58	85.29	43	63.24	80.39	67.65	88.24	6.43	11.13	13.85
9	Madhya Pradesh	9	7	77.78	9	100.00	9	100	7	77.78	92.59	77.78	100.00	7.41	12.83	13.85
10	Maharashtra	44	14	31.82	22	50.00	31	70.45	9	20.45	50.76	31.82	70.45	11.16	19.33	38.08
11	Manipur	23	0	0.00	8	34.78	7	30.43	0	0.00	21.74	0.00	34.78	10.94	18.95	87.18
12	Meghalaya	23	1	4.35	7	30.43	11	47.83	0	0.00	27.54	4.35	47.83	12.63	21.88	79.47
13	Mizoram	29	4	13.79	16	55.17	19	65.52	4	13.79	44.83	13.79	65.52	15.80	27.37	61.06
14	Nagaland	1	0	0.00	0	0.00	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Odessa	79	21	26.58	24	30.38	55	69.62	18	22.78	42.19	26.58	69.62	13.76	23.83	56.47
16	Punjab & Haryana	107	4	3.74	12	11.21	28	26.17	0	0.00	13.71	3.74	26.17	6.59	11.42	83.33
17	Rajasthan	17	8	47.06	7	41.18	13	76.47	4	23.53	54.90	41.18	76.47	10.92	18.91	34.44
18	Sikkim	27	0	0.00	17	62.96	13	48.15	0	0.00	37.04	0.00	62.96	19.01	32.92	88.88
19	Tamil Nadu	113	60	53.10	99	87.61	98	86.73	56	49.56	75.81	53.10	87.61	11.36	19.68	25.95
20	Tripura	16	2	12.50	5	31.25	9	56.25	2	12.50	33.33	12.50	56.25	12.67	21.95	65.85
21	Uttarakhand	48	11	22.92	8	16.67	18	37.5	4	8.33	25.70	16.67	37.50	6.17	10.69	41.60
22	Uttar Pradesh	19	9	47.37	12	63.16	13	68.42	8	42.11	59.65	47.37	68.42	6.32	10.96	18.37
23	West Bengal	57	10	17.54	12	21.05	20	35.09	5	8.77	24.56	17.54	35.09	5.36	9.29	37.81
	Total / Mean	**1459**	**437**	**33.77**	**690**	**49.64**	**814**	**60.54**	**345**	**23.65**						
	SE			6.04		6.22		5.68								
	SD			28.34		29.16		26.62								
	CV			83.91		58.75		43.97								

Table 3. Month wise details of *Saccharum spontaneum* flowering over season

S. No.	Month	Number of accessions flowered and percent flowering									
		Season I		Season II		Season III		Overall Mean	Mean max.	Mean min	SD
		(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(no.)	(no.)	(no.)
1	April	54	7.49	8	1.02	3	0.32	2.94	7.49	0.32	3.95
2	May	10	1.39	2	0.25	1	0.11	0.58	1.39	0.11	0.70
3	June	11	1.53	2	0.25	2	0.22	0.67	1.53	0.22	0.75
4	July	18	2.50	5	0.63	6	0.65	1.26	2.50	0.63	1.07
5	August	81	11.23	110	13.96	64	6.90	10.70	11.23	6.90	3.56
6	September	155	21.50	130	16.50	180	19.40	19.13	21.50	16.50	2.51
7	October	177	24.55	247	31.35	160	17.24	24.38	31.35	17.24	7.06
8	November	128	17.75	176	22.34	216	23.28	21.12	23.28	17.75	2.96
9	December	87	12.07	108	13.71	296	31.89	19.22	31.89	12.07	11.00
	Total / Mean	721	11.11	788	11.11	928	11.11				
	Maximum		24.55		31.35		31.89				
	Minimum		1.39		0.25		0.11				
	SD		8.71		11.33		12.09				

flowering is dependent on interaction of cultivars with environmental factors such as day length and temperature, some varieties can flower profusely in the natural environment but flower sparingly when introduced to other regions (Bull and Glasziou 1979).

More and Nuss (1987) opined that cool night temperatures, high day temperatures and lack of moisture interferes with flower initiation. Coimbatore is having a distinct rainy season which starts after the dry early summer period during March and April . Once the rainy season starts, the *S. spontaneum* accessions flower toward or immediately after the monsoon season. The mean rainfall (RF) over three season was recorded to be 108.10 mm during May after a long spell of dry months during December (13.90 mm RF), January (11.83 mm RF), February (0.00 mm RF), March (29.13 mm RF) and April (29.13 mm RF) respectively. The mean rainfall during May was distributed over 7.67 rainy days with good sunshine (Solar radiation 389.75 Cal./cm2/ Day) followed by gradual reduction in maximum temperature to 30°C with minimum temperature of around 23°C. Subsequently the relative humidity in the forenoon was above 88.0% and in the forenoon around 63.0 % (Table 4) which enhances flowering in *S. spontaneum.* The above result is in concurrence with the earlier finding that the high humidity and increased soil moisture will affect the elongation of the floral axis. The sharp diurnal variation in humidity and temperature towards or immediately after the cessation of rains probably will have a vital relationship with the effective protrusion, dehiscence ad functioning of anthers (Panje and Srinivasan, 1959).

Table 4. Mean data on flowering and weather parameters over three seasons

S. No.	Month	Accessions Flowered (no.)	Max. temp. (°C)	Min. temp. (°C)	Solar radiation (Cal./cm2/ Day)	Rainfall (mm)	Rainy days (mm)	Relative humidity in the forenoon (%)	Relative humidity in the afternoon (%)
1	Jan.	0	29.97	18.53	387.93	11.83	0.67	86.18	51.311
2	Feb.	0	32.77	19.19	409.75	0.00	0.00	84.22	46.42
3	Mar.	0	34.80	21.94	403.60	29.13	2.33	83.62	44.24
4	Apr.	22	35.96	24.06	385.90	25.70	2.33	84.99	48.40
5	May	4	33.46	24.45	389.75	108.10	7.67	85.76	56.65
6	Jun.	5	30.07	23.85	325.35	32.27	4.67	82.95	61.56
7	Jul.	10	30.04	23.09	317.63	48.73	5.00	82.59	60.50
8	Aug.	92	29.41	22.66	300.58	139.03	6.33	86.12	64.82
9	Sep.	148	28.68	22.52	340.63	141.80	7.00	88.69	62.99
10	Oct.	195	29.91	22.07	315.88	174.93	8.67	89.00	63.36
11	Nov.	173	30.11	21.74	329.30	54.23	4.33	88.56	63.63
12	Dec.	164	29.50	20.84	325.40	13.90	1.33	88.13	59.22
Total / Overall mean		812	31.22	22.08	352.64	779.67	50.33	85.90	56.93

Correlation study on flowering over three season weather parameters

Correlation study on flowering over three season weather parameters (Table 5) revealed that relative humidity in forenoon had a highly significant positive correlation (0.886) and also relative humidity in the afternoon had a significant positive correlation (0.657). However, solar radiation had a significant negative correlation on flowering (-0.657). Rainfall and rainy days had positive correlation but it is non-significant. Rainfall had a significant positive significant correlation (0.707) on flowering during season I (Table 6) but non-significant and positive for the remaining two seasons. This is in confirmation with the observation recorded in *S. spontaneum* by Panje and Srinivasan (1959) that collections from areas of high rainfall fail to flower because they have a comparatively long vegetative phase which cannot be completed in short season available for growth and if maintained for second year, it will come to flower. Maximum temperature had a significant negative correlation (-0.560) on flowering during season III. Significant negative correlation was noticed for solar radiation in season I (-0.699) and season III (-0.661) however it was non-significant and negative (-0.451) during Season II. Highly positive and significant correlation was observed for relative humidity in the forenoon for the Season I (0.806) and season III (0.802) and it was only positive and significant in the Season II (0.615). Even though the effect of relative humidity in the afternoon was positive and non-significant for flowering of *S. spontaneum* during Season I and season II, it was highly positive and significant in season III (0.744).

Table 5. Correlation coefficients among qualitative and quantitative weather parameters on flowering of *Saccharum spontaneum* field grown over three seasons during 2017– 2019

Parameter	Maximum temperature	Minimum temperature	Solar radiation	Rainfall	Rainy days	Relative humidity in forenoon	Relative humidity in afternoon
Flowering	-0.560^{NS}	-0.045^{NS}	-0.628^{*}	0.539^{NS}	0.404^{NS}	0.886^{**}	0.657^{*}
Maximum temperature		0.235^{NS}	0.761^{**}	-0.363^{NS}	-0.311^{NS}	-0.444^{NS}	-0.798^{**}
Minimum temperature			-0.278^{NS}	0.394^{NS}	0.641^{*}	-0.192^{NS}	0.325^{NS}
Solar radiation				-0.496^{NS}	-0.537^{NS}	-0.325^{NS}	-0.915^{**}
Rainfall					0.918^{**}	0.520^{NS}	0.642^{*}
Rainy days						0.325^{NS}	0.705^{*}
Relative humidity in forenoon							0.476^{NS}

$^{*}P<0.05$; $^{**}P<0.01$

Table 6. Correlation coefficients among quantitative weather parameters on flowering of *Saccharum spontaneum* field grown over three seasons during 2017– 2019

S. No.	Parameter	Flowering season			
		I	II	III	Overall
	Maximum temperature	-0.498^{NS}	-0.470^{NS}	-0.592^{*}	-0.560^{NS}
	Minimum temperature	0.204^{NS}	-0.301^{NS}	-0.095^{NS}	-0.045^{NS}
	Solar radiation	-0.699^{*}	-0.451^{NS}	-0.661^{*}	-0.628^{*}
	Rainfall	0.707^{*}	0.183^{NS}	0.236^{NS}	0.539^{NS}
	Rainy days	0.453^{NS}	0.253^{NS}	0.269^{NS}	0.404^{NS}
	Relative humidity in forenoon	0.806^{**}	0.615^{**}	0.802^{**}	0.886^{**}
	Relative humidity in afternoon	0.557^{NS}	0.456^{NS}	0.744^{**}	0.657^{*}

$^{*}P<0.05$; $^{**}P<0.01$

Pollen fertility of the germplasm accessions in response to weather parameters during 1st flowering season.

Several environmental stresses are known to affect pollen production and viability. Pollen grains are thought to enter a state of complete or partial developmental arrest and is strongly associated with acquisition of desiccation tolerance to extend pollen viability. The occurrence of developmental arrest in pollen is both species-dependent and is also strongly dependent on the reigning environmental conditions at the time of dispersal (Mesihovic et al., 2016).The wide geographical distribution of *S. spontaneum* is an evidence of its high adaptive potential which presumably are due, in part, to its polyploid nature. *S. spontaneum* reproduces sexually and vegetatively and the vegetative propagation might account for their presence and persistence in a large number of clones (Sreenivasan, 1975). Pollen fertility of the *S. spontaneum* accessions studied during the Season I in 721 accessions (Table 7) revealed that 208 accessions were completely sterile and are grouped into non-fertile accessions. Mesihovic et al., (2016) reported that the adverse environmental conditions affect all stages of male gametophyte development. Because pollen development occurs inside the anther and flowers of the mother plant, negative effects of the environment on the sporophyte are also communicated to the gametophytes (Hinojosa et al., 2018). Less than one per cent to 40 per cent was noticed in seven clones and grouped in low fertile accessions. Medium fertility (41 % to 70%) was recorded in 29 accessions. Four hundred and seven accessions fall under highly fertile group with more than 70 per cent fertility (Fig. 1). Latitudinal displacement for these clones may found to be less and hence flowering was noticed in these accessions. Begcy and Dresselhaus, (2018) was of the opinion that anther and pollen desiccation are crucial to prepare pollen for dispersal when environmental conditions are optimal for pollen survival. When the mother plant experiences stress conditions, this signal will reach the pollen grains and affect preparation and timing of pollen dispersal. Release of pollen in the environment is therefore controlled by equilibrium between the atmospheric conditions and the physiological state of the plant. Many of the *S. spontaneum* studied here had acclimatized with the weather conditions over years at Coimbatore and hence highest percentage of flowering was noticed in these accessions.

Table 7. Details of pollen fertility study in *Saccharum spontaneum* during I flowering season

Category	Pollen Fertility range (%)	Accessions Flowered (no.)	Accessions Flowered (%)
1	0	208	28.89
2	1 to 10	0	0.00
3	11 to 20	1	0.14
4	21 to 30	1	0.14
5	31 to 40	5	0.69
6	41 to 50	11	1.53
7	51 to 60	6	0.83
8	61 to 70	12	1.67
9	71 to 80	62	8.61
10	81 to 90	232	32.18
11	91 to 100	183	12.64
	Total	721	

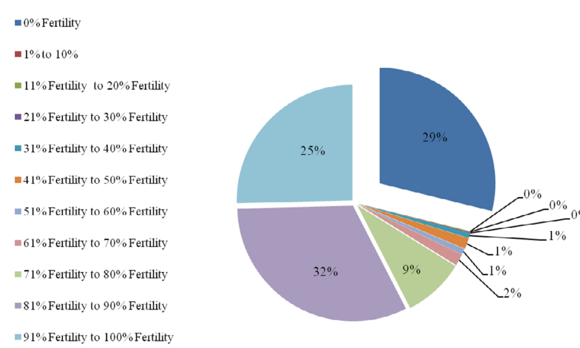

Figure 1. Pollen fertility in *Saccharum spontaneum* during I season of study

Conclusion

A comprehensive study of flowering behaviour of *S. spontaneum* accessions collected over a century (1916-2016) and maintained at the world germplasm collection of *Saccharum sp.* and related genera at ICAR- Sugarcane Breeding Institute, Coimbatore have been undertaken. Being the most complex physiological process requiring various physiological and environmental cues, flowering in the wild germplasm collections from various geographical locations of India and around the world exhibited interesting patterns across the three seasons. For effective utilization of *S. spontaneum* in sugarcane improvement programmes, the information on the extent and patterns of flowering is very essential. The flowering behaviour and consistency of flowering of about 1459 clones of *S. spontaneum* collected from different states of the country and abroad by exchange programmes have been observed at Coimbatore consecutively for three years. In all the three seasons, the germplasm accessions of the southern states *viz.,* Karnataka, Kerala, Andhra Pradesh, and Tamil Nadu expressed profuse flowering along with additional accessions from the states of Madhya Pradesh, Maharashtra, Rajasthan, Odisha and Tripura. Regular photoperiodic exposure of the accessions in their native region and the accessions with latitudinal tolerance allowed the clones to flower consistently even when they were latitudinally displaced. The extreme non-flowering nature was also noticed in highly displaced locations like Sikkim, Nagaland, Manipur and Meghalaya accessions. Flower initiation was observed during fourth month after planting onwards and maximum flowering of the accessions was noticed during October month irrespective of planting date. Weather parameters correlated with flowering of the accessions revealed that both relative humidity in the forenoon as well in the afternoon had a significant positive correlation and solar radiation had a highly negative correlation on flowering. Rainfall and rainy days had positive correlation but it is non-significant and if rainfall is good and number of rainy days is more during different months of the flowering initiation phase in *S. spontaneum,* it will have a positive significance on flowering as observed during season I. Four hundred and seven (56.45%) of the *S. spontaneum* genotypes had more than seventy percent pollen fertility and the optimum temperature required for panicle development and pollen fertility for *S. spontaneum* under Coimbatore was found to be 30°C during day and 22°C at night. Based on our observations, timely utilization of the 345 new flowering *S. spontaneum* germplasm accessions, late flowering genotypes during late November and early December months and accessions sensitive/tolerant to displacement, in the sugarcane improvement program will help to increase the probability of obtaining varieties with stable abiotic and biotic stress tolerance in sugarcane in future.

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