STATUS OF RED ROT RESISTANCE IN WILD RELATIVES OF SUGARCANE, *SACCHARUM SPONTANEUM*, INTERSPECIFIC HYBRIDS AND INTERGENERIC HYBRIDS

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Abstract

Identifying new sources for red rot resistance is a continuous process to enrich parental pools for disease resistance in sugarcane. Earlier, sugarcane varieties under cultivation, interspecific hybrids of *Saccharum officinarum*, *S. spontaneum* and *S. barberi* were screened for red rot caused by *Colletotrichum falcatum* and resistant sources were identified. Subsequently to broaden sources of resistance different *Saccharum* spp clones and their derivatives referred as interspecific hybrids (ISH) were screened and resistant genotypes were identified. Recently intergeneric hybrids (IGH) involving *Erianthus* spp. with *Saccharum* spp or other hybrids were screened to identify red rot resistant sources. Earlier, these populations were screened at Karnal and Motipur under subtropical conditions and Kovvuru and Madhurantakam under tropical conditions against respective pathotypes of the region by plug method of inoculation. Later, the ISH / IGH populations were tested for red rot resistance under controlled condition at Coimbatore and this provided an opportunity to screen large clonal population in a shorter time. Field testing at different locations identified only a few clones exhibiting resistance across the locations. Among the centres, Kovvuru centre in Andhra Pradesh exhibited more susceptibility and only a few resistant types could be identified. Some of the cytoplasmic derivative clones and IGH clones in specific cross combinations exhibited greater red rot resistance. These studies provide an updated information in status of red rot resistance in wild relatives of *Saccharum* spp. and their derivatives.

Key words: Sugarcane, *Saccharum spontaneum*, *Erianthus* spp., interspecific hybrids, intergeneric hybrids, red rot, resistance

Introduction

Red rot has been a major limiting factor for crop productivity in sugarcane for more than 100 years both in the tropical and subtropical India (Viswanathan 2018; Viswanathan et al. 2018). This is one of the major production constraints in all five agro climatic zones identified for sugarcane growing in India (Nair 2011). The disease was first recorded as devastating nature in Godavari district during 1895 and this resulted in search for new varieties resistant or tolerant to the disease (Barber 1901). To manage the disease, concerted efforts were made for more than 100 years by exploiting host resistance in *Saccharum* spp. and allied genera in the germplasm. It was realized that varietal resistance to red rot is very much essential though development of disease resistant varieties is expensive and time consuming. In this regard, understanding of resistance mechanisms and fool proof red rot screening methods are necessary (Srinivasan 1987). Further, host resistance is considered to be cheaper in terms of management costs and sustainability in the long run. Hence, emphasis was given to develop new varieties of high agronomic values with red rot resistance and also it is the major mandate of Indian sugarcane

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breeding programme (Viswanathan 2010). Incorporation of resistant genes in sugarcane varieties is being harnessed from various resources. However, stability of red rot resistance in our sugarcane varieties is low. Most of the elite varieties succumbed to red rot after being in the field for a short span of time. This phenomenon of varietal breakdown occurred during different decades in the country (Viswanathan 2017, 2018).

The modern sugarcane varieties are evolved through interspecific hybridization involving two or more clones of *S. officinarum*, *S. spontaneum* and *S. barberi* (Arceneaux 1965). The identification of successful inter specific hybrids through cane breeding programme is crucial in selection of a variety. The role of *S. spontaneum* and *S. barberi* clones in improving the disease resistance of Indian canes are well known (Sreenivasan 1995). During 1980's, the base broadening programme was started in India through intercrossing, back crossing and crossing with commercial varieties to develop genetic stocks and new varieties. The *Saccharum* spp. and other related genera like *Erianthus, Sclerostachya* and *Narenga* were utilized for intergeneric crosses to improve the productivity of new varieties (Nair 2007). Many sources for red rot resistance have been identified both in germplasm and hybrids for utilization in breeding programme. Baragua, Seleri and Saipan G of *S. officinarum* and IJ 76-332, IJ 76-365, IJ 76-383, IJ 76-384, IJ 76-400, IK 76-78, IK 76-88 and IK 76-99 of *Erianthus,* many clones of *S. spontaneum* and the hybrids such as BO 91, Co 62175, Co 7314, Co 94008, Co 62198 and Co 86249 are being utilized in Indian breeding programme (Nair 2012).

For effective utilization of the available germplasm in breeding programme, apart from evaluation for agronomic traits, a systematic phenotyping for red rot resistance is required and therefore, red rot screening of germplasm, inter specific hybrids (ISH), inter generic hybrids (IGH), progenies etc was carried in the field to identify red rot resistance at different locations of ICAR-SBI viz., Karnal, Motipur and Kovvuru and at a factory location, near Padalam Madhurantakam in Tamil Nadu. Subsequently, both field and controlled condition testing were carried out at Coimbatore. The disease screening programmes carried out during the last two decades at the Institute provided valuable information on red rot resistance in sugarcane germplasm especially wild relatives of *Saccharum* and their derivatives.

Materials and methods

During 1990's, a set of inter-specific progenies with diverse clones of *S. spontaneum* and *S. officinarum* as the progenitors were utilized as genetic stocks for red rot resistance at ICAR-SBI. ISH, IGH, cytoplasmic (CYM), cytoplasmic diverse (CD) and back cross (BC) clones, *Erianthus*-sugarcane hybrid derivatives and half sib progenies were screened under field conditions adopting plug method at Karnal (29.6857° N, 76.9905° E), Motipur, Bihar (26.2525° N, 85.1609° E), Kovvuru, Andhra Pradesh (17.0125° N, 81.7267° E) and Padalam, Madhurantakam taluk, Kancheepuram Dt, Tamil Nadu (12.5995° N, 79.9482° E) and in controlled condition testing (CCT) facility at Coimbatore, Tamil Nadu (11.0168° N, 76.9558° E). Region specific *C. falcatum* (CF) pathotypes were used to phenotype sugarcane clones in different centres for red rot resistance. At Karnal, three pathotypes from sugarcane cvs Co 1148 (CF01), Co 7717 (CF02) and CoJ 64 (CF03), at Motipur, red rot pathotypes from Co 1148, Co 8340, and CoS 687, at Kovvuru, pathotypes from Co 419 (CF04), Co 997 (CF05), Co 8317 and CoC 671 (CF06) and at Padalam, pathotype from CoC 671 (CF 06) were used for red rot resistance screening. The respective cultures maintained as reference red rot pathotypes at the Plant Pathology Lab were multiplied on oatmeal

agar at Coimbatore for inoculation every year, re-isolated from the host cultivars after evaluation, re-isolated and maintained in virulent form.

Plug method

In this method, the screening for red rot resistance was done on 6-7 months old standing canes in the field. Well grown canes free from any borer attack and cracks were selected for inoculation. The field was maintained without spraying any pesticide or weedicide. A bore-hole was made on the 3rd internode from the base by puncturing the cane portion using a red rot inoculator (Mohanraj et al. 2012). About 0.5 ml of *C. falcatum* conidial suspension was dropped in the plug hole, replaced the removed tissue core and sealed with a plastic clay to prevent the entry of ants and secondary contamination. Well known red rot susceptible varieties (Co 1148, CoJ 64 and CoC 671) were included as check along with the test clones in the trials. Sixty days after inoculation, the inoculated canes were cut at ground level, split-open longitudinally and assessed red rot severity. The lesion width, nodal transgression, presence of white spots and condition of the crown, green or dry / yellow were the parameters considered for assessing red rot resistance. A 0-9 scale developed at SBI was followed to rate the disease resistance in the clones as resistant to highly susceptible (Srinivasan and Bhat 1961).

Controlled condition testing (CCT) method

Six to eight months old canes from the field were cut and trimmed to ~1.5 m portion along the crown leaves. A minimum of three canes per clone were inoculated along with a standard susceptible variety (CoC 671). The pathogen was inoculated on two nodes after removing the leaf sheath. The cotton strip dipped in conidial suspension was wrapped around two notes of 6th-8th from the top. The inoculated canes were kept inside the red rot testing chamber on a sand bed and incubated under the conditions of 30-32°C temperature and relative humidity of >90% for 10 days. High humidity was achieved with overhead humidifiers with automated timer controls. Metallic stand with grids were used to keep the canes upright on the sand bed. This method is very effective to screen large number of breeding population and germplasm (Viswanathan et al. 1998, 2018). Disease development and its severity were assessed based on the following parameters, lesions on leaf scar and growth ring, infections on buds and root eyes, nature of lesions on the rind, internal spread of the lesions and fungal growth on the affected tissue.

Results

Field testing at different locations

During 1993-1996, a total of 301 ISH clones were

Table 1. Status of red rot resistance in ISH clones at three locations against plug method of testing

Centre	Total clones screened	Red rot reaction*				
		R	MR	MS	S	HS
Karnal, Haryana	281	2	33	61	36	149
		(0.71)	(11.74)	(21.71)	(12.81)	(53.02)
Kovvuru, AP	185	0	1	3	48	133
		(0.00)	(0.54)	(1.62)	(25.95)	(71.89)
Motipur, Bihar	110	0	6	31	24	49
		(0.00)	(5.45)	(28.18)	(21.82)	(44.55)

* Figures in parentheses indicate per cent values for the respective disease reaction

Table 2. Red rot reaction in ISH clones under plug method of testing at Karnal

Clone No.	Parentage	Progenitors*	Red rot Reactions
ISH-007	(57 NG 77 x NG 77-24) (57 NG 199 x 57 NG 80)	SS	MR
ISH-050	Co 740 (CP43-47 x 57 NG 80)	IFR	MR
ISH-061	Co 740 (CP43-47 x 57 NG 80)	IFR	MR
ISH-062	Co 740 (CP43-47 x 57 NG 80)	IR	MR
ISH-063	Co 740 (CP43-47 x 57NG 80)	IR	MR
ISH-100	Co 7202 [CoC 671 (57 NG 110 x *S. robustum*)	IISR	MR
ISH-110	Co 7704 x Keong	IO	MR
ISH-111	Keong x MS 68/47	OI	MR
ISH-112	Keong x Co 1307	OI	MR
ISH-115	Keong x MS 68/47	OI	MR
ISH-135	Co 62174 x SES 515/3	IS	MR
ISH-146	Co 1148 x SES 49	IS	MR
ISH-176	Co 6806 x Khakai	IB	MR
ISH-177	CP44-101 x Khakai	FB	MR
ISH-188	Keong x Co 1307	OI	MR
ISH-192	Keong x Co 1307	OI	MR
ISH-193	M. Red x Co 62174	OI	R
ISH-198	M. Red x Co 62174	OI	MR
ISH-203	Saipan G x Co 62174	OI	MR
ISH-229	57 NG 222 x Co 62174	RI	MR
ISH-234	Keong x MS68/47	OI	MR
ISH-241	Gungera x Khakai	OB	MR
ISH-243	Gungera x Khakai	OB	MR
ISH-263	Keong x Khakai	OB	MR
ISH-265	Keong x Khakai	OB	MR
ISH-267	Keong x Khakai	OB	R
ISH-268	Keong x Khakai	OB	MR
ISH-286	Mignone x G1690	OS	MR
ISH-292	Kansar x MS68/47	BI	MR
ISH-314	Q68 x SES147-A	FS	MR
ISH-421	H-3, (*S. officinarum* x *S. spontaneum*) MS 68/47	OSI	MR
ISH-425	H-48, *S. spontaneum* x MS 68/47	SI	MR
ISH-431	H-91, Cy80-98 x Co 775		MR
360	CoC 671(57NG110 x *S. robustum*)	IRR	MR
450	CoC 671(57NG110 x *S. robustum*)	IRR	MR

*B = *S. barberi*; R = *S. robustum*; S = *S. spontaneum*; O= *S. officinarum*; I= Indian hybrids; F= Foreign hybrids

Table 3. Red rot reaction in improved ISH clones under plug method of testing at different locations

No.	Cross	Red rot resistance in ISH clones*			
		Total number of clones	R	MS	S
	Karnal				
1	ISH 62 x Co 8209	4	3	-	1
2	ISH 63 x Co 8209	4	-	3	1
3	ISH 175 x Co 89003	3	-	-	3
4	ISH 244 x Co 89003	4	-	-	4
5	ISH 153 x Co 1148	3	-	1	2
6	ISH 21 x Co 1148	6	1	1	4
7	ISH 28 x Co 1148	2	-	-	2
8	ISH 110 x Co 775	4	-	2	2
9	ISH 153 x Co 775	1	-	-	1
10	ISH 21 x Co 775	3	1	2	-
11	SES 137B x Co 7201	27	-	3	24
12	SES 144 x Co 7201	25	-	3	22
13	SES 146 x Co 7201	28	-	1	27
14	F1 33 x Co 7314	13	-	4	9
15	ISH 62 x Co 7314	3	3	-	-
16	SES 268 x Co 7314	9	-	2	7
17	SES 274 x Co 7314	8	-	1	7
18	SES 275 x Co 7314	10	-	1	9
19	SES 605 x Co 7314	13	-	2	11
20	ISH 100 x Co 89012	1	-	1	-
21	ISH 153 x Co 8347	1	-	-	1
22	ISH 175 x Co 8373	5	-	-	5
23	ISH 175 x CoSi 776	3	-	-	3
24	ISH 175 x ISH 133	2	-	-	2
25	ISH 216 x Co 62422	8	-	3	5
26	ISH 34 x Co 740	10	-	2	8
26.	ISH 63 x Co 7314	2	-	-	2
27.	ISH 69 x Co 7915	2	-	-	2
28.	SES 268 x Co 62422	9	-	1	8
29.	ISH 180 x Co 7205	3	-	2	1
	Sub Total	216	8	35	173

No.	Cross	Red rot resistance in ISH clones*			
		Total number of clones	R	MS	S
	Motipur				
1	Co 7201 x IND 82-321	40	-	15	25
2	Co 7201 x IND 82-321	43	3	28	12
3	Co 7201 x IND 82-319	40	7	27	6
4	Co 7201 x IND 82-319	43	1	13	29
5	Co 7201 x IND 82-254	40	5	23	12
6	Co 7201 x IND 82-254	48	8	17	23
7	DW82208 x SES 605	39	-	10	29
8	Co 7201 x SH 216	42	1	28	13
	Sub Total	335	25	161	149
	Kovvuru				
1	SES 515/7 x Co 6806	6	-	6	-
2	SES 2 x Co 6806	28	-	3	25
3	SES 121 A x CoC 671	3	-	-	3
4	SES 2 x CoC 671	8	-	-	8
5	SES 148 x CoC 671	21	-	-	21
6	SES 515/7 x CoC 671	21	-	3	18
7	SES 515/7 x Co 7704	25	9	7	9
8	Co 7201 x SES 147B	101	0	8	93
9	Co 7201 x SES 148	42	3	9	29
10	Co 7201 x SES 137B	116	2	8	106
11	Co 62198 x SES 147B	20	2	1	16
12	Co 62198 x SES 148	35	4	3	28
	Sub Total	426	20	48	356
	Padalam				
1	Co 7201 x SES 147B	79	13	14	52
2	Co 7201 x SES 148	63	9	12	42
3	Co 7201 x SES 137B	84	14	21	43
4	Co 62198 x SES 147B	20	2	4	14
5	Co 62198 x SES 148	35	4	5	26
	Sub Total	281	42	56	177
	Grand Total	1258	95	300	855

*Reactions comprised both R and MR reactions; S reactions comprised both S and HS reactions.

screened for red rot resistance at three locations viz., Karnal, Motipur and Kovvuru by plug method (Table 1). At Karnal, of the 281 ISH clones evaluated for red rot resistance only two resistant clones were identified viz., ISH-193 and ISH-267 derived from Mauritius Red x Co 62174 and Keong x Khakai respectively. About 33 ISH clones were identified as moderately resistant (MR) to red rot. These ISH clones possessing resistance to three prominent pathotypes of the subtropical region had a diverse genetic background (Table 2). The clones such as ISH-007, -100, -135, -146, -286, -314, -421 and -425 had *S. spontaneum* in their parentage. The clones such as ISH-177, -241, -243, -263, -265 and ISH-268 had *S. officinarum* and *S. barberi* in their parentage.

At Motipur, of the 110 ISH clones screened against red rot pathotypes from the cvs Co 1148, Co 8340, and CoS 687, only six viz., ISH-185, -241, -242, -258, -267 and -286 were found to be resistant. At Kovvuru, of the 185 ISH clones screened against a mixture of the pathotypes from Co 419, Co 997, Co 8317 and CoC 671, it was observed that all of them were found to be highly susceptible (HS) and only one clone ISH-012 was found to be MR. The only one clone ISH-267 (Keong x Khakai) which was found to be resistant at Karnal and Motipur behaved as HS at Kovvuru. Subsequently, a total of 1258 improved ISH clones were screened at Karnal, Motipur, Kovvuru and Padalam for red rot resistance (Table 3). At Karnal, of the 216 clones screened only eight were resistant, 35 were moderately susceptible (MS) and 173 were susceptible. At Motipur, 25 clones were identified as resistant out of 335 clones. However, many of the cross derivatives of ISH and popular varieties were found to be red rot susceptible. At Kovvuru, of the 426 clones screened, 20 were resistant, 48 were MS and 356 were susceptible. Only derivatives from SES 515/7 x Co 7704 cross were found to harbour red rot resistance at Kovvuru. When the parent Co 7201 crossed with *S. spontaneum* clones (1982 series), many progenies were found to be red rot resistant at Kovvuru indicating improvement of resistance in the susceptible varieties through incorporation of resistance genes from *S. spontaneum*. About 16% of clones of Co 7201 x SES 147B crosses were resistant at Padalam whereas no resistant clone was identified for the same cross at Kovvuru (Table 3). The same trend was observed while screening Co 7201 x SES 137B progenies. In case of Co 62198 x SES 147B population, equal number of resistant clones were obtained both at Kovvuru and Padalam locations.

Controlled condition evaluation

CYM hybrids

The derivatives of *S. spontaneum* and *Erianthus* sp. were inter crossed with commercial cane hybrids such as BO 130, Co 775, Co 62198, Co 89029 and CoC 671 to improve commercial traits in the CYM hybrids. While screening 462 progenies derived from many of these crosses for red rot resistance, under controlled conditions with CF06 pathotype, 155 CYM clones were found to show red rot resistance (Table 4). It was observed that 86 % of clones derived from CYM 07-649 x Co 89029 were found to be resistant whereas, the cross CYM 07-980 x Co 62198 resulted in many susceptible clones (95.7%).

When the crosses derived from common male parent were combined, the results indicated that the red rot susceptible clone CoC 01061 contributed highest frequency (66.7%) followed by Co 94008 (62.5%) towards resistance (Table 4). When Co 775 was used as a pollen parent, there was slightly low frequency (21.0%) of resistant clones and Co 62198 resulted in the highest frequency of susceptible clones (72.7%) than any other male parents when crossed with CYM clones for improving red rot resistance. While

Table 4. Red rot resistance in cytoplasmic clones crossed with popular varieties tested under controlled conditions testing

Cross	No. of clones	Segregation pattern*			% segregation		
		R	MS	S	R	MS	S
CYM 07-986 X CoPant 97222	12	8	1	3	66.7	8.3	25.0
CYM 07-955 X CoPant 97222	7	2	1	4	28.6	14.3	57.1
Sub Total	19	10	2	7	52.6	10.5	36.8
CYM 07-971 x CoC 671	19	5	2	12	26.3	10.5	63.2
CYM 06-1308 x CoC 671	7	0	3	4	0.0	42.9	57.1
CYM 08-922 x CoC 671	9	0	0	9	0.0	0.0	100.0
CYM 07-986 x CoC 671	11	2	1	8	18.2	9.1	72.7
CYM 07-971 x CoC 671	3	0	0	3	0.0	0.0	100.0
CYM 07-910 x CoC 671	23	4	10	9	17.4	43.5	39.1
CYM 06-1308 x CoC 671	9	1	3	5	11.1	33.3	55.6
CYM 05-230 x CoC 671	6	3	1	2	50.0	16.7	33.3
CYM 04-4520 x CoC 671	2	0	2	0	0.0	100.0	0.0
Sub Total	89	15	22	52	16.9	24.7	58.4
CYM 06-292 X CoC 01061	5	3	0	5	60.0	0.0	100.0
CYM 04-403 X CoC 01061	1	1	0	0	100.0	0.0	0.0
Sub Total	6	4	0	5	66.7	0.0	83.3
CYM 08-997 x Co 99006	8	4	2	2	50.0	25.0	25.0
CYM 08-973 x Co 99006	3	1	1	1	33.3	33.3	33.3
CYM 06-292 x Co 99006	6	4	0	2	66.7	0.0	33.3
Sub Total	17	9	3	5	52.9	17.6	29.4
CYM 08-922 x Co 94008	3	2	0	1	66.7	0.0	33.3
CYM 08-903 x Co 94008	6	5	1	0	83.3	16.7	0.0
CYM 08-828 x Co 94008	6	3	3	0	50.0	50.0	0.0
CYM 08-686 x Co 94008	1	0	0	1	0.0	0.0	100.0
CYM 08-671 x Co 94008	3	0	0	3	0.0	0.0	100.0
CYM 08-314 x Co 94008	13	10	3	0	76.9	23.1	0.0
Sub Total	32	20	7	5	62.5	21.9	15.6
CYM 08-729 x Co 89029	3	3	0	0	100.0	0.0	0.0
CYM 08-691 x Co 89029	4	1	0	3	25.0	0.0	75.0
CYM 07-941 x Co 89029	12	6	2	4	50.0	16.7	33.3
CYM 07-893 x Co 89029	4	3	1	0	75.0	25.0	0.0
CYM 07-882 x Co 89029	14	6	0	8	42.9	0.0	57.1
CYM 07-649 x Co 89029	29	25	4	0	86.2	13.8	0.0
CYM 07-561 x Co 89029	1	1	0	0	100.0	0.0	0.0

Cross	No. of clones	Segregation pattern*			% segregation		
		R	MS	S	R	MS	S
CYM 05-97 x Co 89029	7	3	0	4	42.9	0.0	57.1
CYM 04-388 x Co 89029	7	4	0	3	57.1	0.0	42.9
Sub Total	81	52	7	22	64.2	8.6	27.2
CYM 07-986 x Co 775	15	0	2	13	0.0	13.3	86.7
CYM 07-980 x Co 775	59	13	22	24	22.0	37.3	40.7
CYM 07-963 x Co 775	9	2	1	6	22.2	11.1	66.7
CYM 07-900 x Co 775	1	1	0	0	100.0	0.0	0.0
CYM 06-590 x Co 775	1	0	0	1	0.0	0.0	100.0
CYM 06-374 x Co 775	2	2	0	0	100.0	0.0	0.0
CYM 05-184 x Co 775	7	0	0	7	0.0	0.0	100.0
CYM 04-420 x Co 775	6	3	2	1	50.0	33.3	16.7
CYM 04-395 x Co 775	5	1	2	2	20.0	40.0	40.0
Sub Total	105	22	29	54	21.0	27.6	51.4
CYM 07-981 x Co 62198	9	0	1	8	0.0	11.1	88.9
CYM 07-980 x Co 62198	28	1	14	13	3.6	50.0	46.4
CYM 07-678 x Co 62198	1	0	0	1	0.0	0.0	100.0
CYM 07-391 x Co 62198	1	1	0	0	100.0	0.0	0.0
CYM 07-1008 x Co 62198	23	0	1	22	0.0	4.3	95.7
CYM 04-397 x Co 62198	4	0	0	4	0.0	0.0	100.0
Sub Total	66	2	16	48	3.0	24.2	72.7
CYM 07-895 x BO 130	1	0	1	0	0.0	100.0	0.0
CYM 07-871 x BO 130	34	16	1	17	47.1	2.9	50.0
CYM 06-554 x BO 130	12	5	1	6	41.7	8.3	50.0
Sub Total	47	21	3	23	44.7	6.4	48.9
Grand total	462	155	89	221	33.5	19.3	47.8

* 'R' reactions comprised both R and MR reactions; 'S' reactions comprised both S and HS reactions.

considering the progeny population having more than 40, Co 89029 contributed more resistance (64.2%) followed by BO 130 (44.7%). Only 3% of resistant progenies were obtained when Co 62198 was used as pollen parent, however the well known red rot susceptible parent CoC 671 contributed 16.9 % resistant progenies.

CD clones

Segregation for resistance and susceptibility was observed in various crosses of CD clones with different *S. spontaneum* cytoplasm, tested with CF06 pathotype (Table 5). Many crosses had only very few progenies and the segregation pattern could not be derived. The progenies obtained from

Table 5. Red rot resistance status of cytoplasmic diverse (CD) and back-cross (BC) clones tested under controlled conditions

No.	Cross	Total	Segregation pattern*			% Segregation		
			R	MS	S	R	MS	S
1	CD 11 x CoC 8001	26	9	9	8	34.6	34.6	30.8
2	BC 27 x CoT 8201	17	9	1	7	52.9	5.9	41.2
3	BC 66 x Co 775	16	3	0	13	18.8	0.0	81.3
4	CD 04-79 x CoC 8001	15	5	0	10	33.3	0.0	66.7
5	BC 2 x CoC 671	8	3	0	5	37.5	0.0	62.5
6	BC 51 x Co 86002	8	5	2	1	62.5	25.0	12.5
7	CD 04-67 x Co 775	7	2	1	4	28.6	14.3	57.1
8	BC 116 x Co 1148	6	3	2	1	50.0	33.3	16.7
9	CD 170 x CoT 8201	5	5	0	0	100.0	0.0	0.0
10	BC 51 x CoS 8436	4	3	0	1	75.0	0.0	25.0
11	CD 2 x CoC 671	4	1	0	3	25.0	0.0	75.0
12	CD 04-99 x Co 62198	3	0	1	2	0.0	33.3	66.7
13	CD 116 x Co 94008	3	1	2	0	33.3	66.7	0.0
14	BC 52 x Co 1148	2	1	0	1	50.0	0.0	50.0
15	CD 04-60 x Co 1148	2	1	0	1	50.0	0.0	50.0
16	CD 16 x BO 110	2	0	0	2	0.0	0.0	100.0
17	CD 04-3 x CoP 9301	1	0	0	1	0.0	0.0	100.0
18	CD 12 x CoC 8001	1	1	0	0	100.0	0.0	0.0
19	CD 50 x Co 89029	1	1	0	0	100.0	0.0	0.0
	Total	131	53	18	60	40.5	13.7	45.8

*Reactions comprised both R and MR reactions; S reactions comprised both S and HS reactions.

the cross BC 27 x CoT 8201 showed a high level of red rot resistance (52.9%). The CD 11 x CoC 8001 cross had 34.6% resistant progenies and CD 04-79 x CoC 8001 produced 33.3% resistant progenies.

Germplasm utilization (GU) clones

Screening of the derivatives involving *S. officinarum* x *E. arundinaceous* and *S. spontaneum x E. arundinaceous* hybrids for red rot resistance under controlled conditions revealed that all the derivatives from GU 01-572 x BO 99 are red rot resistant, whereas the derivatives of GU 00-858 x Co 96011 show 38.9% resistance (Table 6). While screening 1081 half sib progenies against CF06 pathotype for red rot resistance, we found 418 as resistant, 180 MS and 483 susceptible (Table 7). More number of resistant progenies were observed in the crosses 987032 x Co 93009 (87.5%), 987042 x Co 7301 (84.2%) and RS93-2182 x Co 93009 (81.3%). Both the clones 987032 and 987042 were derived from the cross Co 8353 x Co 86011. There were no susceptible clones in 987042 x Co 7301 and RS93-2182 x Co 93009 crosses and only resistant and MS category clones were obtained. This results indicate the possibility of obtaining red rot resistant clones through wide hybridization programme.

Table 6. Red rot resistance of *Erianthus*-sugarcane hybrid derivatives tested under controlled conditions

No.	Cross	Total	Segregation pattern*			% segregation		
			R	MS	S	R	MS	S
1	GU 00-858 x Co 96011	18	7	1	10	38.9	5.6	55.6
2	GU 01-572 x BO 99	5	5	0	0	100.0	0.0	0.0
3	GU 01-43 x BO 99	2	1	1	0	50.0	50.0	0.0
4	Co 62175 x IK 76-91	2	1	1	0	50.0	50.0	0.0
5	IK 76-91 x Co 98007	1	0	1	0	0.0	100.0	0.0
6	CoJ 64 x 98 GU 497	1	0	1	0	0.0	100.0	0.0
7	94 GU 2437 x BO 99	1	1	0	0	100.0	0.0	0.0
	Total	30	15	5	10	50.0	16.7	33.3

*Reactions comprised both R and MR reactions; S reactions comprised both S and HS reactions.

Discussion

Screening for red rot resistance is a continuous process to generate new sources of red rot resistance from diverse background. However, the narrow genetic base for red rot resistance is alarming and it is necessary to use wild germplasm of *Saccharum*. The introduction of resistant genes from *S. spontaneum* in breeding programmes for achieving durable resistance is a long-term measure to manage red rot in sugarcane. The effectiveness of using *S. spontaneum* in sugarcane breeding has been realized since the development of POJ 2878 and Co 205. Further, many crosses were made to widen the cytoplasmic base using *S. spontaneum, S. barberi* and *S. sinense* as female parents and *S. officinarum* or popular commercial varieties as male parent for developing improved varieties. Recently, we reported identification of *S. officinarum* clones Baragua, Koelz 11131, Koelz 11132, *S. robustum* clones 28 NG 251 and 57 NG 238, *S. barberi* clones Chin, Dhaur Kalig, Kansar, Maneria IMP-1552, Mungo 254, Nargori, Kewali-14G and Manga (SIC) and *S. sinense* clones Reha, Ikhri and Kalkya for red rot resistance, consistently under both plug and controlled condition testing (Viswanathan et al. 2017a). Further, Alarmelu et al. (2018) also reported that apart from *S. spontaneum*, resistant hybrids involving improved *S. robustum* and *S. barberi* germplasm could also be used as source for red rot resistance in sugarcane.

Since 1980, the institute has a focus on genetic enhancement with new and previously unutilized germplasm resources of *Saccharum* spp and related genus *Erianthus*. Several ISH clones were identified with red rot resistance and they have been utilized to develop several hybrids of diverse genetic background at the Institute's breeding programme. Alexander et al. (1990) identified many red rot resistant *S. spontaneum* genotypes and observed a high level of resistance following plug method of red rot screening in India. It was speculated that among the *Saccharum* spp. *S. spontaneum* was showing moderate resistance against red rot (Alexander 1995). Screening of *S. spontaneum* germplasm collected recently from Maharashtra, Punjab and Haryana for red rot resistance revealed that 88.34% of the 43 accessions were resistant to red rot, indicating a high proportion of the wild species clones with

Table 7. Red rot resistance status of half sib progenies tested under controlled conditions

No.	Cross	Total	Segregation pattern*			% Segregation		
			R	MS	S	R	MS	S
1	987032 x Co 93009	32	28	0	4	87.5	0.0	12.5
2	987042 x Co 7301	19	16	3	0	84.2	15.8	0.0
3	RS93-2182 x Co 93009	32	26	6	0	81.3	18.8	0.0
4	984843 x CoH 110	36	22	5	9	61.1	13.9	25.0
5	984819 x Co 1148	35	21	6	8	60.0	17.1	22.9
6	981843 x CoM 9220	36	21	7	8	58.3	19.4	22.2
7	985931 x Co 775	36	21	0	15	58.3	0.0	41.7
8	987001 x Co 98006	36	21	2	13	58.3	5.6	36.1
9	987001 x CoM 9220	36	21	11	4	58.3	30.6	11.1
10	987080 x Co 1148	34	19	3	12	55.9	8.8	35.3
11	9869110 x Co 1148	36	20	5	11	55.6	13.9	30.6
12	9844195 x CoA 7602	36	19	7	10	52.8	19.4	27.8
13	986179 x CoH 110	36	19	10	7	52.8	27.8	19.4
14	986179 x Co 87002	34	13	6	15	38.2	17.6	44.1
15	971862 x Co 85002	36	18	8	10	50.0	22.2	27.8
16	986095 x Co 94008	35	16	10	9	45.7	28.6	25.7
17	ISH 1 x Co 94008	31	14	8	9	45.2	25.8	29.0
18	87 A 298 x Co 1148	36	14	5	17	38.9	13.9	47.2
19	973402 x Co 775	33	11	2	20	33.3	6.1	60.6
20	9896110 x Co 62198	33	11	6	16	33.3	18.2	48.5
21	971235 x Co 62198	36	11	5	20	30.6	13.9	55.6
22	971862 x Co 8371	36	7	7	22	19.4	19.4	61.1
23	986046 x Co 775	35	6	11	18	17.1	31.4	51.4
24	971236 x Co 62198	36	5	2	29	13.9	5.6	80.6
25	9871144 x Co 775	35	4	6	25	11.4	17.1	71.4
26	985735 x Co 62198	22	2	7	13	9.1	31.8	59.1
27	985094 x CoH 76	36	3	9	24	8.3	25.0	66.7
28	985040 x Co 1148	36	2	3	31	5.6	8.3	86.1
29	987124 x Co 775	36	3	7	26	8.3	19.4	72.2
30	971862 x Co 98003	18	1	11	6	5.6	61.1	33.3
31	986095 x Co 62198	35	1	1	33	2.9	2.9	94.3
32	986140 x Co 1148	34	0	0	34	0.0	0.0	100.0
33	985719 x Co 1148	8	2	1	5	25.0	12.5	62.5
	Total	1081	418	180	483	38.7	16.7	44.7

* 'R' reactions comprised both R and MR reactions; 'S' reactions comprised both S and HS reactions.

red rot resistance (Pazhany et al. 2018) and this study reiterates *S. spontaneum* as store house for red rot resistance. Further studies of Suganya et al (2018) revealed that among eight *S. spontaneum* cytotypes, the cytotype 80 incorporated red rot resistance at a higher frequency during development of ISH involving different cytotypes and commercial varieties. Their studies indicated that enhanced ploidies with genome size increases resistance. However, Srinivasan and Chennulu (1956) observed a differential reaction against red rot pathogen exhibited by *S. spontaneum* and it is speculated that horizontal resistance to red rot is derived from *S. spontaneum* and vertical resistance is from *S. officinarum* and *S. sinense* (Natarajan et al. 1998).

Hemaprabha et al. (2018) recently reported phenotyping of the two way cross progenies for red rot resistance and drought tolerance. They found a high proportion of progenies from the cross Co 95005 (*S. robustum* base) x CYMA 09-1369 (with *Erianthus* cytoplasm) for red rot and seven clones combined with red rot and drought tolerance and most of them were from the cross CYM 08-922 x ISH 176. They further opined that exploiting germplasm resources for developing climate resilient sugarcane cultivars with a broad genetic base and red rot resistance. Furthermore, Mohanraj et al. (2018) recently reported exploitation of *Erianthus procerus* as a potential source for diversifying the genetic base in sugarcane for higher yield, red rot resistance and drought tolerance. Such an IGH between *E. procerus* and *Saccharum* (GU 04(28) EO-2) was back crossed with hybrid varieties and they identified good number of BCI hybrids with enhanced red rot resistance. They reported that these genotypes could be a potential source for developing sugarcane varieties with *Erianthus* base of red rot resistance.

Worldwide, efforts are being made to develop commercial sugarcane varieties in the recent years by utilizing *S. spontaneum* and *Erianthus arundinaceus* for incorporation of various traits viz., drought, water logging, disease and insect pest resistance. In China, crosses of *Saccharum* spp. × an intergeneric hybrid (*Erianthus arundinaceus* × *Saccharum spontaneum*) were utilized in broadening the genetic base (Gao et al. 2013). The importance of crossing *S. officinarum* with *S. spontaneum* was realized in Thailand during 1980's and many clones with higher tonnage but with lower sucrose content were developed (Heinz 1980). The progenies from inter-specific hybridization between commercial cultivars and *S. spontaneum* were screened for higher sugar yield in ratoon crop under low soil moisture conditions in Thailand (Ponragdee et al. 2013).

Standardization of controlled condition testing, a rapid method to assess red rot resistance has been a boon to sugarcane breeding at ICAR-SBI (Viswanathan et al. 2018). This methodology enabled identification of resistant parents against a virulent pathotype. Further, this testing facilitated downsizing the progeny population through selection in two early stages for red rot resistance and that formed major selection parameter. Benefit of this early screening for red rot is also witnessed by a very high proportion of more than 90% resistance in Coimbatore (Co) canes bred at the Institute since 2006 (Hemaprabha et al. 2018). Field testing for red rot testing is time consuming and requires huge resources in terms of land, manpower and other resources. Our controlled condition testing for red rot circumvents these constraints and enables rapid testing of more number of clones. In the present study, though we identified more number of resistant clones at Padalam in Tamil Nadu, their behaviour is different at Kovvuru in Andhra Pradesh. This indicates a probable higher virulence of the pathogen under typical deltaic conditions of

Godavari belt combined with high moisture / water logging at the location. Similar trend was observed when same set of sugarcane genotypes and isolates were used simultaneously at Karnal and Coimbatore (Alexander and Rao 1976). The controlled condition testing for red rot resistance avoids such ambiguities in the field.

Overall, this analysis summarizes the red rot resistance potential in the sugarcane germplasm, its utilization and development of new genetic stocks in both ISH and IGH. Development of controlled condition testing has benefitted phenotyping of all these clones for red rot resistance and supports the Institute's various breeding and germplasm utilization programmes in developing sugarcane varieties with tolerance to various abiotic stress factors combined with good agronomical traits and red rot resistance. *C. falcatum* exhibits huge variation for their virulence and new variants also emerges continuously under field conditions (Viswanathan et al. 2017b). A new pathotype CF12 has been designated from tropical region based on its consistent higher virulence over CF06 (Viswanathan 2017) hence further studies need to be continued to update red rot resistance in the germplasm, parental clones and various ISH/IGH progenies against the new pathotype.

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