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WINTER SPROUTING INDEX OF SUGARCANE GENOTYPES IS A MEASURE OF WINTER RATOONING ABILITY

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ABSTRACT

Introduction: The low temperature prevails during winter season in the subtropical region of India limits stubble sprouting and tillering ability of sugarcane clones. Therefore, identification of high yielding, high sugar, disease resistant varieties coupled with better winter ratooning ability is given priority in the subtropical sugarcane breeding programmes.
Aim of the study was to assess the winter sprouting index of sugarcane germplasm.
Methods: To evaluate sugarcane clones for winter ratoonability, an index called winter sprouting index (WSI) was constructed. On the basis of WSI, sugarcane genotypes were classified into four categories namely, excellent winter sprouting (WSI>3.0), good sprouting (WSI=2.01-2.99), poor sprouting (0.10 to 2.00) and low temperature sensitive (LTS) clones (WSI<0.10).
Results: 632 germplasm were evaluated at Karnal, Haryana, India (representing subtropical climate) from 2009 to 2015 for winter sprouting. Genetic differences among clones for this trait was observed. Fourty three clones exhibited excellent winter sprouting (WSI>3.00) and 44 clones were classified as LTS clones (WSI<0.10). Positive correlation between WSI and number of millable canes in plant as well as ratoon crop and ratoon cane yield was observed hence WSI may be used as a tool for evaluating winter ratooning ability of sugarcane germplasm.

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INTRODUCTION

About 56% of sugarcane growing area in India falls under subtropical region comprising the states of Assam, Bihar, Haryana, Jharkhand, Punjab, Rajasthan, Uttarakhand, Uttar Pradesh and West Bengal where the crop is suffer from extremes of weather *i.e.* high temperature during summer and low temperature during winter. The extreme weather in the subtropical states limits active growth of sugarcane as a result the average cane yield in this region is always lower (61.8 t/ha) than that of tropical region (67.3 t/ha). To fulfil sugarcane crushing demand of sugar industries, sugarcane in subtropical region is planted in three season *viz*., autumn (Oct planting), spring (Feb-Mar planting) and summer (Apr-May planting). The ratoon crop, autumn planted plant crop and early varieties planted in any of the seasons are ready for harvest during November-December coinciding peak winter season (December-January). If sugarcane is planted or ratooned during winter, most of the subterranean buds remain dormant during winter and starts sprouting with the rise of temperature during spring (Feb). By that time the potentiality of buds to germinate is greatly reduced. This is a major abiotic factor which limits ratoon productivity in subtropical India. The yield of ratoon crop in this region is lesser by 10 to 20% than that of plant crop (Verma, 2002). Autumn planting and multi-ratooning which has potential to improve cane yield and sugar recovery, is not gaining popularity in this region because harvesting of preceding plant crop and ratoon coincides with winter. Therefore, identification of sugarcane germplasm with good sprouting potential during winter is viewed as a way forward to address the abiotic stress. The ICAR-Sugarcane Breeding Institute (SBI), Regional Centre, Karnal (Haryana state) located in the subtropical belt of India has been engaged in breeding sugarcane varieties with high sugar, high yield coupled with winter ratoonability. Sahi *et al*. (2002) and Ram *et al.* (2012) conducted studies on winter ratoonability and reported existence of genetic variability in sugarcane germplasm for this trait. Such information have practical utility in sugarcane improvement for North India, studies on winter sprouting have been intensified at the Centre with of germplasm of diverse origin. In this article, winter sprouting or winter ratooning ability of 632 clones is presented. Winter ratoonability can be assessed by two ways, i) by assessing the ability of sugarcane clones to sprouts during low temperature period *per se i.e.* during winter months and or ii) by assessing the ability of dormant buds to revive and sprouts after winter season is over *i.e.* during early spring. The first approach is followed in our research.

MATERIALS AND METHODS

A series of 15 field experiments were conducted at ICAR-SBI, Regional Centre, Karnal from 2010-11 cane season to 2015-16 season, involving Co clones, Co allied clones, released sugarcane varieties, inter-specific hybrids (ISH), inter-generic hybrids (IGH) and exotic clones (foreign hybrids). The list of sugarcane germplasm screened and period of screening are presented in Table 1. Each clone was planted in two row plot of 6 m long. The row to row spacing was 0.90 m. Within a row, two budded setts were planted by end to end method @ 12 buds/m. Cultural practices as recommended in the state of Haryana were followed to raise good plant crop. Observations such as on germination percentage at 45 days after planting (DAP), number of tillers per plot at 120 DAP, number of millable canes per plot at 240 DAP, stalk length, stalk diameter, single cane weight, cane yield per plot at harvest (12^{th} month) were recorded. Juice analysis was carried out using 5 randomly selected plants in plant crop trials at 8^{th}, 10^{th} and 12^{th} month after planting; brix%, pol%, purity% of juice were estimated in laboratory as per ICUMSA methods (Chen, 1985). Canes in each row (half-row *i.e.* upto 3m length) in each trial were cut at ground level during 2^{nd} fortnight of December, coinciding with peak winter. Canes in the remaining 3 m length row were kept un-harvested for juice analysis, seed purpose and for comparison. The stubbles after harvest were covered with remnant dried leaves and cane trashes. Irrigation was given immediately after harvest. The ratooned stubbles were allowed to sprout during winter (Dec to Feb). The number of stubbles (clumps) alive and sprouted per plot and number of shoots formed in each clump during winter was counted at 45^{th} days after ratooning which coincides with the onset of spring (Feb). To ascertain winter sprouting potential of sugarcane genotypes, an index named as "winter sprouting index" (WSI) was constructed and it is given below.

$$\text{Winter Sprouting Index (WSI)} = \frac{\text{Percentage of alive and sprouted clumps per plot} \times \text{No. of shoots emerged per clump}}{100}$$

On the basis of WSI, sugarcane genotypes were grouped into four categories as shown below.

WSI	Sprouting category
3.00 and above	Excellent winter sprouting
2.01 to 2.99	Good winter sprouting
0.10 to 2.00	Poor winter sprouting
< 0.10	Low temperature sensitive (LTS) clones

Simple correlation coefficient between WSI and agronomic and juice quality parameters recorded in the respective plant crop trial were worked out by following Gomez and Gomez (1984).

RESULTS

Weather condition at test location

The weekly mean minimum and mean maximum soil temperature recorded at 10cm depth and air mean temperature prevailed at test location *i.e.* Karnal during winter months as well as during the period of this study (Dec 2010 to Feb 2014) was recorded and is presented in Fig 1a and 1b. The mean minimum soil temperature at Karnal ranged from 9.7 ^{o}C during 8-14 January to 12.1 ^{o}C during 5-11 February. The mean minimum air temperature at the location ranged from 5.1 ^{o}C during 24-31 December to 8.2 ^{o}C during 5-11 February which is a typical cold weather in subtropical India and is considered critically low for sprouting of sugarcane stubbles.

Sprouting of sugarcane genotypes during winter

Out of 632 clones evaluated for winter sprouting, 44 clones did not sprout during winter (Table 2). These clones were designated as 'low temperature sensitive clones' (LTS clones). About 64% of the non-sprouted clones belong to cytoplasmic diverse clone abbreviated as CYMA clones and the remaining clones were of exotic origin. Neither the 'Co canes' evolved at ICAR-SBI, Research Centre, Karnal nor the 'Co allied' varieties bred by other research stations in the subtropical states of India falls under LTS category thereby indicating that the winter tolerance trait was taken care of by the breeders while evolving varieties suitable for this region. In the remaining clones (other than LTS clones), the percentage of stubble sprouting ranged from 4.17 to 100% with an average of 59.75% (Table 3). Twenty nine clones recorded 100% sprouting even at the low temperature regime. This means all the underground stubbles of these clones were alive and stubble sprouting began as soon as the plant crop was cut or harvested during winter. The list of cent percent sprouted clones includes Co, Co allied clones such as Co 12026, Co 12027, Co 1148, CoP 2061, CoPant 99214, CoPb 09181, CoS 767; exotic clones such as B 33-65, B 43-238, CP 79-318, F 133, GU 92-085, KM 724, L 62-37, LF 65-119, LF 65-3661, LF 63-1617, Mali, Q 65, SP 80-1816 and ISH and IGH clones such as 99-304, 99-356, 99-488, 97-12, 99-316, CYMA 09-903, CYMA 09-898 and GU 00-139. Among the different category of germplasm, high percentage of stubble sprouting was recorded in subtropical varieties (68.31%), followed by Co canes identified at Karnal centre of SBI (64.48%) and least sprouting (50.93%) was in ISH and IGH clones (Table 3). It was observed that low temperature tolerance trait of sugarcane stubbles alone did not give good ratoon crop. The clone should have high tillering ability during winter and produce more shoots per clump immediately after harvest. Such high tillering clones would certainly record satisfactory cane yield in the ratoon crop. Therefore, in the present study yet another trait namely the number of shoots (tillers) formed in each clump during winter was taken into account. The number of shoots per clump at 45^{th} day after harvest of plant crop ranged from 0.00 to 6.50 with an average of 1.96 shoots/clump (Table 3). The winter sprouting index of 632 clones ranged from 0.00 to 6.50 with a mean of 1.35. Among different category of germplasm screened, subtropical varieties showed highest WSI value (1.68) followed by Co canes (1.30) and least by ISH and IGH clones (1.18). On the basis of WSI, the clones were rated into excellent winter sprouting (WSI >3.00), good sprouting (WSI=2.01 to 2.99), poor sprouting (WSI=0.10 to 2.00) and LTS (WSI< 0.10) categories and the result is given in Table 2. Co canes such as Co 06035, Co 12026, Co 12027, commercial varieties such as CoP 9302, CoPant 96219, CoS 02264, CoS 109, CoS 797, CoS 94270, CoS 95222, CoS 97258, CoS 97264, CoSe 95422, exotic clones such as BO 348, BM 368, B 33-65, BM 555, BM 61/1, CP 11-61, F 133, L 62-37,

Table 1. List of sugarcane clones evaluated for winter sprouting at Karnal (Haryana, India)

Germplasm Category	No. of clones + standards evaluated	Date of planting	Field design
Co canes	44+4	14 Feb 2012	RBD- 2 replications
(evolved at ICAR-SBI Coimbatore)		23 Mar 2013	RBD- 2 replications
Released varieties	129+4	19 Mar 2010	RBD-3 replications
(for subtropical region of India)		Ratoon of above	
		16 Feb 2012	RBD- 3 replications
		22 Mar 2013	Augmented- 2 row/variety
Exotic clones	28+3	01 Apr 2011	RBD-3 replications
(foreign hybrids)	15+3	29 Mar 2012	RBD-2 replications
	45+3	30 Mar 2012	RBD-2 replications
	114+4	23 Mar 2013	RBD-2 replications
	58+3	6 Mar 2014	RBD-3 replications
Inter-specific and inter-generic	29+3	01 Apr 2011	RBD-3 replications
hybrid clones	24+3	23 Mar 2012	RBD-2 replications
(ISH / IGH clones)	32+4	25 Mar 2013	RBD-3 replications
	67+4	28 Mar 2013	RBD-2 replications
	47+3	8 Mar 2014	RBD-3 replications

Table 2. Classification of sugarcane germplasm on the basis of winter sprouting index

1. Excellent winter Sprouting (WSI >3.00) Co canes: Co 06035, Co 12026, Co 12027. Released varieties: CoP 9302, CoPant 96219, CoS 02264, CoS 109, CoS 797, CoS 94270, CoS 95222, CoS 97258, CoS 97264, CoSe 95422. Exotic clones: BO 348, BM 368, B 33-65, BM 555, BM 61/1, CP 11-61, F 133, L 62-37, LF 64-2815, LF 65-3661, Mali, PR 1013, SP 80-1816, TUC 472. ISH / IGH clones: 20-200, 97-12, 99-304, 99-316, 99-356, 99-488, CYM 06-935, CYM 06-1144, CYM 07-284, GU 07-1841, GU 07-3704, GU 07-3730, GU 07-3774, KGS 99-1109, KGS 2004-72 and KGS 2004-20.
2. Good winter sprouting (WSI=2.01 to 2.99) Co canes: Co 0237, Co 0327, Co 0331, Co 06033. Released varieties: BO 91, BO 99, BO 109, BO 120, BO 137, BO 147, BO 153, Co 0118, Co 0238, Co 05011, Co 6617, Co 6811, Co 89003, Co 89029, Co 98014, Co 1148, CoB 94164, CoBln 9104, CoH 128, CoH 56, CoH 92, CoJ 88, CoLk 7901, CoLk 8001, CoLk 94184, CoP 9702, CoP 2061, CoPant 84211, CoPant 84212, CoPant 90223, CoPant 99214, CoPant 08221, CoS 00257, CoS 03252, CoS 510, CoS 767, CoS 770, CoS 8207, CoS 8436, CoS 88230, CoS 91269, CoS 95255, CoS 95270, CoS 96275, CoSe 00235, CoSe 01424, CoSe 92423, CoSe 96436, CoSe 98231, UP 5. Exotic clones: B-42-261, LF 61-52, LF 65-4329, Q 65, Argentina, LF 63-1617, POJ 290, PR 1044, PR 1054, BM 61/1, CP 34-79, CP 84-1198, KT 367, LF 61-52, MOL 894, SP 80-185, SP 81-783, SP 81-783, BM 368, BM 555, LF 65-3661, POJ 290, B 43-238, LF 63-1617, LF 65-119, Q 65,. ISH / IGH clones: 1687-1067, 2004-103, 20-200, 20-70, 96-813, 96-820, 97-92, 99-29, 99-304, 99-97, BC 51, CYM 06-1162, CYM 06-924, CYM 07-644, CYM 07-678, CYM 07-931, CYMA 09-379, CYMA 09-903, GU 07-3764, GU 07-3784, GU 07-3785, GU 07-3803, GU 07-3849, GU 92-085, WL 00-276.
3. Poor winter sprouting (WSI=0.10 to 2.00) Co canes: Co 0116, Co 0122, Co 0123, Co 0240, Co 0241, Co 0424, Co 05010, Co 06032, Co 06034, Co 06036, Co 06037, Co 07022, Co 07023, Co 07024, Co 07025, Co 07026, Co 07027, Co 07028, Co 09020, Co 09021, Co 09022, Co 10035, Co 10036, Co 10037, Co 10039, Co 11026, Co 11027, Co 12028, Co 13033, Co 13034, Co 13035, Co 13036. Released varieties: BO 139, BO 110, BO 128, BO 129, BO 130, BO 136, BO 138, BO 141, BO 145, BO 146, Co 0124, Co 0237, Co 0239, Co 05009, Co 1158, Co 1336, Co 419, Co 453, Co 6425, Co 7717, Co 87263, Co 87268, CoBln 9101, CoBln 9102, CoBln 9103, CoBln 9105, CoH 110, CoH 119, CoH 160, CoH 35, CoH 99, CoJ 64, CoJ 83, CoJ 85, CoJ 89, CoLk 8102, CoP 9206, CoP 9301, CoPant 90222, CoPant 97222, CoPant 03220, CoPb 09181, CoS 01235, CoS 01256, CoS 02258, CoS 03261, CoS 03279, CoS 245, CoS 443, CoS 514, CoS 541, CoS 687, CoS 8118, CoS 8315, CoS 8432, CoS 90265, CoS 90269, CoS 91230, CoS 93259, CoS 94257, CoS 96258, CoS 96268, CoS 96269, CoS 97248, CoS 97261, CoS 98259, CoS 99259, CoSe 95436, UP 0097, UP 9530. Exotic clones: B-33-65, B 34-12, B 37-261, B 38-292, B 39-246, B 40-98, B 43-238, B 43-337, B 44-130, B 44-261, B 44-52, B 45-116, B 46-199, B 739, B 208, B 39-274, B 40-105, B 41-242, B 43-229, B 43-238, B 45-24, B 47-258, Bamboo hybrid, BN 111, BN 74, BO 2121, BO 348, BO 186, C 47-72, C 278, CF 44-154, CL 41-70, CP 11-65, CP 31-511, CP 36-111, CP 36-13, CP 377, CP 44-155, CP 50-11, CP 50-28, CP 53-18, CP 57-6114, CP 57-6114, CP 63-354, CP 63-369, CP 63-369, CP 63-372, CP 63-384, CP 72-2086, CP 72-2086, CP 78-2114, CP 79-318, CP 79-318, CP 80-1827, CP 84-1198, CP 89-1762, CP 93-1340, CP 94-1100, CP 94-1100, CP 96-1262, CYM 07-678, CYM 07-931, D 166-37, D 419/33, EPC 37-028, EPC 37-207, EPC-37-082, EROS, F 108, F 134, F 31-762, F 36-819, FB 37-172, Fiji-n-cane, FP 37-172, GU 00-139, GU 07-1841, GU 07-2533, GU 92-085, H 37-1933, H 39-7058, H 43-1447, H 44-2772, H 44-3098, H 49-5, H 50-7000, H 51-8194, H 52-3683, H 57-5174, H 59-3775, H 59-3775, KM 674, KM 674, KM 674, KM 724, KM 86, KT 367, KT 730, L 61-43, L 62-37, LF 61-5257, LF 61-666, LF 62-2810, LF 62-37, LF 64-2694, LF 64-2815, LF 65-119, LF 65-5943, LF 65-68, LF 69-814, LF 69-953, LF 79-814, M 112/34, M 165/38, M 13/40, M 63/39, M 73/39, M 85, Mali, Media luna, Mercy data, MOL 914, MS 49-7, NCD 351, NCo 151, NCo 376, NOC-339, OBR 40-47, OBR-6, Petecuca striped, POJ 228, POJ 279, POJ 290, POJ 2961, POJ 30, Pomex 60, Pomex 85, PR 1000, PR 1028, PR 1028, PR 1039, PR 1049, PR 1069, PR 1080, PR 1083, PRB, PT 33-86, Q 47, Q 61, Q 68, Q 69, Q 70, SP 79-2233, SP 80-1816, SP 80-1816, SP 80-1842, SP 80-3280, SP 81-3250, TA 7, TUC 472, TUC 521, Uba Marrot, US 16-94, Yasawa, Yuetang 85-177. ISH /IGH clones: 2004-90, 20-075, 20-17, 20-182, 20-421, 20-57, 20-75, 20-98, 56-339, 56-378, 56-397, 56-475, 93 WL 1233, 93 WL 1889, 96-782, 96-862, 97 WL 907, 97-12, 98-70, 99-101, 99-132, 99-133, 99-356, 99-380, 99-438, 99-489, 99-49, 99-81, 99-83, CYM series clones such as 06-1136, 06-1145, 07-336, 07-356, 07-660, 07-976, 07-991, 08-502, 08-720, 08-828, 08-922, CYMA clones like 09-1004, 09-1047, 09-1085, 09-1178, 09-1268, 09-1371, 09-1386, 09-1405, 09-1447, 09-1454, 09-1612, 09-165, 09-191, 09-492, 09-525, 09-526, 09-550, 09-568, 09-760, 09-799, 09-813, 09-817, 09-828, 09-829, 09-888, 09-898, 09-900, 10-38, 10-135, 10-475, 10-1020, 10-1038, 10-1060, 10-1088, 10-1111, 10-1460, 10-1528, 10-1566, 10-1673, 10-1488, 10-1672, 10-747, 10-874,10-948; GU series clones such as 00-100, 00-139, 00-243, 01-1363, 04-431, 04-432, 07-1821, 07-1840, 07-2533, 07-312, 07-3860, 94-410, 98-1395, 99-219; IG 87-153, KGS clones such as 2004-13, 2004-183, 2004-186, 2004-48, 2004-60, 99-100, 99-104, 99-1109, 99-232, 99-234, 99-95.
4. Low temperature sensitive (LTS) clones (WSI<0.10) Exotic clones: Regnar, BT-739, F 134, F 31-450, M 165/38, M 171/30, POJ 3067, PR 1085, Q 27, Q 45, SW 111, CP 78-2114, H 50-7209 and PoJ 29-61. ISH /IGH clones: GU 98-1482, KGS 2004-72, CYMA series clones such as 99-61, 09-1358, 09-1405, 09-1442, 09-1523, 09-157, 09-1588, 09-1597, 09-171, 09-364, 09-473, 09-504, 09-521, 09-524, 09-529, 09-548, 09-561, 09-565, 09-568, 09-765, 09-776, 09-782, 09-784, 09-795, 09-810, 09-836, 09-886 and 10-1494.

LF 64-2815, LF 65-3661, Mali, PR 1013, SP 80-1816, TUC 472 and ISH and IGH clones such as 20-200, 97-12, 99-304, 99-316, 99-356, 99-488, CYM 06-935, CYM 06-1144, CYM 07-284, GU 07-1841, GU 07-3704, GU 07-3730, GU 07-3774, KGS 99-1109, KGS 2004-72 and KGS 2004-20 recorded excellent winter sprouting index of more than 3.0. The WSI values of these clones are given in Table 4.

Association between WSI and yield contributing traits

Simple correlation coefficient between % sprouted stubbles per plot and number of shoots per clump was worked out and the *'r'* value (0.52) was found to be significant (Table 5). To further investigate the relationship between these two component traits of winter ratoonability, the frequency

Table 3. Variability for winter sprouting potential among 632 sugarcane genotypes

No of Germplasm screened & its category	Parameters	% of sprouted clump per clone	No. of shoots per clump	WSI
Co canes (44 Nos)	Range	8.33-100.00	0.08-6.00	0.01-6.00
	Mean	64.48	1.80	1.30
Released varieties (129 Nos)	Range	0.00-100.00	0.00-4.41	0.00-3.90
	Mean	68.31	2.37	1.68
Exotic clones (215 Nos)	Range	0.00-100.00	0.00-5.80	0.00-5.80
	Mean	60.11	1.86	1.27
ISH and IGH clones (215 Nos)	Range	0.00-100.00	0.00-6.50	0.00-6.50
	Mean	50.93	1.77	1.18
Pooled (632 clones)	Range	0.00-100.00	0.00-6.50	0.00-6.50
	Mean	59.75	1.96	1.35
	CV%	45.90	53.59	76.24

Table 4. Name of sugarcane clones showing high winter sprouting index

Sl. No.	Name of the clone	% of sprouted clump	No. of shoots / clump	Winter sprouting index
A	Co canes			
1	Co 12026	100.00	6.00	6.00
2	Co 12027	100.00	3.80	3.80
3	Co 06035	90.00	3.82	3.44
B	Exotic clones			
4	F-133	100.00	6.50	6.50
5	L 62-37	100.00	5.80	5.80
6	B 33-65	100.00	4.63	4.63
7	Mali	100.00	4.60	4.60
8	LF 64-2815	89.29	4.78	4.27
9	BM 555	96.88	4.27	4.13
10	PR 1013	90.00	4.25	3.83
11	CP 11-61	81.82	4.28	3.50
12	BM- 368	96.67	3.53	3.42
13	BM 61/1	86.70	3.59	3.11
14	TUC 472	95.00	3.26	3.10
15	BO 348	90.91	3.30	3.00
16	LF 65-3661	100.00	3.00	3.00
17	SP 80-1816	100.00	3.00	3.00
18	20-200	100.00	6.50	6.50
19	CYM 06-935	95.24	6.03	5.74
C	ISH and IGH clones			
20	99-304	100.00	4.83	4.83
21	99-356	100.00	4.50	4.50
22	99-316	94.21	4.18	3.94
23	KGS 99-1109	88.72	4.40	3.90
24	GU 07-3730	95.86	3.89	3.73
25	GU 07-3704	97.92	3.77	3.69
26	GU 07-3774	85.00	4.30	3.66
27	CYM 06-1144	95.56	3.78	3.61
28	GU 07-1841	96.67	3.74	3.61
29	2004-20	80.00	4.40	3.52
30	99-488	100.00	3.50	3.50
31	CYM 07-284	85.00	4.10	3.49
32	97-12	100.00	3.33	3.33
33	KGS 2004-72	83.33	3.80	3.17
D	Subtropical varieties			
34	CoPant 96219	98.61	3.96	3.90
35	CoSe 95422	96.67	3.97	3.84
36	CoS 97264	87.56	4.17	3.65
37	CoS 94270	94.87	3.79	3.60
38	CoS 797	79.29	4.29	3.40
39	CoS 02264	94.44	3.59	3.39
40	CoS 97258	88.43	3.78	3.34
41	CoP 9302	75.07	4.41	3.31
42	CoS 95222	86.11	3.61	3.11
43	CoS 109	84.90	3.64	3.09
44	CoS 767	87.33	2.75	2.40
45	Co 1148	77.86	2.95	2.30
46	CoJ 64	67.50	3.03	2.05
47	CoS 8436	83.33	2.43	2.02

Table 5. Correlation coefficient between winter sprouting index and yield attributing traits in plant and ratoon crop

Parameters	Germination% at 45 DAP	Tillers/ha at 120 DAP or after earthing up	NMC/ha at 240 DAP	Stalk length at harvest	Stalk dia. at harvest	Single cane weight	Juice Extraction % 10th month	Brix % 10th month	Sucrose % 10th month	Juice purity %	Cane Yield at harvest	CCS yield at harvest	% of sprouted clump	Sprouts/clump	Winter Sprouting Index
1. Plant Crop															
% of sprouted clump	0.23	0.38**	0.33**	0.17	-0.13	-0.10	-0.15	0.00	0.03	0.08	0.11	0.10	1.00		
Sprouts / clump	0.22	0.32*	0.26*	0.08	-0.03	-0.02	-0.06	-0.09	0.01	0.22	0.13	0.13	0.52**	1.00	
Winter Sprouting Index	0.26*	0.45**	0.37**	0.10	-0.11	-0.08	-0.12	-0.08	0.00	0.20	0.15	0.14	0.72**	0.91**	1.00
2. Ratoon crop															
% of sprouted clump		0.35**	0.35**	0.28*	-0.19	-0.06	-0.17	0.01	0.00	-0.01	0.24	0.24	1.00		
Sprouts / clump		0.28*	0.31*	0.16	-0.05	0.00	-0.03	0.06	0.05	0.05	0.19	0.20	0.52**	1.00	
Winter Sprouting Index		0.41**	0.42**	0.25	-0.14	-0.03	-0.09	0.04	0.04	0.02	0.28*	0.28*	0.72**	0.91**	1.00

Note: * and ** refers to significant at p= 0.01 and 0.001

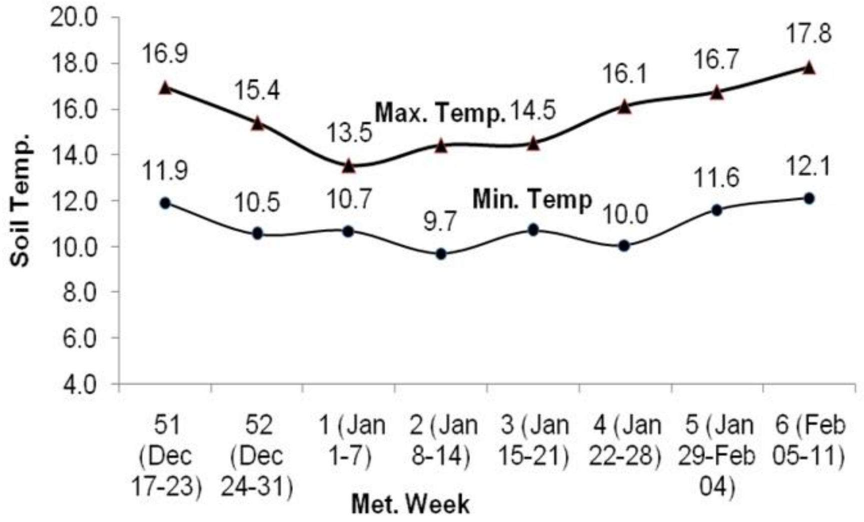

Fig 1 a. Soil Temperature (10 cm depth) at Karnal during winter months (2010-2014)

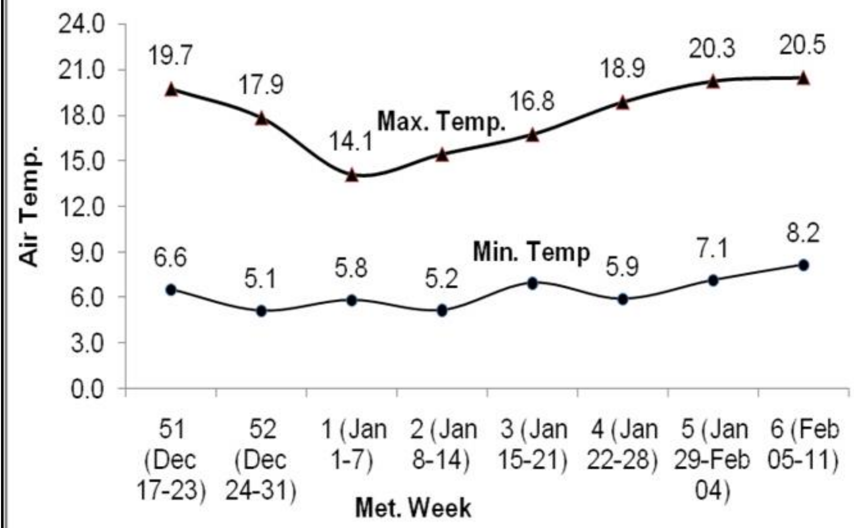

Fig 1 b. Air Temperature at Karnal during winter months (2010-2014)

Fig 1. Mean soil and air temperature during winter season at Karnal (Haryana state, India)

distribution of clones in each sprouting class and the mean shoots per clump in each sprouting class was worked out (data not shown). As the percentage of sprouted clump increases, the mean shoots per clump as well as the frequency of clones with more than 3.00 shoots per clump has also increased. This means the chances of getting clones with high shoots per clump will be more in those clones which exhibits high sprouting during winter. Further, to ascertain as to whether WSI would reflect tillering potential of ratoon crop and to find out the traits in plant crop are truly associated with WSI, phenotypic correlation between WSI and various morphometric traits of plant and ratoon crop was worked out and the results are shown in Table 5. The data recorded during 2010-11 season plant crop trial and 2011-12 season ratoon trial involving 129 released varieties were used for the purpose. Significant and positive correlation between winter sprouting index and tillers in plant crop (r=0.45) and number of millable canes in plant crop (r=0.37) was discernible (Table 5). Same was the kind of association between WSI and tillers/ha (r=0.41) and NMC/ha in ratoon crop (r=0.42). WSI was positively correlated with cane yield in ratoon crop (r=0.28), though the r value seems to be low, because cane yield is a complex traits influenced by other traits such as stalk length, stalk diameter, stalk weight etc. The correlation coefficient between the percentage of sprouted clumps per clone *versus* WSI (r=0.72), WSI *versus* number of shoots per clump (r=0.91) were positive and highly significant.

DISCUSSION

Sugarcane require an optimum temperature of 26-32 ^oC for better germination. Temperature below 15.5 ^oC is critically low and <8.0 ^oC is too low for germination (VanDillewijn, 1952). In the subtropical states of India low air and soil temperature is prevailing during early harvest period. The minimum air temperature (average of 3 years) during peak winter (December-January) in the region was 6.3-10.4 ^oC at Pusa (Bihar), 3.7-9.7 ^oC at Shahjahanpur (Uttar Pradesh), 4.4-7.0 ^oC at Jalandhar (Punjab) and 3.1-6.5 ^oC at Karnal (Haryana). The soil temperature during the same period was 16.3-17.6 ^oC at Pusa, 14.5-15.8 ^oC at Shahjahanpur and 10.95-18.8 ^oC at Karnal. Out of 2.7 million hectare cane area in the region (2016-17), more than 50% area was under ratoon crop and its harvest happen from October to December. Poor stubble sprouting particularly those fields harvested during November to January is one of the reasons for low ratoon productivity in the region (Jain *et al.* 2007). To address the issue cane growers and sugar mills in North India prefers high yielding, high sugar varieties combined with red rot resistance and tolerance to hot and cold weather of this region and breeders are continually searching better germplasm to be used as parents for their breeding programmes. Cold tolerance was correlated with ratooning ability and genetic difference among clones for cold tolerance was reported by earlier workers (Brandes, 1937; Irvine, 1967; Hale, 2011; Ram and Sahi, 2002). In view of these, as many as 632 germplasm of diverse origin was screened in the study for winter sprouting. The weather condition prevailed at the study location (Karnal, Haryana state, India) was ideally suited for screening large germplasm for winter sprouting. The minimum soil temperature in Karnal during the study period was 11.9 ^oC in December to 12.1 ^oC in February fist fortnight. This low temperature regime is more or less same as in other subtropical states at the time of harvesting of early maturing cane varieties. If sugarcane germplasm are screened under field condition where the soil or air temperature remains below at 15.5 ^oC for a considerable period of time, say for 30-45 days and if any sugarcane genotype sprouts during the chilling period such genotype may be considered as having high winter ratooning potential. Genotypes with better winter sprouting index identified at Karnal will be a prospective donor for winter ratoonability. Among different kinds of germplasm screened for winter sprouting, poor sprouting was recorded in CYMA clones and exotic clones. However, the proportion of LTS clones in the germplasm was found to be low (only 7.0%). The LTS clones has its origin in countries like Australia (Q 27, Q 45), Barbados (BT-739), Fiji (F 134, F 31-450, Ragnar), Hawaii (H 50-7209), Indonesia (POJ 3067, PoJ 2961, SW-111), Mauritius (M 165/38, M 171/30), Puerto Rico (PR 1085) and USA (CP 78-2114). These clones were not selected for subtropical climate hence nothing surprise to observe poor sprouting during winter in them. Perhaps the optimum temperature regime for these clones may be different as reported by Whiteman et al. (1963) and it was not met at this location. The poor sprouting CYMA clones such as 99-61, 09-1358, 09-1405, 09-1442, 09-1523, 09-157, 09-1588, 09-1597, 09-171, 09-364, 09-473, 09-504, 09-521, 09-524, 09-529, 09-548, 09-561, 09-565, 09-568, 09-765, 09-776, 09-782, 09-784, 09-795, 09-810, 09-836, 09-886 and 10-1494 were inter-generic hybrids, derived by backcrossing the F_1 hybrids of *Erianthus arundinaceus* x *Saccharum spontaneum*, 3 to 4 times with high sugar commercial cane varieties. The selection and evaluation of CYMA clones was carried out at ICAR-SBI, Coimbatore (Tamil Nadu) and its research centre, Agali (Kerala), representing tropical climate and hence most of the CYMA clones did not sprout during winter in subtropical region. Another possible reason for low sprouting may be the lower level of reducing sugars in these clones which was correlated to poor winter sprouting by Jain *et al.* (2007).

As many as 43 clones (6.8%) showed excellent winter sprouting with WSI greater than 3.0. The Co canes and subtropical varieties which recorded high winter sprouting namely, Co 06035, Co 12026, Co 12027, CoP 9302, CoPant 96219, CoS 02264, CoS 109, CoS 797, CoS 94270, CoS 95222, CoS 97258, CoS 97264, CoSe 95422 were selected for low temperature regime of subtropical condition hence these varieties exhibit better winter sprouting. Foreign hybrids bred in Argentina (TUC 472), Barbados (B-348, B 3365, BM 368, BM 555, BM 61/1), Brazil (SP 80-1816), Fiji (F 133, Mali), Puerto Rico (PR 1013) and USA (CP 11-61, L 62-37, LF 64-2815, LF 65-3661) recorded excellent winter sprouting. Except Florida clones others were not selected for winter tolerance. So the added advantage of these clones is an indication of genetic differences among clones. Brandes (1939) and Irvine (1978) suggested utilization of wild species, *Saccharurm spontaneum* and related genera like *Ripidium* (now *Erianthus) bengalense* in breeding for cold tolerance. Ram and Sahi (2012) recorded 98.61% sprouting during winter in *S. spontaneum* clones, 84.17% in *S. barberi* clones and poor sprouting (19.24%) in *S. robustum* clones under subtropical region of India. Recently, Glowacka *et al.* (2016) reported cold tolerance in *S.spontaneum* x *Miscanthus* hybrid named as 'Miscane-US84-1058'. In the present study sixteen inter-specific and inter-generic hybrids bred at ICAR-SBI, Coimbatore namely 20-200, 97-12, 99-304, 99-316, 99-356, 99-488, CYM 06-935, CYM 06-1144, CYM 07-284, GU 07-1841, GU 07-3704, GU 07-3730, GU 07-3774, KGS 99-1109, KGS 2004-72 and KGS 2004-20 recorded WSI>3.0. ISH clones like 20-200, 97-12, 99-304, 99-316, 99-356, 99-488 were derived from crosses involving *S.officinarum, S.spontaneum* and *S.robustum* as one of the parent in their immediate geneology. KGS series clones were the backcross derivatives of *S.barberi*, *S.sinense* crossed with commercial varieties. GU series clones and the two CYM clones namely CYM 06-1144 and CYM 07-284 were of inter-generic hybrids between *S.spontaneum* x *Erianthus bengalense* backcrossed with commercial varieties. The direct utilization of these high winter sprouting clones for commercial cultivation in the subtropical India will be limited as most of the clones were lacking desired agronomic and quality attributes such as high cane yield, non-lodging, high sucrose %, high juice extraction % and resistance to red rot. Nonetheless, these clones will serves as ideal parents for transferring winter ratoonability trait in an otherwise good commercial cultivar. Irvine (1978), Tai and Miller (1986) used % green leaf area after frost injury and number of shoots per plot to measure cold tolerance and ratooning ability. Arceneaux *et al.* (1951) and Irvine (1966) classified cold tolerance into three categories: resistance of leaves and buds to frost damage, resistance of stalks to freezing and subsequent deterioration, and the ability to ratoon after a severe winter. In the present study, the number of stubbles alive and sprouted per plot and number of shoots emerge in each clump during winter month *i.e.* 45^{th} days after harvest of plant crop is taken into account to construct an index called WSI. The genotypes were classified into four winter sprouting categories. Considerable variability and genetic difference among sugarcane germplasm for winter sprouting was observed. Clones bred under subtropical climate right from seedling nursery to final release showed better sprouting in comparison to ISH and IGH clones. Significant and positive correlation between WSI and number of tillers (r=0.41) and millable canes in ratoon crop (r=0.42) was observed in the study. Hence, WSI may be used with confidence to adjudge winter ratooning ability of sugarcane genotypes. Nonetheless, in this study a definite association was not observed between the stalk diameter, sucrose percentage in juice *versus* WSI although there was report (Irvine, 1978) indicating thin stalk and low sucrose varieties are more tolerant to low temperature than high sugar and thick stalk clones

Conclusion

From the study it may be stated that the winter sprouting index is an efficient measure to identify low temperature tolerant clones for subtropical region and sugarcane breeders may use this methodology with confidence to screen germplasm. While selecting donors for winter ratooning ability clones with high percentage of alive and sprouting stubbles coupled with high number of shoots per clump immediately after winter is over may be looked for. The differential response of clones to winter sprouting was well documented and the possibility of identifying donor for winter sprouting among subtropical varieties and India's inter-specific and inter-generic hybrid clones is presented. Progenies derived from crosses involving *S. spontaneum*, *S. barberi* and *Erianthus bengalensis* showed excellent winter sprouting. Since the subtropical varieties and Co canes got selection advantage against winter during the course of their evolution and evaluation, hence they did not fall under LTS category. On the other hand, most of the CYMA clones which are the near commercial advanced generation stocks of inter-genic hybrid involving *Erainthus arundinaceus* and *Saccharum spontaneum*, due to their evolution and selection under tropical environment falls under LTS and poor winter sprouting category in subtropical India. Therefore, while attempting to incorporate adaptive traits against the abiotic stresses from related genera and species of *Saccharum* and in the base broadening breeding programmes, the pre-breeding material should be selected under targeted environment *i.e.* winter climate.

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