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SHORT RESEARCH ARTICLE

Evaluation of sugarcane clones for yield, quality and adaptive characters under waterlogged condition

M. Nisha*, K. Chandran, P. P. Gireesan, V. Krishnapriya[1], Mayalekshmi, R. Gopi and B. Mahendran

Abstract

Sugarcane clones specifically bred for tolerating waterlogging were evaluated for yield, juice quality and aerial root formation under natural waterlogged conditions. Clone, WL12-92 had the least and WL12-366 had the maximum aerenchyma in the aerial root. Cane yield and juice quality evaluation showed that test clones outperformed the check varieties for most of the traits. Clones WL12-101, WL12-509 and WL12-314 gave higher CCS yield per plot. Number of nodes with aerial root had negative correlation with all yield and quality traits except cane length and hand refractometer brix 8th month. Area occupied by aerenchymatous tissue in aerial root showed a positive correlation with yield, cane length and CCS yield per plot.

Keywords: Aerenchyma, aerial root, adaptive characters, Sugarcane, waterlogging.

Waterlogging is one of the abiotic stresses affecting sugarcane crop's cane yield and juice quality. In India, about 2.2 lakh ha area faces a waterlogging threat, especially in parts of Uttar Pradesh, Bihar, Odisha, Maharashtra, coastal areas of Andhra Pradesh and Karnataka (Nair 2012). Waterlogging affects almost all stages of crop growth ranging from the germination, tillering and grand growth period, thereby reducing biomass yield and quality (Zhou et al. 2020). Though Sugarcane is fairly tolerant to waterlogging, the extent of yield and juice quality reduction depends on genotype, stage of the crop when stress occurs and the duration of waterlogging in the field *per se*. The ability of superior varieties to withstand waterlogging is related to physiological, morphological, biochemical and anatomical adaptation. Waterlogging tolerant varieties can form aerenchyma roots that help sustain the biological processes under the anoxia condition. Aerenchyma formation varies with the genotypes; some require waterlogging conditions to produce such aerenchyma, whereas others produce it constitutively (Glaz et al. 2004). Root system is the first plant part to be affected by waterlogging stress. Anoxia condition results in poor root development and insufficient respiration for normal functioning of roots (Yamauchi et al. 2018; Pan 2021). A poorly developed root system affects the absorption of nutrients and water. Aerotropic development of roots under oxygen deficiency and specialized aerenchymatous floating roots are also inherent traits to combat Sugarcane's waterlogging stress (Gomathi et al. 2015).

Seven sugarcane clones bred specifically for waterlogging tolerance along with three standard varieties were evaluated for pattern of aerial root formation, yield and quality traits at the ICAR-Sugarcane Breeding Institute Research Centre, Kannur, Kerala, India (11°52 N, 75°25 E, 11 m amsl) during 2019-20 crop season. Natural waterlogging occurs during the rainy days, causing water stagnation even up to a height of 30 cm. The submergence level was up to 30 cm during the evaluation period for four months from June to September. The water level rose up to 1-m for a period of 1-week in the month of August. The clones were planted in two rows of 3 m length and replicated thrice. Recommended cultural practices of Sugarcane are adopted. The clones were

ICAR-Sugarcane Breeding Institute Research (SBI) Centre, Kannur 670 032, Kerala, India.

[1]ICAR-SBI, Coimbatore 641 007, Tamil Nadu, India.

***Corresponding Author:** Nisha M., ICAR-Sugarcane Breeding Institute Research Centre, Kannur 670 032, Kerala, India, E-Mail: nishathanima@yahoo.com

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evaluated for various yield traits, juice quality traits, patterns of aerial root formation and root anatomical studies and were statistically analysed using SPSS statistical software.

Pattern of aerial root formation

Sugarcane varieties that can develop adventitious roots are known to perform better under waterlogged conditions. The number of nodes with aerial roots ranged from 1.1 to 3.3 among test clones and 1.6 to 1.8 for check varieties. Co 99006 (Neeraj), a waterlogging tolerant check variety, showed stress adaptive physiology and morphological traits has also been reported earlier (Gomathi et al. 2015). The results (Table 1) indicate that the test clones recorded wide variation for a number of aerial roots. Clones WL12-811 and WL12-366 showed more number of internodes with better aerial roots. The intensity of aerial roots at the nodes were scored from low to high based on visual observation and a number of aerial roots present on an individual node. The intensity showed variation among all the clones ranging from high (WL12-811, WL12-366, Co 99006 and Co 62175) to low (WL12-101 and WL12-92).

Anatomical studies on root

Under waterlogged conditions, the sugarcane crop produces adventitious roots due to the hypoxia-induced hormonal imbalance and reduced oxygen supply to the submerged tissues. The enhanced intercellular spaces in adventitious roots were found to be associated with clones that are tolerant to waterlogged conditions. Though selection for adventitious root development may not increase sugarcane yield under waterlogging, aerenchyma development of stalk is a useful criterion to identify the tolerant clones (Sukchain and Dhaliwal 2005; Gilbert et al. 2007). The presence of large interconnected intercellular gas-filled space (aerenchyma) that extends from the shoots to the root tip is a special feature exhibited by almost all species that grow well in wet places (Gomathi et al. 2015). So the anatomical study was done to know the area occupied by the aerenchyma cell total area of the root.

The cross-sectional area of the roots ranged from 1.01 mm^2 (WL12-314) to 2.5 mm^2 (Co 99006). The highest total root area was recorded for the clone WL12-92 (1.8 mm^2). Variation among the clones for total root area was significant at P=0.05 (Table 2). Area occupied by the cortex tissues ranged from 0.99 to 1.45 mm^2. The clone WL12-509 showed the least area occupied by cortex tissues, whereas WL12-92 had the most occupied area. Co 99006 recorded the highest total area of cortex tissue, around 75.2% of the total root area. Area occupied by the cortex tissues in the total root area ranged from 71.8% (WL12-300) to 82.4% (WL12-366). Area of aerenchyma tissues on cut surface ranged from 0.046 mm^2 to 0.307 mm^2 for the test clones and 0.039 to 0.475 mm^2 for check varieties. The variety Co 62175 recorded the highest area of aerenchyma tissues in the aerial roots, while among the test clones, WL12-366 had more aerenchyma. The clone WL12-92 which was having high total area of aerial root showed minimal area occupied by aerenchyma tissues. The variety Co 62175 had the highest area occupied by aerenchyma tissues. The percent of aerenchyma tissues with respect to the cortex tissues ranged from 5.9% (WL12-92) to 32.1% (WL12-366) in test clones and 3.8 (Co 86032) to 41.7% (Co 62175) in check varieties. The percent of aerenchyma tissues per total area of the aerial root ranged from 4.6% (WL12-314) to 24.2% (WL12-366) for the test clones, and 3.1% (Co 86032) to 33.7% (Co 62175) for the check varieties. The variety Co 990006 had 12% area occupied by the aerenchyma tissue per total area of aerial root (Table 2).

Waterlogging stress that causes anoxia condition to

Table 1. Pattern of aerial root formation in waterlogging-resistant clones

S. No.	Clone	Mean No. of internodes with aerial roots	Mean length of aerial roots cm	The intensity of aerial roots at nodes
1	WL 12-811	3.3	5.7	High
2	WL 12-366	2.3	4.7	High
3	WL 12-509	1.1	5.0	Low
4	WL 12-314	1.4	4.6	Low
5	WL 12-300	1.4	5.1	Medium
6	WL 12-101	1.1	5.3	Low
7	WL 12-92	1.2	6.0	Low
8	Co 62175 (Check)	1.6	3.5	High
9	Co 86032 (Check)	1.6	4.2	Medium
10	Co 99006 (Check)	1.8	7.5	High
F value at 18 d.f.		9.5*	0.7	
SE		0.3		
CD		0.6		

*F value significant at P=0.05

Table 2. Anatomical data of the aerial root and aerenchyma tissues

S. No.	Clone	Total area of aerial root tissues mm^2	Area of cortex tissues mm^2	% area occupied by the cortex tissues/ Total area of aerial root	Area of aerenchyma tissues mm^2	%area of aerenchyma cell/ area of cortex cell	%area of aerenchyma cell/ area of total root cell
1	WL 12-811	1.253	1.014	80.9	0.223	22.0	17.8
2	WL 12-509	1.256	0.985	78.5	0.246	25.1	19.7
3	WL 12-92	1.800	1.449	80.5	0.086	5.9	4.8
4	WL 12-101	1.647	1.319	80.1	0.190	14.3	11.5
5	WL 12-300	1.606	1.153	71.8	0.119	6.9	5.3
6	WL 12-366	1.392	1.147	82.4	0.307	32.1	24.2
7	WL 12-314	1.015	0.778	76.6	0.046	6.0	4.6
8	Co 86032	1.221	0.989	81.0	0.039	3.8	3.1
9	Co 99006	2.490	1.872	75.2	0.298	15.9	12.0
10	Co 62175	1.470	1.169	79.5	0.475	41.7	33.7
F value at 18 df		5.9*	5.8*		5.5*	58.1*	42.8*
SE d		0.24	0.18		0.1	2.36	2.18
CD		0.5	0.4		0.2	5.0	4.6

*F value significant at $p = 0.05$

the roots in turn, inhibits water and nutrient uptake. In sugarcane N, P and K deficiency due to waterlogging cause growth reduction (Singh et al. 2019). The decreased rate of photosynthesis under waterlogging can be attributed to stomata closure, reduction in leaf chlorophyll content, ethylene production, reduced sink demand, and disruption in photosynthetic transport (Bamrugrai 2021). Production of tiller and elongation of the established tiller in Sugarcane is reduced under waterlogging. Waterlogging stress during the grand growth phase can cause 5 to 30% yield loss due to lack of nutrition and water uptake (Gomathi et al. 2015). In addition, a reduction in sugarcane yield by 14–50% was reported. Adventitious roots that have high porosity help the plants to survive under waterlogged conditions and are induced by ethylene accumulation (Jaipong et al. 2016)

Cane yield and juice quality traits

Cane yield and juice quality traits studied included NMC, cane thickness, cane length, HR brix 8th month, SCW, brix 10th month, sucrose%, CCS%, cane yield and CCS yield per plot (Table 3). Test clones like WL12-101, WL12-509 and WL12-314 had higher CCS yield per plot and high sucrose content at 10th month compared to the check varieties. These three clones had medium resistant reactions to red rot pathogen and, therefore can be effectively utilized as genetic stock of high sucrose.

Correlation studies on anatomical and agronomical traits

Number of nodes with aerial root, one of the adaptive characters for waterlogging stress, showed a negative correlation with all cane yield and quality traits except cane length and HR brix 8th month. Such a negative correlation may be due to more partitioning of biomass resources for the formation of aerial roots during survival under waterlogging stress. A weak positive correlation was observed between a number of nodes with aerial root and HR brix 8th month. The correlation between the number of nodes with aerial root and cane length was also positive (Table 4). The area of occupied by aerenchyma tissues in the aerial root showed a positive correlation with cane length, cane yield and CCS yield per plot. Co 62175 with the highest area of the aerenchyma tissues was the highest yielder among the clones. The clones WL 12-92 and WL 12-300 with least area of the aerenchyma tissues were poor yielders among clones. Genetic correlation of root traits under waterlogging shows that selection for adventitious roots development may not increase sugar yield (Sukchain and Dhaliwal 2005). However, aerenchyma development is a useful criterion for the selection of waterlogging tolerant clones (Gilbert et al. 2007). The positive correlation between area occupied by the aerial root's aerenchyma tissues and CCS yield per plot was not significant.

Similarly positive correlation between the area occupied by the aerial root's aerenchyma tissues and cane length was not significant. The traits like HR brix 8th month, SCW, brix 10th month, sucrose% and CCS% had negative correlations with area of occupied by aerenchyma tissues in the aerial root. The highest yielding variety Co 62175 with more area of aerenchyma tissues exhibited inferior juice quality traits among the clones. Co 86032, WL 12-101, WL12-92 with lowest area occupied by aerenchyma tissues exhibited greater sugar content.

Studies on various adaptive characters of sugarcane

Table 3. Performance of clones for yield and quality traits

Clone	NMC	Cane thickness cm	Cane length cm	HR brix % 8th month	SCW kg	Brix %10th month	Sucrose %	CCS %
WL 12-101	48	2.3	246	23.2	1.0	23.7	22.5	16.0
WL 12-300	44	2.1	210	19.9	0.7	18.9	17.4	12.3
WL 12-314	43	2.7	223	18.8	1.2	20.7	18.9	13.3
WL 12-366	49	2.5	217	19.6	0.9	19.8	18.1	12.7
WL 12-509	80	2.1	230	20.3	0.7	20.1	18.3	12.8
WL 12-811	56	2.1	272	21.1	0.8	20.1	18.8	13.3
WL 12-92	36	2.6	248	20.0	1.0	20.4	19.1	13.5
Co 62175	63	2.7	276	18.4	1.3	17.9	16.3	11.5
Co 86032	34	2.8	290	20.2	1.5	20.3	19.1	13.6
Co 99006	46	2.3	280	21.3	1.1	20.7	18.6	13.0
F value at 18 df	5.9*	6.9*	17.3*	10.6*	20.9*	9.7*	11.5*	11.1*
SE	8.0	0.1	9.9	0.6	0.8	0.7	0.7	0.5
CD	16.7	0.3	20.7	1.2	1.6	1.4	1.4	1.1

* F value significant at p=0.05

Table 4. Correlation coefficients between adaptive and agronomic traits

Traits	*No. of internodes with aerial roots*	*Area of aerenchyma tissues mm²*
Mean No. of internodes with aerial roots	1.00	0.23
Area of aerenchyma tissues mm2	0.23	1.00
HR brix % 8th month	0.01	-0.11
SCW kg	-0.15	-0.08
Brix % 10th month	-0.21	-0.38
Sucrose %	-0.19	-0.42
CCS %	-0.19	-0.43
Cane length	0.22	0.21
Yield kg	-0.08	0.67*
CCS yield/plot kg	-0.14	0.55

*. Correlation is significant at the 0.05 level

Fig.1: Aerial root formation in the water logging clones

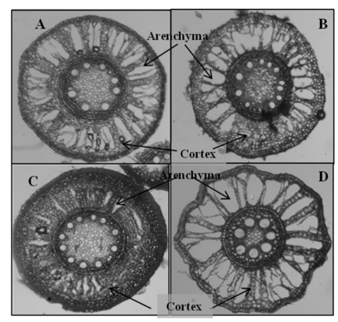

Fig.2: Cross section of aerial root of waterlogging tolerant clones A)WL 12-366 B) WL 12-509 C)WL 12-92 D) Co 99006

clones to waterlogging stress indicate that the variety Co 99006 a waterlogging tolerant clone had profuse and long aerial roots on the node. The variety Co 62175 with high intensity of aerial roots had the highest area of aerenchyma tissues in the aerial root. As per the correlation coefficients, a positive association was evident between adaptive traits and agronomic traits like cane length, cane yield and CCS yield per plot. Clones like WL12-101, WL12-509 and WL12-314 exhibited higher CCS yield per plot along with better juice quality under waterlogging conditions and, therefore, can be effectively utilized to develop waterlogging tolerant varieties.

Author's contribution

Conceptualization of research (NM, KC), Designing the experiment (NM, KC), Conducting the field trial (NM, GPP, ML, GR, MB), Data collection and Laboratory works(NM, GPP, ML, GR, MB), Analysis of the data and interpretation (NM, KV) Preparation of the manuscript (NM, KC, KV).

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