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Full Length Research Paper

A study of sugarcane genotypes under flood stress condition and adaptive mechanisms

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Juice quality, adventitious roots, growth rate and senesced leaves, green leaves were examined under flood stress conditions for six sugarcane genotypes I 112-01, I 6-04, I 39-04, I 152-04, I 189-04 and Isd 38. The pot study was conducted in an artificially created flood in a concrete water tank in the Bangladesh Sugarcane Research Institute during the 2010-2011 cropping seasons to screen flood tolerant clones. The clones I 6-04 and Isd 38 exhibited high tolerance to flooding following 30, 60 and 90 days and 30 cm depth above pot soil sustained floods. These varieties had >45% green leaf after 120 days stress periods. Clones I 112-01, I 39-04 and I 189-04 showed tolerant reactions following 30, 60 and 90d flood stress periods with > 40% green leaf after 90d. Clone I 6-04 produced the highest adventitious root (AR) (145.0 g/plant) followed by Isd 38 (110.0b g/plant).The clones I 6-04 and Isd 38 showed highest growth rate. Isd 38 showed highest Brix percent (20.15) and pol percent (14.52) followed by I 6-04 (Brix 19.95 and pol 14.12). Our results indicate that clone I 6-04 and Isd 38 performed better under flood stress conditions than other clones for selecting a stress tolerant variety.

Key words: *Saccharum Officinarum*, dry and green leaves, adventitious root (AR), growth rate, chlorophyll, juice quality.

INTRODUCTION

Flooding is a natural disturbance affecting crop and forage production worldwide due to the detrimental effects that it provokes on most terrestrial plants [Bailey–Serres and Voesenek, 2008; Colmer and Voesenek, 2009]. Among abiotic stresses, flood is an important stress for sugarcane cultivation in Bangladesh. It is because of increased cultivation of sugarcane in low lying char areas prone to periodic inundation by flood water.

The effect of excess water stress from temporary or continuous flooding has been studied extensively [Scott et al., 1989; Jackson et al., 1978]. Sugarcane root density is greatest near the soil surface with 60% in the 0 to 30 cm depth, but roots may penetrate to 180 cm in well-drained soils [Gascho and Shih, 1983; Paz-Vergara et al., 1980]. One morphological change in sugarcane roots growing under high water tables is a greater proportion of fibrous to thick roots in the soil layer above the water table [Eavis, 1972; Webster and Eavis, 1972]. The reason is probably an adaptation to lower O_2 levels. A thin root has a smaller path-length for O_2 diffusion to respiring tissue than a thicker root [Eavis, 1972]. Presence of root aerenchyma is a key requisite for sustained root activity in flooded soil. The roots of all of the 40 sugarcane genotypes examined contained aerenchyma [Ray et al., 1996; Heyden et al., 1998]. In species that are flood tolerant, aerenchyma formation is usually constitutive, meaning that it requires no external stimulus, such as flood [Drew, 1997]. Glaze et al. [2002] grew nine sugarcane

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Figure 1. Pictorial view of the experiment conducted in a concrete water tank under induced flood stress condition with control.

cultivars under 15 and 38 cm water table depths. They reported a mean yield reduction of 8.3% at the 15 cm water table, but two cultivars had similar yields at both water tables, and the yield of one cultivar was reduced by 25% at the 15 cm water table. Generally, sugarcane is not considered a flood tolerant species, but when it exposed to flood sugarcane produces adventitious roots which contains aerenchyma. These adaptations allow some sugarcane genotypes to sustain growth under flood stress. In previous studies, germination and early seedling growth stages were found most susceptible to flood [Miah and Rahman, 2002]. In Bangladesh, sugarcane is not planted before November through December which reduces the possibility of flood stress during early growth. Some morphological traits associated with tolerance under flood, however are yet to be identified. Main objective of this experiment was to find out the suitable clones for cultivation in low lying areas of Bangladesh.

MATERIALS AND METHODS

An experiment was carried out to screen flood tolerant clones during the 2010-2011 cropping seasons. BSRI produced sugarcane clones I 112-01, I 6-04, I 39-04, I 152-04 and Isd 38 were grown in plastic pots (2 pots per clone). One pre-germinated seed cutting was transplanted in each pot. Irrigations and other cultural practices were done as and when required to all plant in pot for natural growth. Six months after transplanting two pots of each clone were placed in a concrete tank and inundated in running water (30 cm deep above pot soil), while the remaining five pots per clone were kept as non-flooded controls. Green and dry leaves counts were taken after 60, 90 and 120 days of inundation. Data on fresh and dry weight of adventitious roots as well as volume of adventitious roots (ARs) were taken at harvest. ARs were collected and taken in paper bags of known weight and oven dried at 85°C until constant weight. Tolerance rating scale was recorded on greenness of leaves and other factors recorded. Data were recorded on growth rate at 60, 90, 120 days floods. (Figure 1).

Laboratory analysis of cane juice was done after 11 months of growth. The cane samples were crushed in a three-roller mill (power crusher). Soluble solis (^{0}Brix) was determined by Brix hydrometer standardized at 20°C and Horne's dry lead method was used for sucrose determination using an automatic polarimeter (Bellingham and Stanley ADP-220®). Juice purity was calculated as the ratio of the sucrose content and corrected Brix reading. Reducing sugars were determined by the method described in Queensland Laboratory Manual [Bureau Sugar Experiment Stations (BSES), 1970].

Statistical analysis was performed and means values were compared using LSD test at 5% level of significance [Gomez and Gomez, 1984]

RESULTS AND DISCUSSION

Plants develop a suite of anatomical, morphological and physiological responses in order to deal with partial submergence imposed by flooding [Colmer and Voesenek, 2009; Striker et al., 2005]. The most common anatomical response is the generation of aerenchyma in tissues [Seago et al., 2005], which facilitates the transport of oxygen from shoots to roots [Colmer, 2003]. At morphological level, usual responses to flooding include adventitious rooting and increases in plant height and consequently, in the proportion of biomass above water level [Naidoo and Mundree, 1993; Grimoldi et al., 1999]. This also helps to facilitate the oxygenation of submerged tissues through the aerenchyma tissue [Colmer, 2003] and at physiological level, flooding modifies water relations and plants carbon fixation. Closing of stomata, with or without leaf dehydration, reduction of transpiration and inhibition of photosynthesis, are responses that can occur in hours or days, depending on the tolerance to flooding of each plant species [Striker et al., 2005; Insausti et al., 2001; Mollard et al., 2008; Mollard et al., 2010]. The following sections show the main plant responses at those levels associated with tolerance to flooding.

Partitioning to dry and green leaves

Genotypes have significant effect on dry leaf, green leaf and genotypes (Table 1). Genotype I 6-04 produced the highest no of green leaves (51.07%) followed by Isd 38 (45.45%). Highest growth rate was recorded in the genotype I 6-04 (1.280 cm/day) followed by Isd 38 (1.25 cm/day). Flood and control condition has significant effect on dry leaf, green leaf and growth rate variables. Different days after initiation of stress showed significant effect on dry leaf, green leaf and a non significant effect on growth rate. Interaction of factor A (variety)and factor B (Flood, Control), factor A and factor C (Different days after initiation of flood), factor B and factor C, factor A, factor B and factor C has significant effect on dry leaf, green leaf and growth rate. All the varieties under flood condition at different stress period produced higher no of green leaf, and showed higher growth rate than in control condition. Our findings are in agreement with Tetsushi and Karim [2007] who found that plant height of the flooded plants was noticeably higher than that of the control plants. It is possible because sugarcane has constitutive aerenchyma. For this reason when it falls under stress it can easily survive by using oxyzen which is preserved by aerenchyma cell. Aerenchyma formation in the root cortex is the most studied plastic response to flooding [Seago et al., 2005; Visser et al., 2000; McDonald et al., 2002; Evans, 2003; Grimoldi et al., 2005; Striker et al., 2007]. This aerenchyma tissue provides a continuous system of interconnected aerial spaces (aerenchyma lacunae) of lower resistance for oxygen transport from aerial shoots to submerged roots, allowing root growth and soil exploration under anaerobic conditions [Colmer and Greenway, 2005]. It is predictable that stress from soil flooding on roots also alters shoot morphology because of the close functional interdependence between both of them. In this way, flooded plants of tolerant species are often taller than their non-flooded counterparts as a result of increases in the insertion angles and length of their aerial organs. These responses were well characterized in the dicotyledonous *Rumex palustris* by Cox et al. [2003, 2004] and Heydarian et al. [2010] among others.

Adventitious root

There were significant differences in adventitious roots of various genotypes under stress condition (Table 2). It was found that the clones I 6-04 produced higher adventitious roots (145.0 g/plant) followed by Isd 38 (110.0 g/plant). Flooding induces morphological changes in roots and shoots. In the sugarcane, the formation of adventitious roots is highlighted as a common response of flood-tolerant species. These adventitious roots, which have high porosity, help plants to continue with water and nutrient uptake under flooding conditions, replacing in some way the functions of older root system [Kozlowski et al., 1984]. It is frequent that these adventitious roots are positioned near the better-aerated soil surface. Following the review by Jackson [2004], there are three mechanisms for generating these ‘replacement’ root systems: (i) stimulation of the outgrowth of pre-existing root primordia in the shoot base [Jackson et al., 1981], (ii) induction of a new root system that involves initiation of root primordia and their subsequent outgrowth [Jackson and Armstrong, 1999; Shimamura et al., 2007] and (iii) placing roots at the soil surface involving the re-orientation of the root extension as seen for woody species by Pereira and Kozlowski [1977] and for herbaceous species by Gibberd et al. [2001]. The two first mechanisms appear to be triggered by ethylene, which is thought to increase the sensitivity of plant tissues to auxin [Bertell et al., 1990; Liu and Reid, 1992] (Figures 2 and 3).

Juice quality

Juice quality of sugarcane which was indicated by Brix percentage, Purity percentage, Pol percentage and Reducing Sugar (Table 3). Genotypes showed significant difference on Brix, pol, purity and reducing sugar. Genotype Isd 38 produced highest Brix percentage (20.15) highest pol percentage (14.52) and highest purity percentage (90.55) followed by I 6-04 (Brix 19.95, pol 13.92, purity 90.13). Flood and control condition showed significant difference on Brix and RS. It has no significant effect on pol and purity percentage. All the genotypes produced higher Brix, pol, purity percentage and lower RS in flood condition than in the control condition. Our findings are in agreement with Hasan et al. [2003] who grew some sugarcane genotypes under waterlog condition and found that all the genotypes had higher Brix, pol, purity percentage and lower RS in waterlog than

Table 1. Effects of flood on dry leaf, green leaf and growth rate of sugarcane genotypes.

Treatments Factor A (Genotypes)	Dry leaf	Green leaf	Growth rate
I 112-01 (V_1)	56.75 b	43.25 c	0.720 c
I 6-04 (V_2)	49.10 e	51.07 a	1.280 a
I 39-04 (V_3)	56.12 bc	43.88 c	1.090 b
I 152-04 (V_4)	62.67 a	37.33 e	1.121 b
I 189-04 (V_5)	55.38 cd	41.62 d	1.073 b
Isd 38 (V_7)	54.55 d	45.45 b	1.125 b
LSD (0.05)	0.8569	0.8569	0.08569
Factor B			
Flood (F)	52.65 b	46.794 a	1.189 a
Control (C)	58.87 a	40.739 b	0.948 b
LSD (0.05)			
Factor C (Days)			
60 days (D_1)	47.28 c	52.63 a	1.089 a
90 days (D_2)	56.58 b	42.23 b	1.069 a
120 days (D_3)	63.32 a	36.43 c	1.047 a
LSD (0.05)	1.014	1.014	ns
Factor Ax Factor B			
V_1F	47.10 i	52.90 a	0.8533 g
V_1C	66.40 a	33.60 h	.5867 h
V_2F	48.53 h	51.80 a	1.487a
V_2C	49.67 gh	50.33 b	1.073 def
V_3F	54.97 e	45.03 c	1.127 cde
V_3C	57.27 d	42.73 d	1.053 def
V_4F	62.43 b	37.57 fg	1.266 b
V_4C	62.90 b	37.10 g	.9767 fg
V_5F	51.90 f	44.77 c	1.187 bcd
V_5C	58.87 c	38.47 f	0.960 fg
V_6F	49.83 g	50.17 b	1.213 bc
V_6C	59.27 c	40.73 e	1. 037 ef
LSD (0.05)	1.212	1.212	0.1285
Factor Ax Factor C			
V_1D_1	48.65 hi	51.35 c	.6900 i
V_1 D_2	56.30 e	43.70 f	.7850 i
V_1 D_3	65.30 b	34.70 i	.6850 i
V_2D_1	40.45 k	60.05 a	1.375 a
V_2 D_2	50.85 g	49.15 d	1.305 ab
V_2 D_3	56.00 e	44.00 f	1.160 cde
V_3D_1	47.95 i	52.05 c	1.205 bcd
V_3 D_2	55.50 e	44.50 f	1.000 fgh
V_3D_3	64.90 b	35.10 i	1.170 bcde
V_4D_1	52.90 f	47.10 e	.9750 gh
V_4D_2	63.50 c	36.50 h	1.123 def
V_4D_3	71.60 a	28.40 j	1. 265 abc
V_5D_1	49.65 gh	49.35 d	1.100 defgh
V_5D_2	57.70 d	35.80 hi	1.085 defgh
V_5D_3	58.80 d	39.70 g	1.035 efgh

Table 1 Contd.

V_6D_1	44.10 j	55.90 b	1.190 bcd
V_6D_2	56.25 e	43.75 f	1.115 defg
V_6D_3	63.30 c	36.70 h	.9650 h
LSD (0.05)	1.286	1.286	.1286
	Factor B x Factor C		
FD_1	45.60 e	54.40 a	1.292a
FD_2	52.18 c	46.15 c	1.116 b
FD_3	60.17 b	39.83 d	1.158 ab
CD_1	48.97 d	50.87 b	.8867 c
CD_2	61.18 b	38.32 e	1.022 bc
CD_3	66.47 a	33.03 f	.9350 c
LSD (0.05)	1.434	1.434	.1434
	Factor A x Factor B x Factor C		
V_1FD_1	38.10 q	61.90 b	1.020 hijklm
V_1FD_2	46.90 n	53.10 e	.8200 mno
V_1FD_3	56.30 h	43.70 i	.7200 no
V_1CD_1	59.20 f	40.80 k	.3600 p
V_1CD_2	65.70 c	34.30 n	.7500 no
V_1CD_3	74.30 a	25.70 p	.6500 o
V_2FD_1	44.30 o	55.70 d	1.860 a
V_2FD_2	49.10 m	50.90 f	1.370 bcd
V_2FD_3	55.60 hi	44.40 hi	1.230 cdefg
V_2CD_1	36.60 q	64.40 a	.8900 klmn
V_2CD_2	52.60 jk	47.40 g	1.240 cdef
V_2CD_3	56.40 h	43.60 i	1.090 fghijk
V_3FD_1	45.90 no	54.10 de	1.200 defgh
V_3FD_2	54.00 ij	46.00 gh	.1.020hijklm
V_3FD_3	65.00 c	35.00 n	1.420 bc
V_3CD_1	50.00 m	50.00 f	1.210 defgh
V_3CD_2	57.00 gh	43.00 ij	.9800 ijklm
V_3CD_3	64.80 c	35.20 n	.9200 jklmn
V_4FD_1	55.80 hi	44.20 hi	1.100 fghij
V_4FD_2	62.80 de	37.20 lm	1.217 defgh
V_4FD_3	68.70 b	31.30 o	1.480 b
V_4CD_1	50.00 m	50.00 f	.8500 lmn
V_4CD_2	64.20 cd	35.80 mn	1.030 ghijkl
V_4CD_3	74.50 a	25.50 p	1.050 fghijkl
V_5FD_1	47.20 n	52.80 e	1.340 bcde
V_5FD_2	49.90 m	40.10 k	1.140 efghi
V_5FD_3	58.60 fg	41.40 jk	1.080 fghijk
V_5CD_1	52.10 kl	45.90 gh	.8600 lmn
V_5CD_2	65.50 c	31.50 o	1.030 ghijkl
V_5CD_3	59.00 f	38.00 l	.9900 ijklm
V_6FD_1	42.30 p	57.70 c	1.230 cdefg
V_6FD_2	50.40 lm	49.60 f	1.130 fghi
V_6FD_3	56.80 gh	43.20 ij	1.020 hijklm
V_6CD_1	45.90 no	54.10 de	1.150 efghi
V_6CD_2	62.10 e	37.90 l	1.100 fghij
V_6CD_3	69.80 b	30.20 o	.9100 jklmn
LSD (0.05)	1.819	1.819	.1819

Different letter indicates significance difference as per LSD at 5% level.

Table 2. Adventitious roots (AR) of BSRI bred sugarcane clones under induced flood stress condition (pot experiment).

Varieties / Clones	Fresh weight of AR/Plant (g)	Air dry weight of AR/Plant (g)	Volume of AR/Plant (ml)
I 112-01	41.3 e	7.0 d	44.3 e
I 6-04	145.0 a	28.3 a	135.0 a
I 39-04	38.8 f	7.7 d	42.0 f
I 152-04	75.1 d	14.7 c	88.6 d
I 189-04	93.9 c	17.3 b	112.5 c
Isd 38	110.0 b	18.9 b	101.4 c
Lsd (0.05)	1.779	1.779	1.779 b

Different letter indicates significance difference as per LSD at 5% level

Figure 2. Formation of adventitious root.

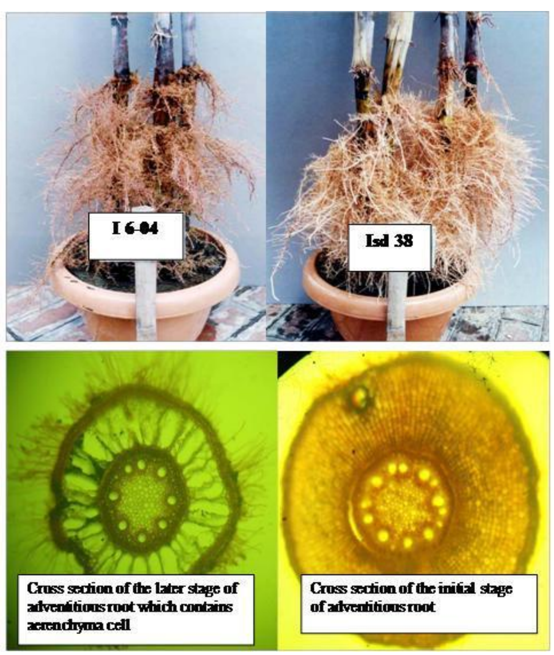

Figure 3. Pictorial view of the adventitious root.

Table 3. Effects of flood on Brix, pol, purity and rs of sugarcane genotypes.

Treatments Factor A (Genotypes)	Brix (%)	Pol (%)	Purity (%)	RS (%)
I 112-01 (V_1)	17.95 b	13.73 abc	88.88 bc	0.9700 a
I 6-04 (V_2)	19.95 a	13.92 ab	90.13 ab	0.3750 c
I 39-04 (V_3)	19.00 ab	13.42 abc	87.72 cd	0.4000 c
I 152-04 (V_4)	19.05 ab	12.66 bc	86.60 d	0.2350 d
I 189-04 (V_5)	19.10 ab	12.24 c	81.78 e	0.6000 b
Isd 38 (V_7)	20.15 a	14.52 a	90.55 a	0.5750 b
LSD (0.05)	1.484	1.484	1.484	0.04693
Factor B				
Flood (F)	19.817 a	13.553	87.673	0.347 b
Control (C)	18.583 b	13.273	87.543	0.705 a
LSD (0.05)	1.234	ns	ns	0.358
Factor Ax Factor B				
V_1F	19.80 ab	13.58 abc	89.80 abcd	0.5300 e
V_1C	16.10 c	13.87 ab	87.95 cde	1.410 a
V_2F	20.30 a	13.96 ab	91.60 a	0.3500 f
V_2C	19.60 ab	13.88 ab	88.65 cd	0.4000 f
V_3F	20.00 ab	13.48 abc	88.99 bcd	0.2000 g
V_3C	18.00 bc	13.36 abc	86.46 ef	0.6000 d
V_4F	19.50 ab	13.00 abc	87.71 de	0.1300 h
V_4C	18.60 ab	12.31 bc	85.48 f	0.3400 f
V_5F	19.50 ab	12.99 abc	85.00 f	0.3900 f
V_5C	18.70 ab	11.50 c	78.56 g	0.8100 b
V_6F	20.50 a	14.64 a	91.13 ab	0.4800 e
V_6C	19.80 ab	14.39 ab	89.97 abc	0.6700 c
LSD (0.05)	2.099	2.099	2.099	0.06637

Different letter indicates significance difference as per LSD at 5% level.

under normal condition.

CONCLUSIONS

It may be concluded that the clones which showed better performance under flood stress condition can be selected as tolerant clones for flood stress. The clones I 6-04 and I Isd 38 showed better performance under stress condition than control condition than other clones. So, we can say that the clones I 6-04 and Isd 38 are better for cultivation under flood stress condition. All these information would help to develop strategies for identifying flood tolerant species.

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