REVIEW ARTICLE

BREEDING FOR WATERLOGGING TOLERANCE IN SUGARCANE

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Abstract

Excess moisture stress/waterlogging stress is one of the major constrains in sugarcane agriculture. About 2.2 Lakh hectares sugarcane is getting affected by waterlogging across the sugarcane growing states in the country. Though waterlogging management may offer relief to short term stress, a permanent solution can be realized only through imparting resistance/tolerance to varieties though conventional breeding or biotechnological means. Heavy rainfall and poor drainage of water from the soil, inundation by the overflowing rivers and excessive irrigation are the major causes of waterlogging. Waterlogging stress affect almost all stages of crop growth in sugarcane; germination, tillering, and grand growth period and thereby reducing the biomass yield and quality. Several genotypes including breeding lines, commercial hybrids, *Saccharum* species and distantly related genera are available as source of tolerance and the breeding approaches need to be directed towards developing varieties with waterlogging tolerance by conventional or biotechnological means. This paper reviews the response of sugarcane plant to waterlogging stress, the availability of gene pool for waterlogging tolerance, breeding approaches and selection parameters for developing waterlogging tolerant varieties.

Key words: Sugarcane, waterlogging, anaerobic respiration, physiological markers, breeding, stress tolerance

Introduction

Sugarcane is the second most important industrial crop in the country occupying about 5 million hectares of area with a production of 376.9 mt which support the production of 32.38 mt of sugar (Anonymous, 2019). About 5 million farmers are involved in the cultivation of sugarcane and sugar industry contributes significantly to the rural economy by providing employment for nearly 4% of the rural population directly or indirectly (http://www.<u>sugarcane.res.in</u> */images/sbi/ article/ sbi_vision_ 2050.pdf*). The sugarcane production is hindered by several biotic and abiotic stresses. Excess moisture stress is one of the abiotic stresses that significantly affect the sugarcane production, productivity and quality of the produce. Waterlogging stress occurs when the water table rises to an extent by which the root zone of the crop get saturated which results in restriction of root zone aeration. For optimum growth of sugarcane the water table should be maintained below one meter (Moore 1987). Waterlogged situation is a major challenge to sugarcane agriculture, and about 2.2 lakh hectares are affected by flood/ waterlogging. The situations is very severe in parts of UP, Bihar, Odissa, Maharashtra, coastal areas of Andhra Pradesh and Karnataka (Nair 2012) and continue to increase in the present scenario of rapid climate change. Sugarcane cultivation is affected by waterlogging mainly during monsoon period. Heavy rainfall and poor drainage of water from the soil, inundation by the overflowing rivers and excessive irrigation are the major causes of waterlogging and it affect almost all stages of crop growth; germination, tillering, and grand growth period and thereby reducing the biomass yield and

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quality. The response of sugarcane to waterlogging mainly depends on the time, duration and nature of flooding.

PLANT RESPONSE TO WATERLOGGING STRESS

The waterlogging stress that affects sugarcane is mainly caused by gas stress and ionic stresses induced as a result of inundation of the soil.

i. Gas stress

When waterlogging occur the root zone get saturated with water. Once the root zone is completely saturated with water, gas stress is the major consequence of waterlogging. As the water table rises water will replace the gas phase of the soil causing a gas stress (Carter 1983, Robinson 1964). The oxygen deficit stress, excess carbon dioxide stress and ethylene excess stresses were identified as the major stress factors and the first one seems to be of major concern (Levitt, 1980). Consequent of oxygen deficit root respiration and cell permeability are reduced and in turn water and nutrient absorption is slowed down. Over and above it affect the root growth, elongation and lateral spread. The O_2 deficit leads to anaerobic respiration, increased metabolic toxins, reduced ion toxins and nutrient ions deficiency (Levitt 1980).

Root system is the first part getting affected by the waterlogging. The oxygen deficiency due to waterlogging results in, poor germination, insufficient respiration and normal functioning of the roots in sugarcane (Sheu and Yang, 1980). As a result of insufficient root system the absorption of nutrients and water is get affected and also the adherence of the plant to soil, ultimately resulting in wilting and lodging of the canes. In a study on O_2 deficiency in soil system revealed that even with the slight difference in O_2 concentration the root growth rate was affected (Banath and Monteith, 1966). The aerotropic development of roots under oxygen deficiency and specialized aerenchymatous floating roots are also found as an inherent trait to combat the waterlogging stress in sugarcane (Venkatraman and Thomas 1929, Shah 1951, Srinivasan and Rao 1960). The aerenchyma in roots apparently maintains the oxygen level and thus improves clonal flooding resistance. Ethylene plays an important role in change of mechanism of plants in deficiency of oxygen and also showed that ethylene induces the genes coding for enzymes associated with aerenchyma formation, glycolysis and fermentation pathways (Alamgir and Uddin 2011, Gowri Manohari 2009). It also been realized that in tolerant sugarcane genotypes the root survival under anaerobic condition is achieved by regulating the metabolites and the genotypes get acclimatized to the waterlogged condition by pre or post translational modification of the proteins associated with it (Jackson and Ricard 2003).

ii. Ionic stress.

Two types of ionic stress that caused due to flooding are mineral deficiency and low oxidation-reduction potential that leads to the reduction some ions to more soluble and toxic forms (Conway 1940). Both of the stresses are caused by the O_2 deficiency in root environment. Due to excess water flow soil nitrogen will be depleted by denitrification and leaching. Thus plants exhibit nutrient deficiency and apparent wilting symptoms. In waterlogged conditions, reduction in growth was accompanied with decrease in N, P and K contents but Ca and Mg increased in the leaf lamina (Samuels, 1971). In sugarcane it is also observed that the waterlogging stress induced 28.07 % and 29.53 % reduction in leaf and stem nitrogen contents respectively. However, reduction in nitrogen was comparatively less in tolerant clones 91WL629, 91WL552, 92WL1390, 98WL1357 and 99WL379 than the other genotypes (Gomathi et al. 2010; Gomathi and Chandran 2012).

EFFECT OF WATERLOGGING

i. Effect on plant growth

The effect of waterlogging on sugarcane crop is the yellowing and subsequent drying of lower leaves. There will be drastic reduction in total leaf area with the reduction in number of leaves and the decrease in length and width of leaves (Lal and Sharma 1998). The time and duration of the waterlogging is very critical and fully submerged condition is very rare occurrence unless it is affected in the very early stage of the crop growth. It is observed that waterlogging during formative phase of the crop (90-170 days after planting) showed 13.00, 21.63, 26.52 and 42.5 % reductions in plant height, tiller production, leaf area and total biomass respectively and result of correlation analysis also revealed that, the shoot population and plant height are highly positively correlated with waterlogging tolerance (Gomathi 2009; Gomathi and Chandran 2009). Results revealed that the varieties which maintained better shoot height and internodal length were better yielder under flooding condition.

ii. Nutrient uptake

The rate of nutrient uptake is influenced by permeability and root respiration which is hampered by low oxygen content in waterlogged soil. This results in nutrient imbalance. As a result of nutrient imbalance yellowing and scorched appearance was observed in sugarcane (Humbert 1963). The reduction in growth with decrease in NPK content in leaf lamina was also reported under waterlogged condition (Samuels 1971). Similarly, the reduction in leaf and stem nitrogen content was observed in waterlogging susceptible genotypes of sugarcane but such reduction was not observed in tolerant genotypes under stress condition (Gomathi et al. 2010; Gomathi and Chandran 2012). However, the phosphorous and potassium content were not affected due to waterlogging stress in sugarcane.

iii. Effect on metabolism

The metabolic processes that are affected by flooding are photosynthesis and respiration. During the shift from aerobic to anaerobic respiration, toxic products like ethanol and pyruvate accumulate in roots (Chirkova et al. 1974). In wheat and rye plants waterlogging induces increase in glycolysis at the tillering zone by accumulation of pyruvate, lactate and ethanol. Further it was showed that the increase in ADH activity was high (36.25%) in tolerant genotype (Co 99006) compared to sensitive genotype (Co 86032) with only14.50%. It indicates that the higher ADH activity in tolerant types may be for providing more energy to plant under anaerobic condition. The study also revealed that the variation in ADH enzyme activity among the genotypes is responsible for difference in expression of anaerobic polypeptides and it plays a major role in tolerance behaviour of sugarcane genotypes.

A marked reduction of nitrate reductase (NRase) in seminal roots was observed during submergence indicative of a change in metabolic activity especially protein metabolism in the leaves. After submergence, plants with low root NRase activity, the nitrate reduction becomes slow and the immediate demand for carbohydrate in the roots decreased (Mazaredo and Vegara 1981). Reduction of NRase in leaves of waterlogged plants is due to rapid depletion of the nitrate and oxygen under anaerobic conditions (Sung and Sun 1990, Hoff, Stummann and Henningsen 1992). In sugarcane, a positive association between nitrogen content of index leaf and NRase activity with flooding tolerance was observed and the nitrogen content in index leaf and NRase activity are suggested as key physiological markers for screening waterlogging resistance (Gomathi and Chandran 2012). A higher ethylene concentration under flooding increases the sensitivity of adventitious root-forming tissues and plays a principal role in aerenchyma formation. Anaerobic polypeptides (ANPs) recently reported have shown to be involved in the pathways which mobilize sucrose or starch for ethanol fermentation, which is necessary to maintain energy production under anaerobic conditions(Gomathi et al., 2015).

iv) Effect on yield and quality

Waterlogging reduces shoot and root growth, dry matter production and total crop yield. Cane yield losses depend upon the duration of waterlogging, stage of crop growth and management practices before, during and after waterlogging. A study conducted in Tamil Nadu, India indicated that water stagnation for two months lead to reduction in cane yield to the tune of 26-36% in various varieties (Manoharan et al. 1990). Studies at Sugarcane Breeding Institute (SBI), Coimbatore showed that the waterlogging caused 22.4%, reduction in number of millable cane, 45.6 % reduction in single cane weight, 30.0% reduction in cane length, 15.9% reduction in internodal length, 17.8% reduction in cane thickness and 40.1% reduction in cane yield (Gomathi and Chandran 2009 ; Gomathi et al. 2010).

Waterlogged cane attains higher juice sucrose content early in the season and with recede in water the juice quality deteriorates rapidly. Such canes shows profuse flowering and the juice quality will be poor with low sucrose, high invert sugars, high non- protein nitrogen and total colloids (Parthasarathy 1972). In general, flood-survived canes showed remarkable improvement in brix, but there was a reduction in sucrose and an increase in glucose. Results of four years field experiment conducted at SBI Research center, Kannur under natural waterlogged condition (90-170 days after planting) indicated that the sucrose % in juice reached maximum peak at 11th month in flooding while in control plot maximum sucrose was recorded only at 12th month. However, the tolerant genotypes (93WL1297, 98WL1357, 88WL2137, 92WL1029, NCO 310 and 57NG136) showed the least resistance to inversion of sucrose as compared to other clones. Hence, inversion of sucrose is a limiting factor for achieving high sugar content under waterlogging condition (Gomathi and Chandran 2013).

MORPHOLOGICAL MARKERS

Stress tolerance/avoidance is achieved by the plants by some developmental character present in them. If the stress is for shorter duration the stress avoiders continue to have good growth, but if it is for longer period only the truly tolerant plants will have better growth (Moore 1987). The stress avoidance may be achieved by plants having barriers to stress effect such as physical barrier like cuticle, wax, etc.; metabolic barriers like ion pump of root cells; morphological adaptations of leaves, roots and plasticity in seasonal development. The stress avoidance occurs when the plant is able to prevent, decrease or repair the injury produced by the stress. The major classes of stress avoidance are 1) stress tolerant but not avoiding, 2) stress tolerant and avoiding and 3) stress avoiding but intolerant (Moore 1987). In the case of waterlogging when the oxygen deficit occurs the resistant plants possessing avoidance will have high oxygen availability in the system where as those with tolerance will have low oxygen content. Consequently, stress avoiding but intolerant plants are generally lower yielding under optimum environments. Profuse development of fibrous floating roots (Srinivasan and Batcha 1963, Sartoris and Blecher 1994) and negatively geotropic roots (Fig 1) with aerenchyma (Shah 1951) were associated with waterlogging tolerant clones. Root anatomical studies conducted under waterlogged condition exhibited variation among the germplasm with regard to the number of air spaces/ lysigenous aerenchyma, number of

Fig. 1. Negatively geotropic roots of sugarcane clones under waterlogged condition

metaxylem vessels, average root diameter and ratio of cortex to stele (un-published).

In clones sensitive to waterlogging the geotropic are not present. Quick growth of a variety and bobbin shaped internodes are found related to waterlogging tolerance (Srivastava et al. 2003). Hidaka and Abdul Karim 2007 reported three types of roots under waterlogged condition, aerial roots (Fig. 2), whitish roots and secondary roots. The whitish roots referred as buttress roots by earlier workers (Jensen 1937 Evans 1934). The anatomy of the buttress roots showed extensive aerenchyma compared to normal roots. In young normal roots the aerenchyma formation was not observed even under waterlogged condition (Fig. 3). During rainy season the aerial roots shows water droplets hanging on the tip on the swollen calyptra (Fig

Fig. 2. Aerial roots of waterlogging tolerant sugarcane clones

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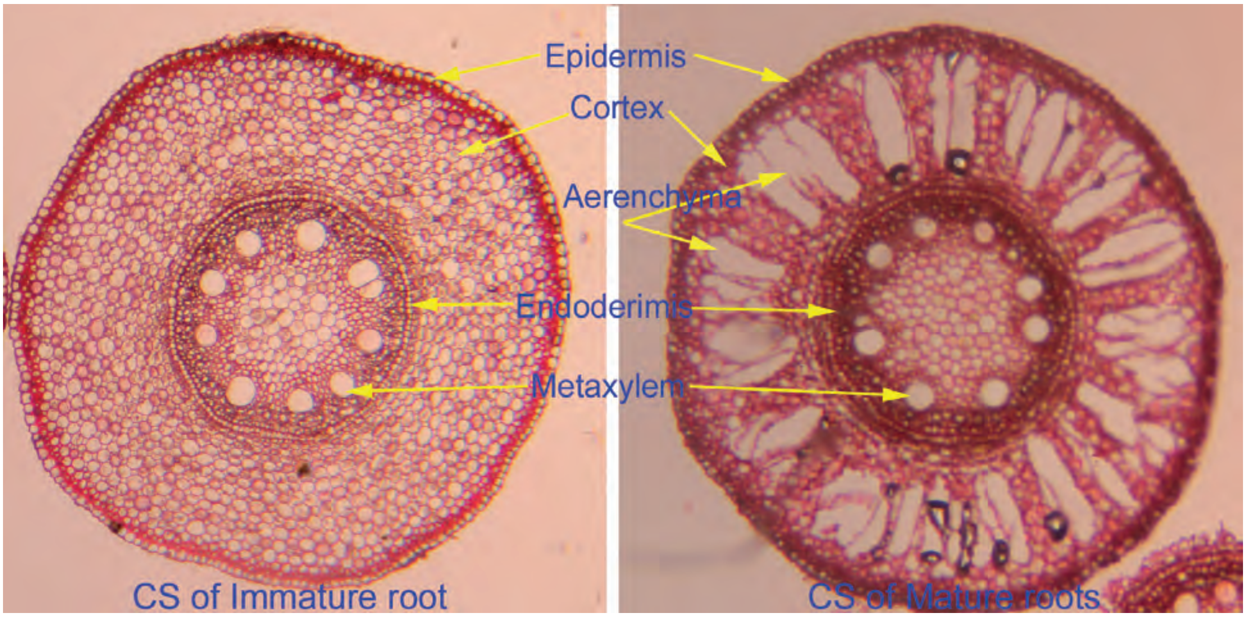

Fig. 3. Cross section (CS) of immature roots and mature roots of sugarcane

4). Studies on roots morphology and architecture are of prime importance in understanding the adaptation to waterlogging tolerance which is less investigated in sugarcane. In a study conducted

Fig. 4. Water drop on swollen calyptras of roots during rainy season

under waterlogged condition, Co 62175, SEL 74/1, WL 11 2263, WL 11 2230, Fiji15 and SS 60/1 were recorded better root length, root surface area, root volume and diameter under waterlogged condition. Co 62175 also showed better biomass and single cane weight, while WL 11-2534 recorded highest brix (23%). Also among 20 species clones the Boeton lictgroen, Kavengerie and Hemja was recorded better brix under waterlogged condition. Root studies in the species clones showed Fiji 15 with better root surface area (617 cm^2), while NG 77-230 recorded with the less root surface area (208 cm^2) Kumar et al. (2017).

PHYSIOLOGICAL CHANGES

Flood tolerant varieties of sugarcane showed increased number of internodes, profuse tillering, increased leaf dry matter and effective leaf area, increased phosphorous content in stem and decrease in leaf nitrogen content (Pandey 1964). An experiment conducted in green house revealed striking similarity in sugar and enzyme responses to deficient and excessive levels of water supply

(Alexander et al. (1972). The visual injury symptoms produced by the deficient and excessive water regimes were virtually indistinguishable. It reported that zero watering and flooding treatments produced wilting of leaf blades, drying of leaf sheaths extensive yellowing of leaf tips, margin and sheaths and severe curling of spindle leaves. Sugar changes were also comparable in both treatments, with sucrose content declining in leaves and initially in immature internode tissue. Invertase from immature storage tissue declined in response to both high and low water regimes.

In a pot experiment under short term flooding conducted in Sugarcane Breeding Institute indicated there was a reduction in total chlorophyll, chlorophyll a/b ratio and NRase activity due to flooding by 31.50, 25.80 and 25.45% respectively over control (Gomathi and Subha Charbut 2008). The flooding stimulated the activity of ADH and root soluble protein by 17.50 and 21.26% over control, respectively. An increase in ADH activity and root soluble protein was high in the waterlogging tolerant clones (Co 62175 and Co 99004). Irrespective of varieties, ethylene production was completely absent in control, while flooding induced production of root ethylene particularly in Co 99004 (1.06 µmole/g) and 0.305 µmole/g in Co 62175 (Gowri Manohari 2009).

In a field evaluation trial under waterlogged condition, it was observed that the physiological traits viz., the leaf nitrogen, total chlorophyll content, total dry matter production and leaf area index recorded after the receding of water were significantly and positively associated with yield. These parameters were identified as key physiological markers for screening waterlogging resistance (Gomathi and Chandran 2010, Gomathi and Chandran 2012). Studies on flooding stress related to seed germination, tiller productivity, stalk growth, morphological aspects, yield and quality was well established in sugarcane (Glaz et al. 2002, Glaz and Gilbert 2006; Robert et al. 2007). However, the mechanisms related to cellular adaptation in response to flooding tolerance was studied recently (Gomathi et al. 2012). This study revealed that the resistant varieties Co 99006, Co 99004 and Co 8371 had higher antioxidant enzyme activity as well as lower level of malondialdehyde (MDA) and low cell membrane leakage indicating their flooding tolerance compared to susceptible varieties (Co 86032 and Co 94012).The study also indicated that the nonspecific peroxidase, ascorbate peroxidase and superoxide dismutase plays a major role to control the reactive oxygen species and protect the cell from membrane damage induced during short term flooding stress.

In sugarcane it is found that anoxia induces enzymes and polypeptides in relation to flooding tolerance (Gomathi and GowriManohari 2010) The flooding stimulated the synthesis of a small group of proteins known as anaerobic polypetides (ANP's) which appear to play an essential role for anoxia survival because it recycles NAD+ for continued glycolysis in the absence of oxygen. Alcohol dehydrogenase (ADH) activity was increased by 20.15% due to flooding in all the varieties studied. However, the increase was highest (36.25%) in tolerant genotype (Co 99006) and low (14.50%) in sensitive genotypes (Co 86032). Result of the study indicated that variation in ADH enzyme activity among the genotypes is responsible for differential expression of anaerobic polypeptides (66 kDa, 98 kDa and 132 kDa) with varying levels of tolerance to waterlogging stress.

GENOTYPIC DIFFERENCE AGAINST WATERLOGGING STRESS

The clonal differences in the response to severe waterlogging was observed when clones of different species of *Saccharum*, allied genera and hybrids were studied under artificially created conditions of prolonged waterlogging (Sartoris and Blecher 1994). This study revealed that *S. officinarum* clones were highly susceptible and did not survive whereas the clones of *S. barberi*, *S. sinense*, *Sclerostachya* and *Erianthus* survived but were susceptible. Several clones of *S. spontaneum*, *S. robustum* and *Narenga* were flood tolerant. The *S. spontaneum* clone SES 220 and *S. robustum* clone 28 NG 219A was well adapted to this adverse environment. Among the hybrid varieties tested Co 1007, Co 1039, M 165/38 and CP 49-50 were found tolerant. Results of the studies on waterlogging stress on sugarcane during formative phase (90-170 days after planting) showed a significant clonal variation for most of the physiological parameters studied. The tolerant clones were able to maintain good vigor, physiological efficiency and yielded better under long term flooding (Gomathi and Chandran 2010). The functional diversity and expression profiling of genes involved in waterlogging tolerance viz., Zinc finger protein, Alcohol dehydrogenase (ADH) sub1A-1, sub1C-1 and Xyloglucan endo- transglycosylase was studied recently in commercial sugarcane cultivars that are tolerant (Co 62175 & Co 99006) and susceptible (CoC 671 & Co 86032) to waterlogging stress. An up regulation of Zinc finger protein and Alcohol dehydrogenase in tolerant genotype compared to susceptible variety was reported in this study (Rajarajan et al. 2012).

It is important to characterize the type of resistance (tolerance, avoidance or escape) that possessed by a genotype to incorporate in the breeding programme. Stress avoidance traits will more likely to result in reduced yield potential than stress escape and tolerance. In the case of sugarcane the escape traits viz., the early shoot elongation facilitate the escape from early submerging and early maturity of the crop facilitate early harvesting before much damage is done in the juice quality due to prolonged waterlogging. In tolerance mechanisms, cells remain productive as in normal condition while being exposed to the stress and potential yield loss is low.

EVALUATION OF BREEDING LINES AND VARIETIES

To identify the genotypes resistant to waterlogged condition the Indian and exotic commercial hybrids available in the sugarcane germplasm collection at Sugarcane Breeding Institute Research Centre, Kannur were evaluated under naturally waterlogged conditions (Premachandran 2006). Out of 612 clones tested in replicated trials in different years and 18 genotypes were identified as waterlogging tolerant with acceptable yield and quality characters.

The clone 84 WL 22 developed at Sugarcane Breeding Institute Research Centre, Kannur was found to be a good parent in breeding for waterlogging tolerance. This clone was selected from the progeny of BO 91 x Co 62175. It is a sparse flowering type with high pollen fertility and good seed set. The promising waterlogging resistant clones developed using 84 WL 22 includes Co 98007 and Co 99006. The progeny evaluation had shown that BO 91, Co 62175, Co 7313, Co 8231 CB 40-13 and F 36-819 are good female parents and Co 775, Co 1148, Co 6304, CP 49-50, CP 52-68, CP 62-251, CP 79-318 as good male parents in the breeding for waterlogging tolerance.

In subsequent evaluation many early hybrid varieties such as Co 785, Co 951, Co 975, BO 91, CoS 837, CoS 8016 and Co 1157 were found to be performing well under waterlogged conditions (Singh,1989). Similarly Bo 99, BO 110, BO 128, Co 8231, Co 8371, CoP 9103, CoP 9104, CoBln 9103, CoS 8118, CoTl 88322, UP 9529 and UP 9530 were also found to tolerate waterlogging. The high yielding mid-late variety CoSe 96436 performed well and out yielded other local waterlogging resistant varieties (Singh et al. 2001). A study on progenies derived from waterlogging tolerant breeding programme showed the genotypes 91WL552, 91WL629, 92WL1029, 93WL1297, 97WL633 and 98WL1357 performed well under natural waterlogged situation and had expressed the physiological markers like high nitrogen content, high total chlorophyll and total dry matter production (Gomathi and Chandran 2012). In an another study during 2011-2014 the sugarcane clones *viz*., WL 10- 85, WL 10-105 and WL 10-24 were recorded better commercial cane sugar (CCS)/plot than the check varieties. WL-10-20 recorded better tillering, leaf length, cane thickness, biomass, while WL-10-83 showed early high brix in bottom, middle and top portion of cane at the 7th month of crop age. WL-10-24 was also observed to have better Pol and CCS percentage at harvest (Kumar et al 2016). In a set of 22 advanced generation of sugarcane selection evaluated at Motipur, Bihar under waterlogged condition the genotypes M 96058, M 96066, M 96200, M96039, M 96160 and M 96232 were found to possess waterlogging tolerance (Govindaraj 2006). These clones were characterized by early fast growth and profuse tillering before monsoon indicative of the traits can be used for preliminary screening of the clones for waterlogging tolerance. Similarly out of the six commercial varieties screened under subtropical condition at Karnal, Haryana, it was observed that Co 98014 and Co 97016 were good performers under waterlogged condition (Bakshi Ram and Kumar 2007).Co 99006 is one of the promising variety developed for waterlogging condition (Gomathi and Chandran 2009). Recently Bakshi Ram (2017) has reported Co 97014, Co 97015, Co 97016, Co 98014, Co 98016, CoLk 8102, CoS 94267, BO 91 as superior clones compared to Co 1148 under waterlogged condition.

HERITABILITY OF THE TRAITS

The studies of important yield and quality characters in sugarcane under waterlogged conditions showed that the heritability of these characters, except that for cane diameter, was not consistent in different trials (Premachandran 1995). This was attributed to the effect of varying intensities of waterlogging in different years and the differences in the composition of the varieties in different trials. Heritability and predicted rates of genetic gain for yield and related characters may be higher in optimum environments as the favourability of the environment strongly affect the ratio of genetic and non-genetic variability observed in tests (Tew 1987). As the heritability for yield and yield components are extremely low when selection is done under stressful environments, the yield selection must be done under several environments including the optimum (Moore 1987). Among the cane characters single cane weight (SCW) and cane diameter had high positive correlation with cane yield (Premachandran 1995). The germination and number of millable canes (NMC) were correlated with cane yield in two out of three experiments, but correlations were not as strong as that of cane diameter or SCW. When commercial cane sugar (CCS) yield was considered it had high positive correlation with cane yield in all the experiments and with single cane weight in two of the experiments. In that study the selection gain was high for SCW and was having high heritability also. As SCW had positive correlation with cane yield it was suggested as a major character for selection of clones with waterlogging resistance. Sucrose % juice being either negatively correlated or not correlated with cane yield and CCS yield, selection of clones with high SCW and having moderate sucrose percentage in juice will be desirable. The cane diameter had high positive correlation with single cane weight and hence in early selection stages under waterlogging, cane diameter can be taken as an indicator of SCW. The earlier studies showed that cane yield was more closely correlated with NMC than SCW or cane diameter (Mariotti 1987). In sugarcane the correlation between the yield and quality characters under optimal and stress environments may vary and selection criteria is to be modified accordingly (Mariotti 1987, Ethirajan 1989).

BREEDING APPROACHES

The identification of stress resistant traits and their effective manipulation is essentially required for the success in evolving stress resistant clones. Steps for the development of stress resistant genotypes are; 1) identifying and characterizing crop traits that are needed for resistance, 2) identifying and characterizing the genotypes that are capable of filling the needs determined, and 3) manipulating genes to develop an adapted genotype with other desirable traits (Zobel 1983). In breeding for stress resistance, the hybridization and selection for yield and resistance are to be considered as the yield of varieties under stress is a function of its response to stress and the yield potential. By selecting for genetic improvement of yield potential under non-stress environments the yield under stress can be improved. Selection for stress resistance under sub optimum environments may advance germplasm with poor yield potential. This may be the case with selection for waterlogging resistance also. Hence, the selection is to be performed in non-stress environments initially for cane yield and sugar yield and the promising clones are to be tested for waterlogging resistance. By this method selection for yield potential and characters associated with resistance can be done (Blum 1985). The resultant genotype with high yield potential will have physiological buffering factors also. It was suggested that the resistance to waterlogging in *S. spontaneum* can be transferred to sugarcane by crossing. *Erianthus arundinaceus*, a wild related grass is found to be resistant to waterlogging. This can be easily hybridized with sugarcane and give fertile progeny making selection in the subsequent back cross generations possible. Recent reports says that *Erianthus* can also contribute to the development of resistance to red rot pathogen and many of the *Erianthus arundinaceus* clones tested resistant/moderately resistant to red rot disease. The progenies of this cross also showed high percentage of resistant clones.

Sugarcane varieties that produce leaf at a faster rate, with comparatively quicker growth rate, greater ability to develop adventitious roots will better perform under waterlogged conditions. The enhance intercellular spaces in adventitious roots, and slow and delayed decline in nitrate reductase activity during water stagnation period and resumption of such activity to the normal level on recede of water found to associated with such genotypes that perform well under waterlogged conditions (Verma 2001). In clones which are susceptible to waterlogging the negatively geotropic roots are not observed.

Conclusion

Breeding for waterlogging tolerance in sugarcane is often complex due to its long crop duration, the nature, duration and period of waterlogging which vary with the place. The spread of red rot disease will be more under waterlogged conditions and the wide occurrence of red rot in such areas demand incorporation of red rot resistance to the waterlogging tolerant varieties. With addition of traits such as red rot resistance and waterlogging tolerance along with all other economic traits of yield, quality and other stress resistance/tolerance in the desired variety, will increase drastically the selection pressure to be applied for developing the variety. Hence, in the selection process it may require to sacrifice on the superiority for other characters such as cane yield and sucrose percentage. A strategy to have the waterlogging tolerance in an otherwise superior variety through biotechnological means will be ideal under this situation. The role of chemicals induced due to flooding in sugarcane like anaerobic poly peptides (ANP's) and HIP's (hypoxic induced proteins) need to be further investigated. The genes involved in complex biochemical pathways such as signal transduction, degradation of protein, carbon and amino acid metabolisms and in protein regulated at transcriptional post transcriptional levels may play an important role in waterlogging tolerance (Gomathi et al. 2015) and this will give a better understanding of the crop under waterlogging stress. Waterlogging tolerance genes found effective in similar crops (sub 1A gene in rice) need to be explored for imparting tolerance to the superior sugarcane variety through transgenic technology. In tropical situation the enhanced flowering under waterlogged condition necessitate the selection of non flowering types with waterlogging tolerance coupled with red rot resistance. Efforts are also to be made for identifying major genes involved in waterlogging resistance and red rot resistance to incorporate in sugarcane through conventional breeding programme or through the biotechnological tools. Identification of molecular markers associated with waterlogging tolerance and marker assisted selection is also necessary to accelerate the selection process by selecting at the early stages. Understanding of root physiology in different species clones of sugarcane under waterlogging stress is crucial in identifying the tolerant ones for the breeding programme. Also the identification of important traits which majorly contributes to tolerance mechanism along with cane yield and better sucrose is needed to be evaluated in commercial clones under natural condition (Kumar et al., 2016).

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