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RESEARCH ARTICLE

Impact of waterlogging stress on the yield of specific sugarcane genotypes yields in the northeastern coastal region of Tamil Nadu

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Abstract

An experiment was conducted at the Sugarcane Research Station, Cuddalore during 2023-2024 to study the physiological, biochemical and yield parameters of sugarcane (*Saccharum* spp.) under waterlogging stress. The sugarcane plants were subjected to waterlogged at the peak growth stage (9th month to 11th month). The four varieties used in the study were Co 86032, Co 62175, CoC 13339, Co G 7 and nine clones used in the study were C 2015 095, G11035, C 16338, C 2014 516, Co 15020, C 2014 021, Si 2014 047, C 2015 006, C 30010. Various morphological, physiological and biochemical parameters such as leaf area index, chlorophyll content, nitrate reductase activities, catalase content, peroxidase activity, yield and quality parameters, were recorded after 240 days of exposure and at harvest. The results of the study indicate that clone C 16338 and variety CoC 13339 can be recommended for growing under anticipated water logging stress conditions. Both the clone C 16338 and variety CoC 13339 showed the least drop in cane yield compared to Co 86032 under waterlogging stress.

Keywords: enzyme activity; physiology; sugarcane; waterlogging stress; yield

Introduction

Sugarcane (*Saccharum* spp.) is a valuable cash crop grown throughout tropical and subtropical regions. New Guinea is considered the center of origin for domesticated sugarcane. Sugarcane is cultivated in 102 countries globally, covering an area of 50.3 million hectares and yielding 3593 million tons (1). In Indian, the sugar industry spans more than 35 million ha and produce over 35 million metric tons annually. The annual production of sugarcane in Uttar Pradesh is 177.43 million tons. This accounts for 45.89 % of India's total agricultural production (1). Ethanol, white sugar and brown sugar are all made from sugarcane juice. Bagasse and molasses are the primary by-products of the sugar industry. The primary by-product and raw material for alcohol and industries reliant on it is molasses. According to Department of Agriculture and Cooperation (2), sugarcane juice has 111.13 kJ of calories, 27.51 g of carbohydrates, 0-27 g of protein per serving at 28.35 g and micro nutrients like calcium - 11.23 mg (1 %) and iron 0.37 mg (3 %) and sodium 17.01 mg (1 %) per serving at 28.35 g. Bagasse is a sustainable by-product that is used as a biofuel to generate power. Because of its high cellulose content, it is used as a raw material for the paper industry (3). It has lately gained favour as a catalyst to create carbon fibers, as a nutrient-dense fiber for bread and as an alternative to wood in the production of wood composites (4).

Globally, waterlogging possesses a significant challenge, reducing the overall production of agricultural systems. Plant growth is retarded under waterlogging, which is explained by a decrease in dry biomass accumulation brought on by physiological process inhibition. Waterlogging is defined as the continuous saturation of soil with water that is at least 20 % higher than the field capacity (5). Because oxygen is weakly soluble and diffuses slowly in water, plants may experience a reduction in oxygen delivery when submerged or waterlogged. Growth is seriously hindered in situations where there is either a lack of oxygen (hypoxia) or an oxygen deficit (anoxia). Wilting results from reduced respiration and the roots inability to produce ATP.

Plants react to a lack of oxygen by switching from oxidative to photo phosphorylation at the substrate level of ADP to ATP (6). The latter reactions mostly include fermentation and glycolysis. Studies show that standing water stress stops the growth of stems, leaves and tillers and changes the direction of shoot extension. Nitrate reductase activity is used as a key indicator when screening crops for waterlogging tolerance. It indicates impaired nitrogen assimilation, a critical physiological response to waterlogging conditions. Thus, the plant's reduced ability to convert nitrate into nitrite through the enzyme nitrate reductase, which is a sign of stress for plant damage.

Reduced cane yield, slower relative growth and higher stalk mortality are some of the main effects of waterlogging. Drainage infrastructure, soil types and standing or flooding water are the main causes of the problem. Although sugarcane can tolerate very high-water levels, a greater groundwater level damages the plant population and stalk bulk when the plant is actively growing. For every inch that the amount of water increases, this results in a yield loss of about one ton per acre. The decline in output is attributed to the tissue's low levels of nitrogen and water during the peak growth stage. Increased internodes, copious tillering, an increase in the proportion of phosphorus in the stem and plant overall and a decrease in nitrogen content were all indicators of flood tolerance (7). The median crop loss due to waterlogging is estimated to be between 15 and 25 percent, however it can reach 40 %, depending on the stage of the crop and the duration of the flooding (8). Ten to thirty percent of India's sugarcane land is affected by waterlogging, which is one of the primary variables influencing crop productivity in the Indo-Gangetic belt and coastal areas. More than 73 % of India's annual rainfall falls during the southwest monsoon, which runs from June to September and is the primary cause of floods and waterlogging (9).

Understanding the physiological and biochemically underpinnings of waterlogging resistance modifications in plants could help choose or develop new crop types that will be more productive in waterlogging situations. Plant responses to waterlogging vary greatly across different organizational levels based on the type of plant, its growth stage and the severity and duration of stress. To study the physiological traits and biochemical response in sugarcane under waterlogging stress.

Materials and methods

At the Sugarcane Research Station in Cuddalore, four standard varieties are Co 86032, Co 62175, CoC 13339, Co G 7 and nine sugarcane clones are C 2015 095, G11035, C 16338, C 2014 516, Co 15020, C 2014 021, Si 2014 047, C 2015 006, C 30010 that were specifically bred for waterlogging tolerance were assessed for morphological, physiological, biochemical, yield and quality parameters traits during 2023-2024 crop season. Rainy days naturally cause waterlogging, which can result in water stagnation up to 40 cm height for 40 days during the peak growth stages (9^{th} month to 11^{th} month). At this stage, physiological and biometric characteristics were compared with susceptible variety (Co 86032) and resistant variety (Co 62175) under waterlogging stress, at the maturity phases, yield and qualities were recorded. And were statistically analysed using GRAPES 1.0.0 software (General R-shiny based Analysis Platform Empowered by Statistics).

Physiological and biochemical parameters

Leaf Area Index (LAI)

LAI was calculated by employing the formula given previously (10):

LAI = Leaf Area (cm^2)/Ground area occupied per plant

Chlorophyll content

Chlorophyll content of rice leaves was estimated by using the previously described (11) and extracted by using dimethyl sulphoxide (DMSO). One g of young rice sample was placed in a tube containing 10ml of Dimethyl sulfoxide solvent. The tube was kept in dark conditions for overnight. The chlorophyll content was calculated by using following formula. It is expressed in mg g^{-1} fresh weight.

Total chlorophyll = [20.2 (OD@ 645nm) + 8.02(OD@ 663nm)] x (V/1000W)

Where,

W - Weight of the leaf sample (g)

V - Volume of supernatant solution made-up

OD - Optical Density

Nitrate reductase activity

Nitrate reductase activity was assayed (12).

Catalase activity

The catalase (CAT, EC 1.11.1.6) activity was determined according to standard procedure with some changes (13). The extract was obtained from 400 mg of leaf material 150 µL was taken from the extract and put in the reaction medium with 50 mM potassium phosphate buffer (pH 7.0) and 50 mM H_2O_2 and final volume of 3 mL distilled water. Once homogenized, the extract was centrifuged at 14000 g for 15 min at 4 °C and the supernatant was used for the analysis. Readings of absorbance were taken at 240 nm for 1 min and the decrease of H_2O_2 concentration was observed.

Peroxidase activity

It was determined according to standard procedure with some changes (14). The extract was obtained from 20 mg of fresh leaves and 30 µL of the extract was taken and put into the reaction medium and then the homogenate was centrifuged at 14000g for 15 min at 4 °C. This medium was prepared with 50 mM potassium phosphate buffer (pH 7.5), 0.05 mM H_2O_2 and 0.5 mM sodium ascorbate and the volume were completed with 3 mL of distilled water. Readings of absorbance were taken at 290 nm for 1 min, observing the decrease of ascorbate concentration.

Yield and yield components

The following yield and yield components were recorded at harvest stage to know the relationship between the yield and its components. Methods followed for estimating these components is described below.

Number of millable canes

The number of millable canes was counted in each plot at harvest.

Cane length

Six canes were selected at random from each plot and cut at the bottom, de topped at mature internode level and the cane length per millable cane were recorded at harvest from randomly selected six canes from the net plot area and data expressed as mean of the canes.

Cane yield

Weight of cane harvested from each net plot area was recorded and expressed as tonnes ha

Commercial cane sugar

Commercial Cane Sugar (CCS) per cent was calculated as follows (15) and expressed as per cent.

CCS % =1.022 pol in juice % - 0.292 brix % in juice

Sugar yield

Sugar yield per hectare was calculated from the commercial cane sugar per cent and cane sugar per cent and cane yield by using the formula (15) and expressed as t ha^{1}

Sugar yield (t ha^{-1}) = CCS % x Yield of cane (t ha^{1})/100

Statistical analysis

Statistical analysis was performed using GRAPES 1.0.0 software (General R-shiny based Analysis Platform Empowered by Statistics). Field evaluation was conducted at two locations, three replication and set up in Randomized Block Design (RBD).

Results and discussion

The cane length results are shown in Fig. 1. In comparison to the normal condition, the waterlogging stress resulted in significantly reduced cane length. The cultivars with highest cane length were recorded in CoC 13339 (220.34 cm) followed by clone C 16338 (219.23 cm) compared to Co 86032 (223.66 cm). The cane length has been regarded as a crucial morphological characteristic due to the economic significance of sugarcane stems. Vigorous plants will develop rapidly until they reach maturity and usually have higher leaves. Flooding has various effects on shoot behavior, including negative impact on growth habits, visual health, internal anatomy and the plant's water and nutrient regulation systems.

The findings of millable cane production are shown in Fig. 2. Results showed that, in comparison to the control, the millable cane production was drastically reduced under waterlogging stress. The C 16338 had the lowest decreased of millable cane (107.58 '000/ha). In contrast, Co 86032 was a significant decline in the amount of millable cane (89.02 '000/ha). In addition to the fact that estimated tillers grow more slowly and that new ones are less likely to be formed at any stage of flooding, the rate of reduction increases with longer flooding durations.

According to a previous study, the tolerant plants were less affected by the drop in chlorophyll concentrations during waterlogging (16). According to Fig. 3, the variety CoC 13339 had the maximum chlorophyll content (4.52 mg/g) under waterlogging stress conditions, followed by clones C 2014 516 (4.45 mg/g) and C 16338 (4.42 mg/g). In contrast, the variety Co 86032 had the lowest chlorophyll content (2.48 mg/g). The outcomes were consistent with the research conducted previously (17, 18). The fact that a plant lacking in minerals decreases both chlorophyll and photosynthesis highlights how crucial chlorophyll is to photosynthesis. Additionally, it was proposed that the yellowing of leaves in susceptible clones could be caused by a decrease in nitrogen in index leaves.

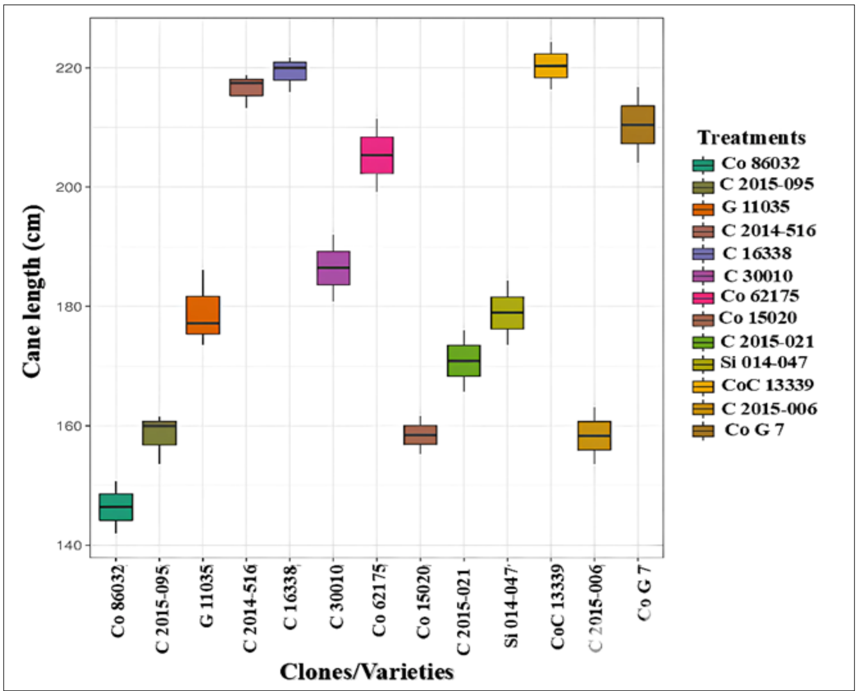

Fig. 1. Cane length (cm) in sugarcane under waterlogging stress condition. Different colours in the graphs denote significant differences between treatments (LSD test, $p < 0.05$).

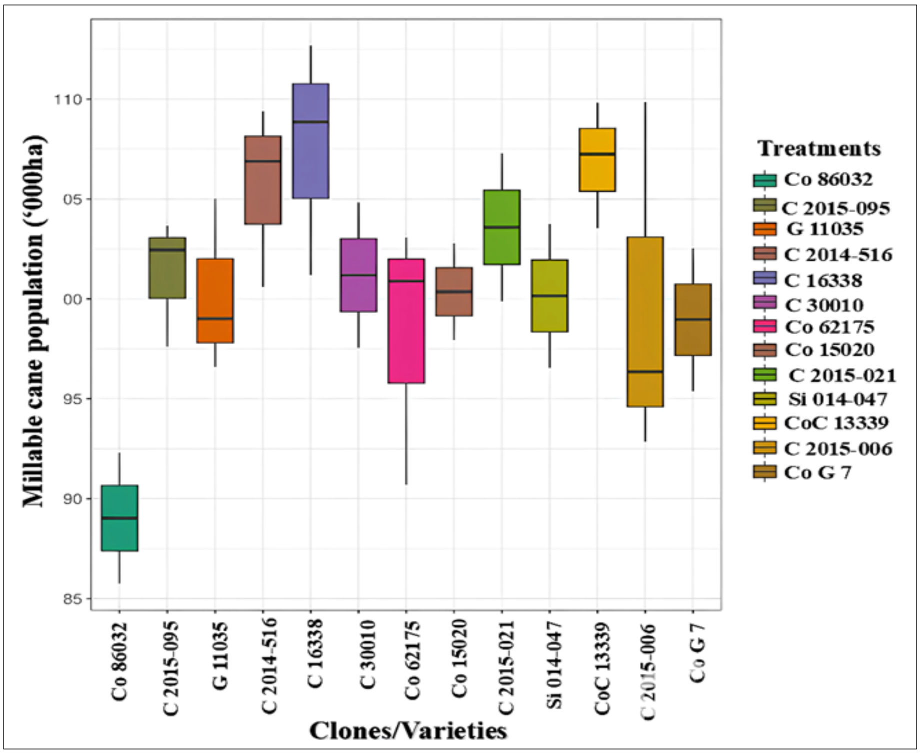

Fig. 2. Millable cane population ($x10^3$/ha) in sugarcane under waterlogging stress condition. Different colours in the graphs denote significant differences between treatments (LSD test, $p < 0.05$).

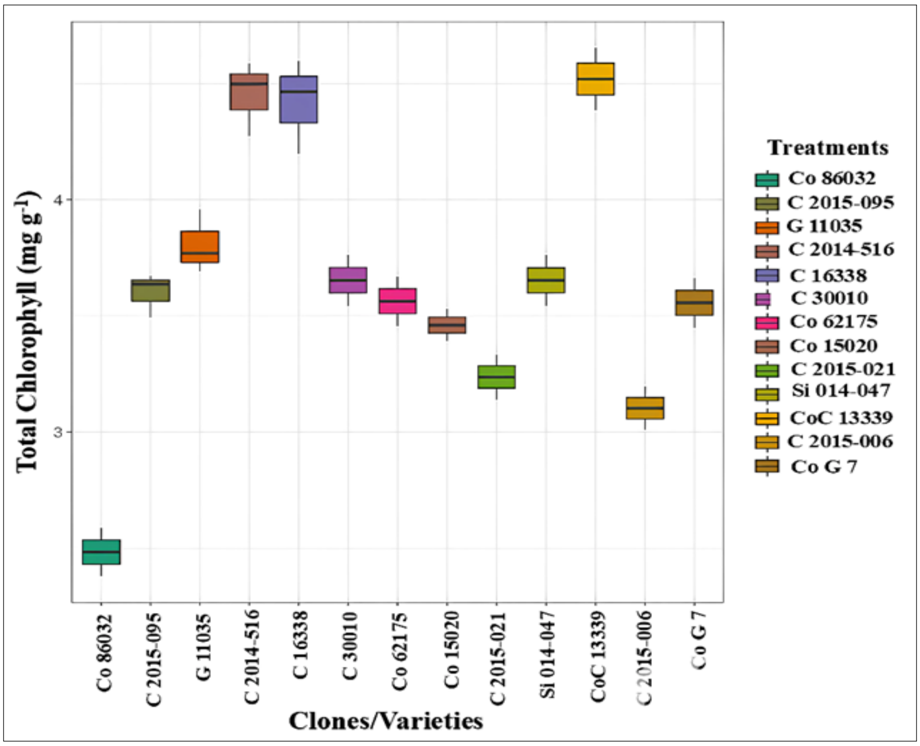

Fig. 3. Total chlorophyll content (mg/g) in sugarcane under waterlogging stress condition. Different colours in the graphs denote significant differences between treatments (LSD test, $p < 0.05$).

The findings of the leaf area index are displayed in Fig. 4. While Co 86032 recorded the lowest LAI of 3.2 under water logging stress conditions, the variety CoC 13339 (4.03) experienced the least reduction in LAI, standing on par with the clones C 2014 516 (3.80) and C 16338 (3.77). Evidence of a reduced LAI and decreased surface area has been found under wet conditions (9). The enzyme nitrate reductase is essential for controlling how much nitrate plants can absorb. Since nitrate reductase needs oxygen to function, lower oxygen levels in wet soil immediately restrict its action. According to Fig. 5, in comparison to the control condition, the waterlogging stress resulted in significantly reduced nitrate reductase activity. Among the varieties, C 16338 had the maximum nitrate reductase activity (84.99 µg nitrate produced g^{-1} fresh weight) under waterlogging stress conditions, followed by clones CoC 13339 (81.67 µg nitrate produced g^{-1} fresh weight) and C 2014 516 (78.33µg nitrate produced g^{-1} fresh weight). In contrast, the variety Co 86032 had the lowest nitrate reductase activity (23.63 µg nitrate produced g^{-1} fresh weight). The nitrate reductase activity is negatively impacted by soil moisture saturation (19). The findings are consistent with previous works (20).

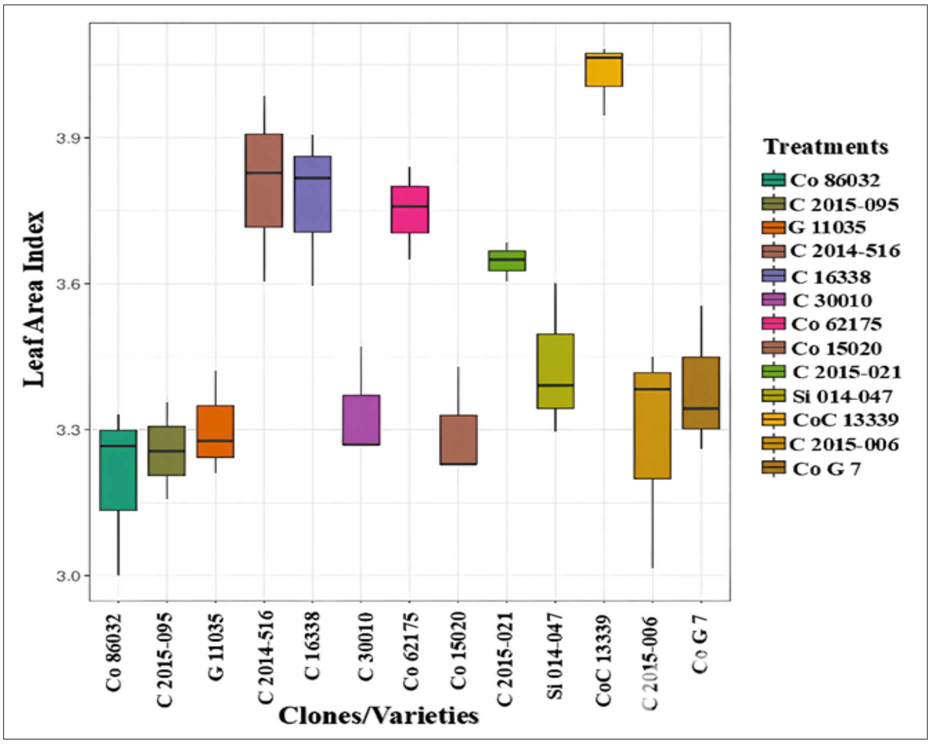

Fig. 4. LAI in sugarcane under waterlogging stress condition, Different colours in the graphs denote significant differences between treatments (LSD test, $p < 0.05$).

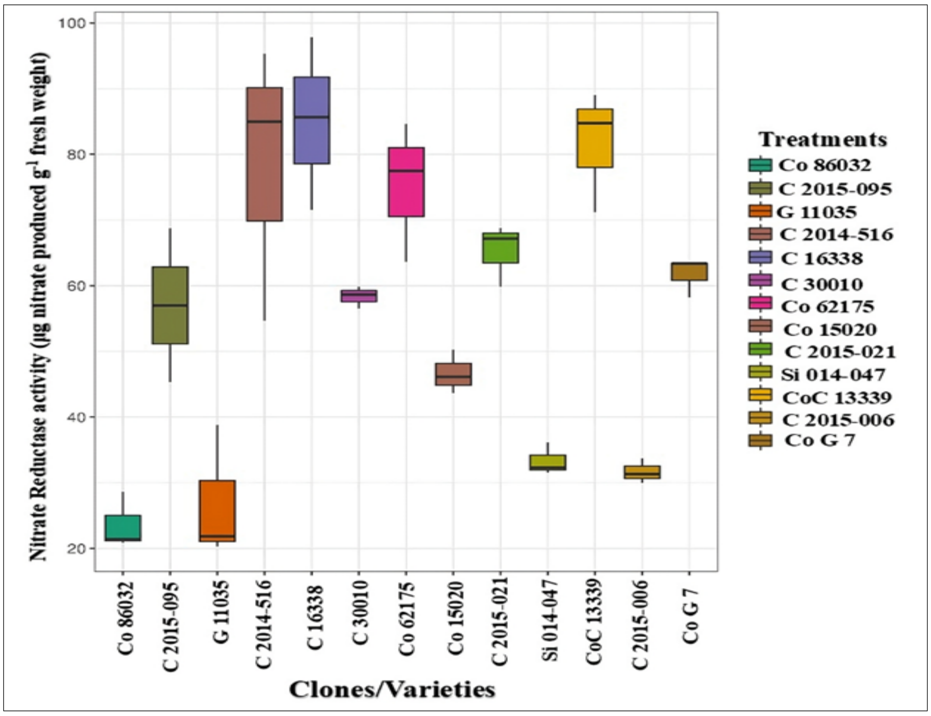

Fig. 5. Nitrate reductase activity (µg nitrate produced g^{-1} fresh weight) in sugarcane under waterlogging stress condition. Different colours in the graphs denote significant differences between treatments (LSD test, $p < 0.05$).

Waterlogging causes alterations in plant metabolism, including a negative impact on the antioxidant system. The findings on catalase are displayed in Fig. 6. It has the greatest catalase output of any variety or clone. CoC 13339 (139.10 µg H_2O_2/g min^{-1}) was the variety with the highest catalase of hydrogen peroxide breakdown to water and oxygen, comparable to the clone C 16338 (133.70 µg H_2O_2/g min^{-1}). However, Co 86032 (68 µg H_2O_2/g min^{-1}) produced the least amount of catalase under waterlogging stress conditions. The plant defends its cells against oxidative stress by combatting Reactive Oxygen Species (ROS) with both enzymes and non-enzymatic detoxifying mechanisms (21).

Nonspecific peroxidase (POX) is essential for regulating ROS and shielding the cell membrane from damage brought on by transient flooding stress. The peroxidase results were displayed in Fig. 7. Under waterlogging stress conditions, the variety with the highest peroxidase, CoC 13339 (4.24 Δ 430 nm g^{-1} min^{-1}), was found to be comparable to the clones C 16338 (4.17 Δ 430 nm g^{-1} min^{-1}) and C 2014 516 (4.14 Δ 430 nm g^{-1} min^{-1}), on the other hand, the variety with least peroxidase was recorded in Co 86032 (2.04 Δ 430 nm g^{-1} min^{-1}). Under water-logging stress conditions, the current findings are consistent with those of previous works (22). According to their findings, the ascorbate glutathione cycle is a major hydrogen peroxide

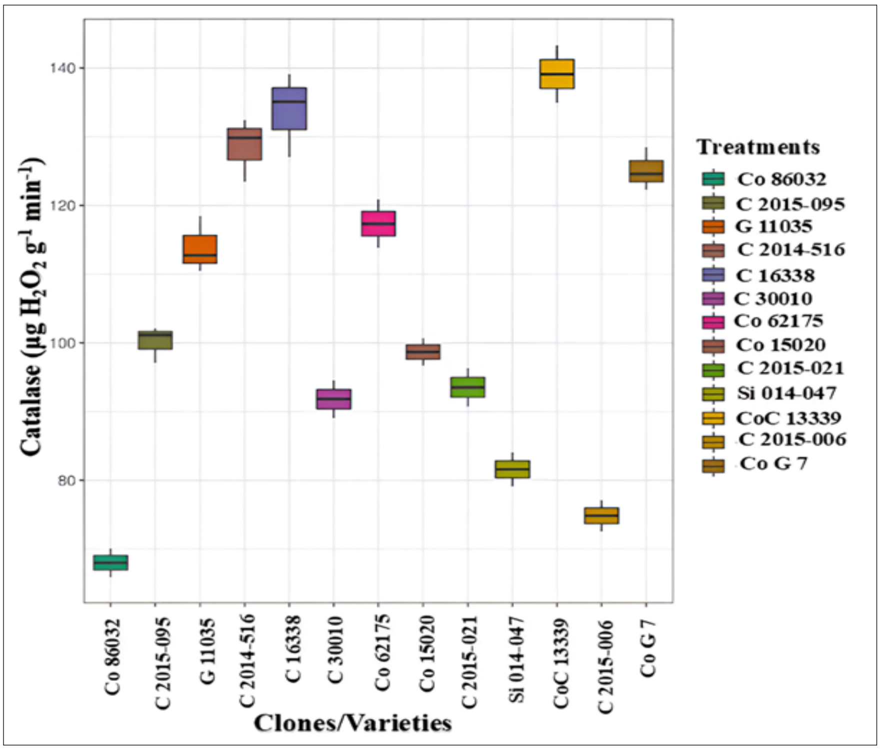

Fig. 6. Catalase (µg H_2O_2/g min^{-1}) in sugarcane under waterlogging stress condition. Different colours in the graphs denote significant differences between treatments (LSD test, $p < 0.05$).

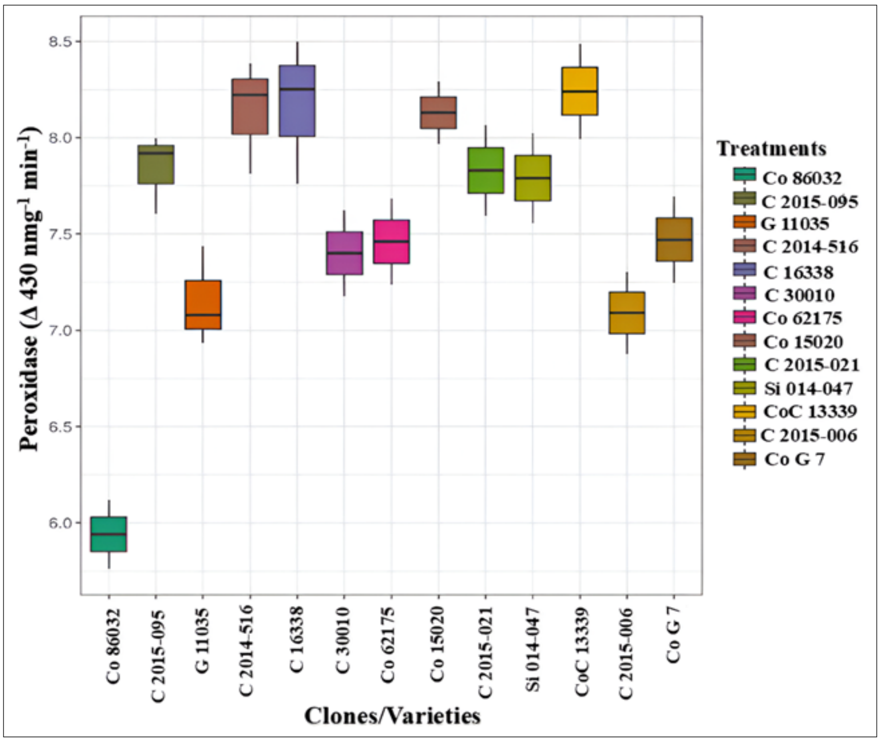

Fig. 7. Peroxidase (Δ 430 nm g^{-1} min^{-1}) in sugarcane under waterlogging stress condition. Different colours in the graphs denote significant differences between treatments (LSD test, $p < 0.05$).

detoxifying system in plant cells. Peroxidase enzymes are essential in this process, catalyzing the conversion of H_2O_2 into H_2O using ascorbate as a specific electron donor that helps shield cell organelles like mitochondria and chloroplasts from oxidative damage caused by ROS.

Research indicates that waterlogging considerably reduces sugarcane yields. In Fig. 8, the cane yield results are displayed. Under waterlogging stress conditions, the clone C 16338 (117.68 t/ha) and variety CoC 13339 (116.49 t/ha) showed a significant drop in cane yield, whereas Co 86032 (88.36 t/ha) showed the lowest cane yield. The type of soil, management practices, environmental conditions, the intensity and duration of waterlogging and the kind of sugarcane can all affect how much of the yield is lost due to waterlogging as a percentage of normal conditions (23)

The results for CCS % are displayed in Fig. 9. The clone C 16338 (11.80 %) followed by the variety CoC 13339 (11.78 %) and C 2014 516 (11.65 %) showed the least reduce in CCS % under waterlogging stress conditions, whereas Co 86032 (9.39 %) exhibited the highest reduction. Although it speeds up the maturity of juices, when the amount of sucrose is decreased, the amount of inverted sugars is increased, gums are

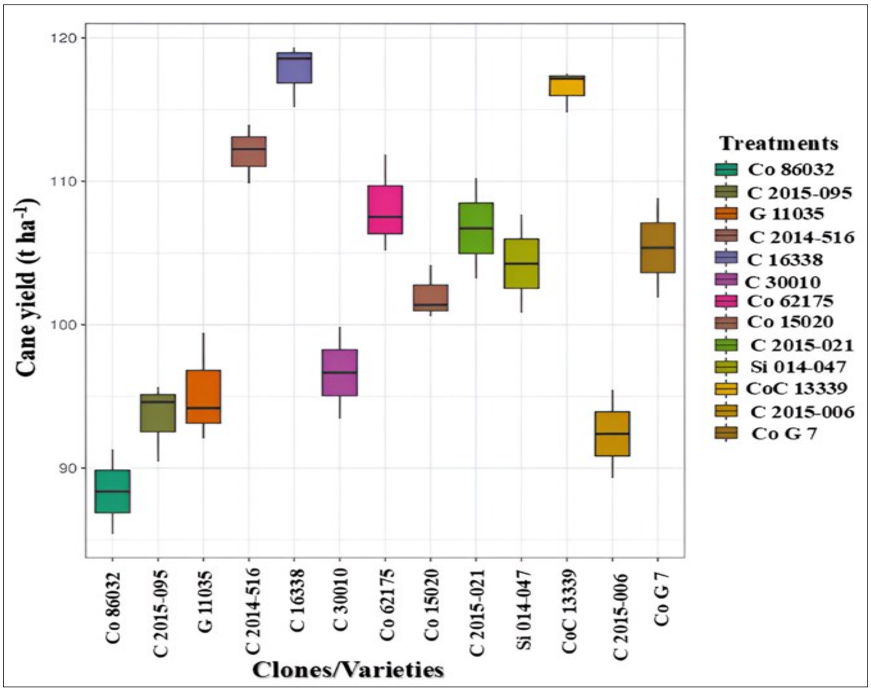

Fig. 8. Cane yield (t/ha) in sugarcane under waterlogging stress condition. Different colours in the graphs denote significant differences between treatments (LSD test, $p < 0.05$).

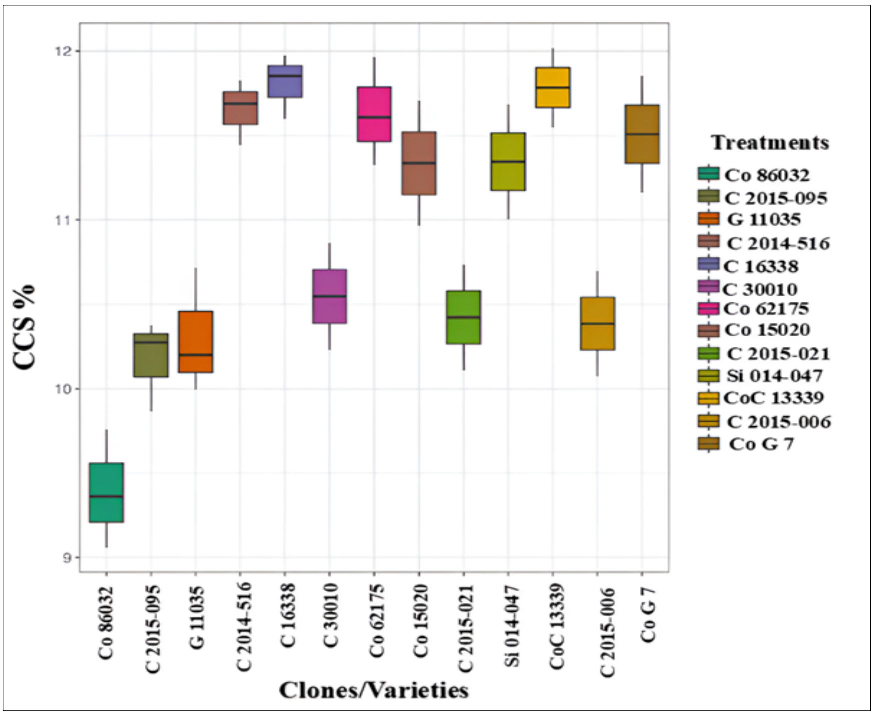

Fig. 9. Commercial cane sugar (%) in sugarcane under waterlogging stress condition. Different colours in the graphs denote significant differences between treatments (LSD test, $p < 0.05$).

plentiful, non-proteinous nitrogen is present and colloids are more prevalent, the quality of the juices deteriorates.

The results for sugar yield are displayed in Fig. 10. The clone C 16338 (13.89 t/ha) followed by the variety CoC 13339 (13.72 t/ha) and showed the least reduction in sugar yield compared to Co 86032 (8.29 t/ha). Waterlogging causes the juice quality to quickly decrease, but if the canes are immersed, the juice quality holds up during the flooding period. When the water evaporates, the juice's quality quickly declines and eventually reaches low sucrose levels. This means that inversion of sucrose will restrict the ability to obtain high sugariness in water logging situations (24).

Conclusion

Waterlogging stress significantly impacts sugarcane cultivation by affecting the plant metabolism, catalase output and nonspecific peroxidase activity leading to reduced cane length, millable cane production and cane yield. The study found that clone C 16338 had the lowest decrease in millable cane production, while the Co 86032 variety experienced a significant decline. Sugarcane yields were significantly reduced under waterlogging stress, with the clone C 16338 and variety CoC 13339 showing the least drop in cane yield.

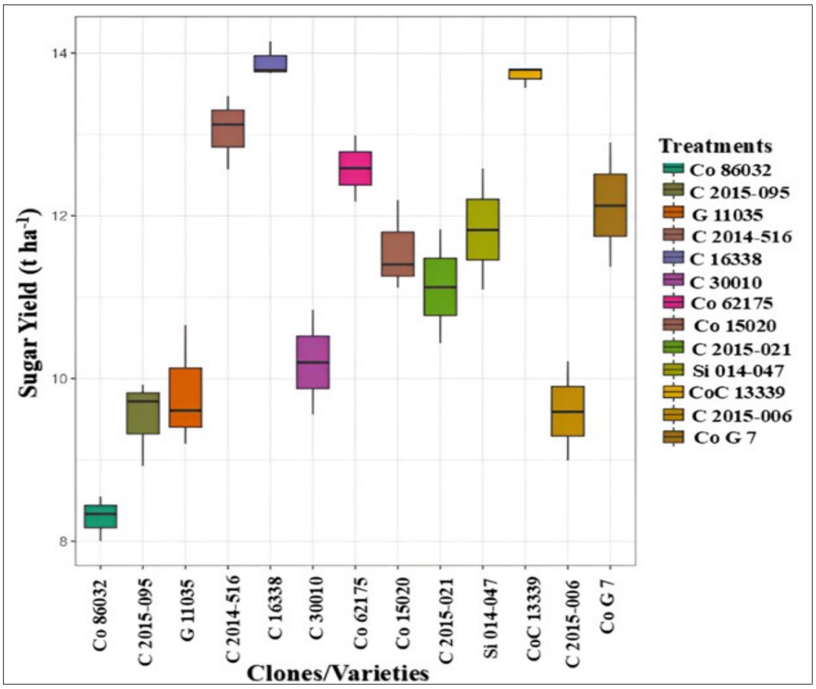

Fig. 10. Sugar yield (t/ha) in sugarcane under waterlogging stress condition. Different colours in the graphs denote significant differences between treatments (LSD test, $p < 0.05$).

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Authors' contributions

AR, JP, SD presented the idea and conceptualization of research article. VD, AL collected scientific materials and contributed to writing the manuscript. Writing and editing were performed by AR, MY and NR. Reviewing the manuscript was done by VD and NR. All the authors have contributed to preparing the final edited draft of this paper.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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