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# Physio-Biochemical Characterization of Sugarcane Genotypes for Waterlogging Tolerance

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**Abstract:** Waterlogging is one of the serious environmental constraints for optimum growth and yield of sugarcane. In India, waterlogging is caused due to excess monsoon rainfall, inadequate and improper drainage facilities. In present study, twenty four sugarcane genotypes including six commercial cultivars were tested under waterlogging and control conditions to determine leaf, stalk, root and whole clump dry weight, specific leaf weight, chlorophyll and carotenoids content for identifying waterlogging tolerant sugarcane genotypes based on tolerance indices. Current study clearly demonstrated that sugarcane plants growing under waterlogging conditions had significantly lower leaf, stalk and whole clump dry weight, specific leaf weight, leaf area, SPAD, chlorophyll a, b, total chlorophyll, carotenoids, P and K contents in leaf tissues. There was a great genotypic variation for all the investigated parameters. Under waterlogged condition stalk elongation rate was varied widely among different genotypes and it ranged between 0.016-0.909 cm/day. SR/AR ratio was found highest (5.59) in CoLk 07201 and lowest (0.795) in S 5087/11 genotype. Tolerance indices for stalk dry weight showed significant positive correlation with total clump dry weight, leaf weight, root weight, specific leaf weight, chlorophyll a, b, total chlorophyll and carotenoids. Sugarcane genotypes had different tolerance indices for the studied parameters; D-6-13, S 5090/11 and S 5085/11 had greater tolerance indices for stalk and whole clump dry weight and S5085/11, B-44-12 and CoS 767 for chlorophyll a, b total chlorophyll and carotenoids contents. Based on relative cane weight S 5085/11, CoLk 12206, LG 06605, LG 04439, UP 9530 and D-6-13 were identified the most waterlogging tolerant lines, while A-27-12 was found most susceptible.

**Abbreviations:** SR- shoot root; AR- Aerial root; P – Phosphorus; K- Potassium; RGR - Relative growth rate; SLW- Specific leaf weight; SPAD- Soil plant analysis development.

**Key words:** Sugarcane · Waterlogging · Physiological attributes · Chlorophylls · Carotenoids · Essential nutrients

## INTRODUCTION

Sugarcane is an important sugar crops. It faces different vagaries of nature including biotic/abiotic stress during its active growth phases [1] Water-logging is one of the serious environmental constraints for optimum growth and yield of sugarcane. Higher rate of tiller mortality, low RGR and reduced cane yield are major effects of water-logging. In India, water-logging is linked with monsoon rainfall, inadequate and improper drainage due to unplanned road development. Reduction in cane yield and juice quality due to water-logging depends upon genotype, environmental conditions, stage of development and duration of stagnation of water. Waterlogging tolerance is related to many physiological, biochemical, morphological and anatomical adaptations of plants. The tolerant species are able to form aerenchyma, which helps for functioning of the plant processes under anoxia conditions [2]. Some genotypes of sugarcane can produce constitutive aerenchyma,

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meaning that plant requires no external stimulus such as flooding for aerenchyma formation, while some genotypes need exposure to flood to form the aerenchyma [3]. Flooding damage in plant is related to several factors, such as flooding depth, duration and flow of water in the field. However, flooding effects on sugarcane physiology and productivity remain inconclusive. Researchers have tested a higher cane yield or unaffected yield in some of the genotypes in the wetter field [3, 4, 5]. Different cultivars of sugarcane when grown under water table depths of 32-84 cm did not showed any yield difference [6]. Flooding induces a neutral or positive response of gas exchange characteristics to sugarcane [5]. Several other workers also reported a significant growth reduction under anoxia conditions [7, 8, 9].

Higher water table during grand growth phase (July-September in subtropical India) adversely affects stalk weight and plant population resulting in yield loss at the rate of about one ton per acre for one inch increase in excess water, although sugarcane is a relatively tolerant to high water tables and flooding. Some physiological effects of cane are found due to water-logging are reduced transpiration rates, photosynthesis and growth rates due to stomata closer. A shift in respiratory metabolism from aerobic to anaerobic is one of the main effects of oxygen deficiency under water-logging condition. The effects of water-logging on respiration rate depend on the varieties and its physiological age. Nutrient uptake is adversely affected under water-logging. It is also reported that under water-logging condition, some morphological, anatomical, physiological and biochemical changes take place in plant for the sake of adaptation/survival [10]. Present study was therefore mainly aimed to identify waterlogging tolerant sugarcane genotypes based on dry matter production, SLW, photosynthetic pigments and essential nutrient contents and tolerance indices using twenty four sugarcane genotypes grown under waterlogged and non-waterlogged conditions.

## MATERIALS AND METHODS

Twenty four sugarcane genotypes (eighteen germplasms/lines and six commercial varieties) were evaluated for waterlogging tolerance for two years at Kharika Block of Indian Institute of Sugarcane Research, Lucknow. For waterlogging treatment, crop was grown in deep plot which was naturally waterlogged during rainy season along with non-waterlogged control treatment. Data on dry weight of different plant parts, SLW, SPAD reading, chlorophyll and carotenoids were measured in the month of August.

In dry leaf tissues, P and K were estimated after digestion in di-acid ($HNO_3$: $HClO_4$) mixture (10:1 ratio). K was measured in clear digest using Flame Photometer (Systronics make). Phosphorus was measured in suitable aliquot of clear digest by the method described earlier [11].

Amount of chlorophyll content was determined in fresh leaf [12]. 50mg fresh leaf material was homogenized in 80% acetone and centrifuged for 10 minutes. The supernatant was collected and absorbance was read at 663, 645 and 470 nm, spectrophotometrically. Chlorophyll and carotenoids contents were calculated using the formula given below and the amounts were calculated as mg/g fresh weight of leaf:

- Chlorophyll a (mg/g fwt) = $((12.7 \times A_{663}) - (2.69 \times A_{645})) \times 0.2$
- Chlorophyll b (mg/g fwt) = $((22.9 \times A_{645})-(4.68 \times A_{663})) \times 0.2$
- Carotenoids (mg/g fwt) = $(((1000 \times A_{470}) - (1.9 \times \text{Chl a}) - (63.14 \times \text{Chl b}))/214) \times 0.2$

Waterlogging tolerance/susceptibility indices (TI) were calculated for each genotype using the following equation:

TI = (Measured plant parameter under waterlogged condition/ measured plant parameter under control condition) x 100

Data obtained from the experiments were subjected to analysis of average mean of three replications, SE± and SD.

## RESULT AND DISCUSSION

Results of present study indicated leaf yellowing, faster drying of older leaves, aerial rooting and crop lodging due to waterlogging stress (Figure 1). Based on dry weight of leaf, leaf sheath, stalk, root and whole clump, chlorophyll a, chlorophyll b, total chlorophyll, carotenoids contents and specific leaf weight, the response of genotypes under waterlogged and control conditions differed significantly (Table 1). Due to waterlogging stress, dry weight of different plant parts, whole clump weight, specific leaf weight, P and K content except root dry weight decreased as compared to non-waterlogged control plants. Reduction in stalk, leaf and total dry weight was also reported earlier [13] due to waterlogging stress under tropical region of India.

Fig. 1: Variable level of aerial rooting and leaf color among sugarcane genotypes under waterlogged condition.

Table 1: Mean Plant parameters measured under control and waterlogged condition

| Parameters | Control | Waterlogged |
|---|---|---|
| Leaf dry weight (kg) | 0.178 | 0.131 |
| Leaf Sheath dry weight (kg) | 0.107 | 0.089 |
| Stalk dry weight (kg) | 0.695 | 0.678 |
| Root dry weight (kg) | 0.022 | 0.040 |
| Whole clump dry weight (kg) | 1.002 | 0.938 |
| Chlorophyll a (mg/g fwt) | 2.548 | 2.101 |
| Chlorophyll b (mg/g fwt) | 0.710 | 0.630 |
| Total Chlorophyll (mg/g fwt) | 3.256 | 2.720 |
| Carotenoids (mg/g fwt) | 3.879 | 3.310 |
| SLW (gm dry wt/$m^2$) | 109.9 | 106.1 |
| K content (%) | 1.676 | 1.446 |
| P content (%) | 0.386 | 0.331 |

Table 2: Mean comparison of dry matter of different plant parts and specific leaf weight under control and waterlogged conditions

| | Stalk wt (kg) | | Leaf wt (kg) | | Leaf sheath wt (kg) | | Root wt (kg) | | Whole clump wt (kg) | | SLW (g $m^{-2}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Genotype | C | WL | C | WL | C | WL | C | WL | C | WL | C | WL |
| CoLk 94184 | 0.624 | 0.658 | 0.108 | 0.130 | 0.073 | 0.071 | 0.0195 | 0.0256 | 0.823 | 0.885 | 112.4 | 99.9 |
| BO 91 | 0.488 | 0.447 | 0.118 | 0.102 | 0.076 | 0.063 | 0.0180 | 0.0301 | 0.700 | 0.642 | 92.7 | 94.5 |
| CoS 767 | 0.463 | 0.386 | 0.140 | 0.103 | 0.090 | 0.068 | 0.0152 | 0.0202 | 0.707 | 0.577 | 111.6 | 88.3 |
| CoJ 64 | 0.544 | 0.525 | 0.133 | 0.123 | 0.074 | 0.078 | 0.0098 | 0.0295 | 0.760 | 0.756 | 120.2 | 91.8 |
| CoS 97264 | 0.819 | 0.813 | 0.240 | 0.171 | 0.186 | 0.120 | 0.0223 | 0.0462 | 1.267 | 1.150 | 111.9 | 100.0 |
| UP 9530 | 0.790 | 0.870 | 0.187 | 0.140 | 0.157 | 0.123 | 0.0277 | 0.0583 | 1.162 | 1.191 | 108.0 | 79.7 |
| CoLk 12204 | 0.506 | 0.500 | 0.156 | 0.117 | 0.107 | 0.230 | 0.0247 | 0.0255 | 0.793 | 0.871 | 104.0 | 108.2 |
| CoLk 12202 | 0.735 | 0.690 | 0.214 | 0.148 | 0.143 | 0.075 | 0.0277 | 0.0327 | 1.119 | 0.945 | 95.7 | 91.8 |
| CoLk 12206 | 0.571 | 0.615 | 0.101 | 0.128 | 0.067 | 0.079 | 0.0188 | 0.0305 | 0.758 | 0.852 | 98.5 | 100.6 |
| CoLk 07201 | 0.520 | 0.519 | 0.158 | 0.117 | 0.082 | 0.066 | 0.0270 | 0.0428 | 0.786 | 0.745 | 131.9 | 129.0 |
| CoLk 04238 | 0.725 | 0.483 | 0.175 | 0.107 | 0.067 | 0.054 | 0.0255 | 0.0298 | 0.993 | 0.674 | 94.8 | 97.1 |
| LG 06605 | 0.511 | 0.643 | 0.151 | 0.137 | 0.071 | 0.099 | 0.0135 | 0.0302 | 0.746 | 0.910 | 110.6 | 125.8 |
| LG 04439 | 0.695 | 0.812 | 0.176 | 0.118 | 0.100 | 0.088 | 0.0183 | 0.0447 | 0.990 | 1.062 | 89.7 | 107.5 |
| LG 05350 | 0.575 | 0.477 | 0.140 | 0.091 | 0.066 | 0.058 | 0.0127 | 0.0200 | 0.794 | 0.646 | 100.8 | 101.9 |
| LG 05020 | 0.403 | 0.426 | 0.159 | 0.112 | 0.060 | 0.066 | 0.0135 | 0.0310 | 0.635 | 0.636 | 103.7 | 96.0 |
| LG 03040 | 0.708 | 0.549 | 0.163 | 0.095 | 0.098 | 0.070 | 0.0105 | 0.0253 | 0.980 | 0.739 | 100.8 | 115.8 |
| A-46-11 | 0.840 | 0.818 | 0.241 | 0.140 | 0.114 | 0.085 | 0.0157 | 0.0635 | 1.210 | 1.107 | 117.2 | 109.9 |
| B-44-12 | 0.775 | 0.810 | 0.192 | 0.132 | 0.121 | 0.067 | 0.0203 | 0.0759 | 1.109 | 1.084 | 111.7 | 117.9 |
| A-27-12 | 0.855 | 0.558 | 0.202 | 0.114 | 0.111 | 0.059 | 0.0178 | 0.0227 | 1.187 | 0.754 | 113.3 | 100.5 |
| D-12-9 | 0.812 | 0.700 | 0.199 | 0.132 | 0.113 | 0.063 | 0.0203 | 0.0428 | 1.144 | 0.939 | 114.7 | 109.9 |
| D-6-13 | 0.926 | 1.327 | 0.229 | 0.144 | 0.126 | 0.121 | 0.0260 | 0.0493 | 1.307 | 1.640 | 119.3 | 124.6 |
| S 5085/11 | 0.756 | 0.989 | 0.186 | 0.200 | 0.119 | 0.133 | 0.0398 | 0.0719 | 1.101 | 1.393 | 114.0 | 128.3 |
| S5087/11 | 1.230 | 0.593 | 0.311 | 0.154 | 0.227 | 0.087 | 0.0740 | 0.0365 | 1.842 | 0.871 | 130.7 | 108.3 |
| S 5090/11 | 0.820 | 1.074 | 0.195 | 0.181 | 0.112 | 0.116 | 0.0142 | 0.0790 | 1.141 | 1.449 | 129.0 | 119.6 |
| Mean | 0.695 | 0.678 | 0.178 | 0.131 | 0.107 | 0.089 | 0.022 | 0.040 | 1.002 | 0.938 | 109.9 | 106.12 |
| SE± | 0.038 | 0.046 | 0.010 | 0.005 | 0.080 | 0.008 | 0.003 | 0.004 | 0.056 | 0.057 | 2.37 | 2.72 |
| SD | 0.019 | 0.227 | 0.048 | 0.027 | 0.041 | 0.038 | 0.013 | 0.018 | 0.272 | 0.277 | 11.62 | 13.35 |

C- Control; WL- Waterlogged; SD- Standard deviation; SE- Standard error

Under waterlogged condition, stalk dry weight ranged between 0.386 and 1.327 kg. D-6-13 genotype had highest increase in cane dry weight while S 5087/11 showed highest decrease. While under control condition, stalk dry weight ranged between 0.403 and 1.230 kg, S 5087/11 and LG 05020 showed highest and lowest stalk dry weight, respectively. The results are in agreement with the finding of other worker [1] who has worked on variability among genotypes for waterlogging tolerance (Table 2).

CoLk 12206, CoLk 94184 and S 5085/11 showed increase in leaf dry weight while all other had declined in leaf dry weight. CoLk 12204 had significant increase in leaf sheath dry weight than other genotypes.

Root weight was relatively higher in waterlogged affected plants; S 5090/11 had highest increase in root dry weight followed by A-46-11 genotype (Table 2). Increase in root dry weight might be due to higher root density as reported earlier [14]. Aerial roots that formed in response to waterlogging helped in maintaining root activity by supplying necessary oxygen [2]. These newly developed aerial roots might help in higher dry matter accumulation in waterlogging tolerant genotypes [15]. In waterlogged condition, whole clump dry weight varied between 0.577 and 1.640 kg. Highest and lowest were obtained in D-6-13 (1.64 kg) and CoS 767 (0.577 kg), respectively whereas, S 5090/11 and S 5085/11 showed highest percent increase in whole clump dry weight.

Under waterlogged condition specific leaf weight decreased as compared to control plants. It varied between 96 g $m^{-2}$ and 129 g $m^{-2}$ under waterlogged condition; highest was observed in CoLk 07201 followed by CoS97264 and CoLk 12204. Under control condition specific leaf weight varied between 89.7 g $m^{-2}$ and 131.9 g $m^{-2}$; highest was obtained in CoLk 07201 followed by S 5087/11 and S 5090/11. Reduction in SLW was also reported in bread wheat seedlings under waterlogging condition [16].

As shown in Table 3, higher chlorophyll a, b, total chlorophyll and carotenoids contents were obtained in CoLk 94184 followed by CoJ 64 and S 5090/11 and CoLk 12206 showed highest SPAD value under control condition. However, under waterlogged condition, CoLk 12206 had highest chlorophyll a, b, total chlorophyll and carotenoids content with 3.12 mg $g^{-1}$ fwt, 0.95 mg $g^{-1}$ fwt, 4.07 mg $g^{-1}$ fwt and 4.80 mg $g^{-1}$ fwt, respectively while LG 05020 had the lowest chlorophyll a, b and total chlorophyll with value 1.17 mg $g^{-1}$ fwt, 0.31 mg $g^{-1}$ fwt and 1.48 mg $g^{-1}$ fwt, respectively. A-46-11 genotype showed lowest carotenoids content with 2.09 mg $g^{-1}$ fwt. Genotype S 5085/11 showed highest percent increase in chlorophyll a, b, total chlorophyll and carotenoids content while A-46-11 showed highest decrease. S 5090/11 had highest SPAD value and highest increase over control. The chlorophyll pigments play an important role in the process of photosynthesis by changing light energy into the chemical energy. Solar energy absorbed by chlorophyll and used to decipher water molecules, forming gaseous oxygen and reduced NADP molecules to NADPH. The chlorophyll content in waterlogged treatment tended to be lower than non-waterlogged condition [17, 18]. The formation of chlorophyll is influenced by several factors such as light, leaf size and water status of growing media. Excess water caused depreciation in size of leaves in terms of reduced leaf area so the formation of chlorophyll may be declined as recorded in present investigation. In present study reduction in chlorophyll and carotenoids contents was similar to results reported by earlier researchers [14, 16, 19, 20].

Leaf tissues of waterlogged affected plants showed lower K and P content as compared to control plants. B-44-12 and LG 05020 genotypes had highest phosphorus (P) and potassium (K) content in leaf with a value of 0.539 and 2.79 percent, respectively in control treatment (Table 3). In waterlogged condition, S 5090/11 and LG 06605 genotypes had highest P and K with 0.475 % and 1.946 %, respectively. CoS 767 showed highest increases over control in P content while LG 06605 genotype showed highest increase in K content. Reduction in leaf nutrient content during flooding was also reported earlier [21-24] which might be due to reduced uptake of both macro and micronutrients under oxygen deficiency causes leaf yellowing and scorched appearance.

Under waterlogged condition stalk elongation rate was ranged between 0.016-0.909 cm/day; the highest in genotype S5087/11 followed by LG05350 (0.883 cm/day) and CoLk 12202 (0.842 cm/day) while lowest in genotype A-27-12 (Table 4).

Shoot root /aerial root ratio (SR/AR ratio) was greatly varied among different sugarcane genotypes; genotype CoLk 07201 showed highest SR/AR ratio (5.59) and lowest (0.795) in S 5087/11 genotype (Table 4).

Waterlogging tolerance has been defined as biomass production or yield under conditions ranging from waterlogged to non-waterlogged [25]. To evaluate sugarcane genotypes for waterlogging tolerance, twelve tolerance indices (tolerance index for leaf dry weight, leaf sheath dry weight, stalk dry weight, root dry weight, whole clump dry weight, chlorophyll a, b, total chlorophyll content, carotenoids content, SLW, K and P)

Table 3: Comparison of Chlorophyll a, b, total chlorophyll, SPAD carotenoids and P and K content under control and waterlogged conditions as per genotype

| | Chl a | | Chl b | | Total chl | | SPAD | | Carotenoids | | P | | K | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Genotype | C | WL | C | WL | C | WL | C | WL | C | WL | C | WL | C | WL |
| CoLk 94184 | 3.86 | 2.28 | 1.15 | 0.80 | 5.01 | 3.09 | 39.7 | 36.2 | 5.59 | 3.89 | 0.461 | 0.286 | 1.774 | 1.758 |
| BO 91 | 2.86 | 2.28 | 0.77 | 0.63 | 3.63 | 2.91 | 36.5 | 33.9 | 4.49 | 3.73 | 0.332 | 0.332 | 1.771 | 1.612 |
| CoS 767 | 2.29 | 2.94 | 0.62 | 0.89 | 2.91 | 3.83 | 36.7 | 36.3 | 3.59 | 4.21 | 0.189 | 0.299 | 1.717 | 1.683 |
| CoJ 64 | 3.84 | 2.12 | 1.06 | 0.60 | 4.90 | 2.73 | 35.4 | 32.3 | 5.45 | 3.08 | 0.267 | 0.247 | 1.086 | 1.094 |
| CoS 97264 | 2.49 | 2.03 | 0.67 | 0.56 | 3.16 | 2.59 | 38.3 | 30.3 | 3.68 | 3.00 | 0.435 | 0.260 | 1.291 | 1.194 |
| UP 9530 | 2.71 | 1.71 | 0.74 | 0.80 | 3.45 | 2.22 | 42.7 | 34.5 | 4.13 | 2.72 | 0.520 | 0.423 | 1.671 | 1.322 |
| CoLk 12204 | 1.91 | 1.30 | 0.50 | 0.46 | 2.41 | 1.76 | 27.4 | 24.1 | 2.92 | 2.29 | 0.397 | 0.338 | 1.560 | 1.438 |
| CoLk 12202 | 2.85 | 2.76 | 0.77 | 0.78 | 3.61 | 3.53 | 38.9 | 31.4 | 4.35 | 4.20 | 0.267 | 0.299 | 1.593 | 1.364 |
| CoLk 12206 | 2.77 | 3.12 | 0.81 | 0.95 | 3.57 | 4.07 | 43.3 | 35.9 | 4.38 | 4.80 | 0.286 | 0.286 | 1.780 | 1.398 |
| CoLk 07201 | 2.35 | 2.03 | 0.64 | 0.64 | 2.99 | 2.67 | 38.4 | 32.9 | 3.65 | 3.24 | 0.358 | 0.384 | 2.120 | 1.690 |
| CoLk 04238 | 2.38 | 1.56 | 0.67 | 0.49 | 3.05 | 2.06 | 40.3 | 36.1 | 3.71 | 2.44 | 0.319 | 0.403 | 1.923 | 1.590 |
| LG 06605 | 2.53 | 2.02 | 0.71 | 0.57 | 3.24 | 2.59 | 36.8 | 30.6 | 3.94 | 3.25 | 0.429 | 0.384 | 1.659 | 1.946 |
| LG 04439 | 2.53 | 1.89 | 0.71 | 0.54 | 3.24 | 2.43 | 26.9 | 34.5 | 3.67 | 3.08 | 0.384 | 0.260 | 1.545 | 1.312 |
| LG 05350 | 3.00 | 2.19 | 0.84 | 0.64 | 3.84 | 2.83 | 39.0 | 33.7 | 4.60 | 3.52 | 0.449 | 0.306 | 1.890 | 1.501 |
| LG 05020 | 2.20 | 1.17 | 0.62 | 0.31 | 2.82 | 1.48 | 32.7 | 29.7 | 3.35 | 2.15 | 0.409 | 0.397 | 2.797 | 1.891 |
| LG 03040 | 2.26 | 1.66 | 0.63 | 0.46 | 2.88 | 2.13 | 42.5 | 41.2 | 3.31 | 2.70 | 0.410 | 0.280 | 1.339 | 1.281 |
| A-46-11 | 2.69 | 1.25 | 0.77 | 0.37 | 3.47 | 1.62 | 35.3 | 32.5 | 3.80 | 2.09 | 0.429 | 0.286 | 1.676 | 1.440 |
| B-44-12 | 1.70 | 2.33 | 0.47 | 0.66 | 2.16 | 2.99 | 33.9 | 31.0 | 2.81 | 3.76 | 0.539 | 0.319 | 1.744 | 1.366 |
| A-27-12 | 2.85 | 3.05 | 0.85 | 0.95 | 3.70 | 4.01 | 37.9 | 41.5 | 4.30 | 4.64 | 0.371 | 0.221 | 1.385 | 0.981 |
| D-12-9 | 2.55 | 1.95 | 0.71 | 0.56 | 3.25 | 2.51 | 33.0 | 32.3 | 3.75 | 3.08 | 0.468 | 0.319 | 1.833 | 1.336 |
| D-6-13 | 1.99 | 1.92 | 0.54 | 0.54 | 2.53 | 2.46 | 36.1 | 27.9 | 3.30 | 3.19 | 0.409 | 0.325 | 1.574 | 1.291 |
| S 5085/11 | 1.32 | 2.71 | 0.34 | 0.76 | 1.66 | 3.47 | 35.4 | 34.4 | 2.20 | 4.11 | 0.377 | 0.403 | 1.804 | 1.482 |
| S5087/11 | 3.11 | 2.11 | 0.86 | 0.61 | 3.96 | 2.72 | 41.7 | 32.0 | 4.83 | 3.30 | 0.306 | 0.410 | 1.209 | 1.380 |
| S 5090/11 | 2.12 | 2.04 | 0.58 | 0.55 | 2.70 | 2.59 | 28.8 | 37.5 | 3.29 | 2.98 | 0.442 | 0.475 | 1.477 | 1.360 |
| Mean | 2.55 | 2.1 | 0.71 | 0.63 | 3.26 | 2.72 | 36.6 | 33.5 | 3.88 | 3.31 | 0.386 | 0.331 | 1.676 | 1.446 |
| SE± | 0.118 | 0.109 | 0.036 | 0.034 | 0.154 | 0.142 | 0.918 | 0.784 | 0.161 | 0.152 | 0.017 | 0.013 | 0.069 | 0.047 |
| SD | 0.581 | 0.534 | 0.176 | 0.169 | 0.756 | 0.696 | 4.50 | 3.84 | 0.79 | 0.744 | 0.084 | 0.65 | 0.339 | 0.232 |

C- Control; WL- Waterlogged; SD- Standard deviation; SE- Standard error

Table 4: Elongation rate and SR/AR ratio of sugarcane genotypes under waterlogged condition

| Genotype | Elongation rate (cm/day) | SR/AR ratio |
|---|---|---|
| CoLk 94184 | 0.664 | 3.053 |
| BO 91 | 0.132 | 4.171 |
| CoS 767 | 0.299 | 2.667 |
| CoJ 64 | 0.124 | 2.161 |
| CoS 97264 | 0.343 | 2.259 |
| UP 9530 | 0.470 | 2.070 |
| CoLk 12204 | 0.275 | 1.217 |
| CoLk 12202 | 0.842 | 3.261 |
| CoLk 12206 | 0.294 | 4.545 |
| CoLk 07201 | 0.800 | 5.590 |
| CoLk 04238 | 0.405 | 4.114 |
| LG 06605 | 0.226 | 2.694 |
| LG 04439 | 0.153 | 1.763 |
| LG 05350 | 0.883 | 1.500 |
| LG 05020 | 0.588 | 1.138 |
| LG 03040 | 0.704 | 1.111 |
| A-46-11 | 0.188 | 5.145 |
| B-44-12 | 0.376 | 4.987 |
| A-27-12 | 0.016 | 1.615 |
| D-12-9 | 0.569 | 2.620 |
| D-6-13 | 0.319 | 2.947 |
| S 5085/11 | 0.163 | 3.585 |
| S5087/11 | 0.909 | 0.795 |
| S 5090/11 | 0.465 | 1.619 |
| Mean | 0.425 | 2.776 |
| SE± | 0.054 | 0.284 |
| SD | 0.264 | 1.39 |

SD- Standard deviation; SE- Standard error

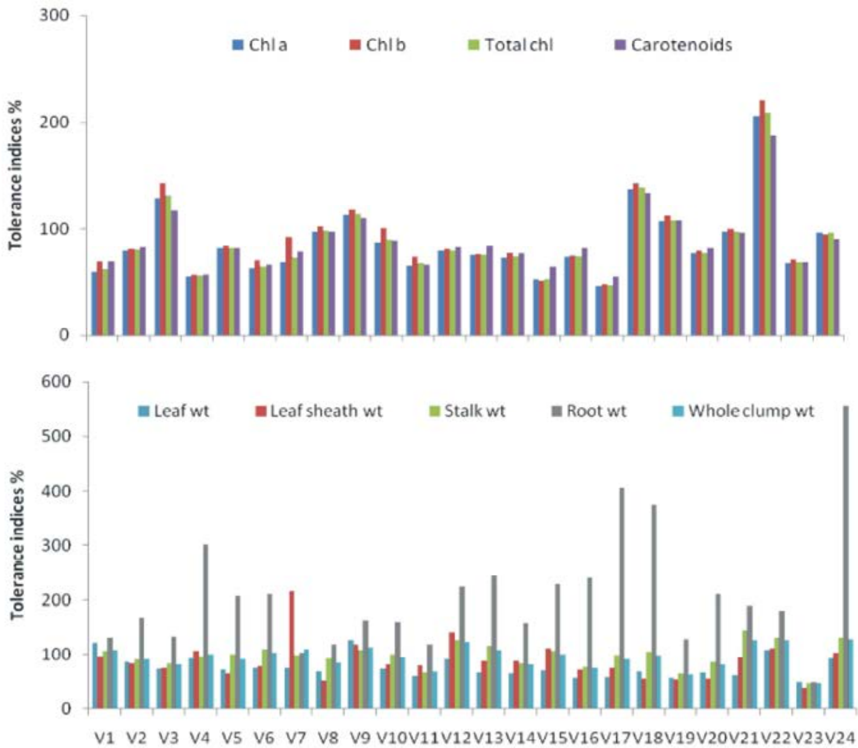


Fig. 2: Percent tolerance indices for physiological attributes
V1-CoLk 94184; V2-BO 91; V3-CoS 767; V4-CoJ 64; V5-CoS 97264; V6-UP 9530; V7-CoLk 12204; V8-CoLk 12202; V9-CoLk 12206; V10-CoLk 07201; V11-CoLk 04238; V12-LG 06605; V13-LG 04439; V14-LG 05350; V15-LG 05020; V16-LG 03040; V17-A-46-11; V18-B-44-12; V19-A-27-12; V20-D-12-9; V21-D-6-13; V22- S 5085/11; V23-S 5087/11; V24-S 5090/11

Table 5: Mean comparison of tolerance indices for different plant parameters

| Genotype | SPAD | SLW | P | K |
|---|---|---|---|---|
| CoLk 94184 | 91.1 | 109.2 | 62.0 | 99.1 |
| BO 91 | 92.8 | 87.8 | 100.0 | 91.0 |
| CoS 767 | 98.8 | 77.2 | 158.2 | 98.0 |
| CoJ 64 | 91.1 | 85.5 | 92.5 | 100.7 |
| CoS 97264 | 78.9 | 106.2 | 59.8 | 92.5 |
| UP 9530 | 80.8 | 91.2 | 81.3 | 79.1 |
| CoLk 12204 | 88.0 | 117.1 | 85.1 | 92.2 |
| CoLk 12202 | 80.6 | 96.7 | 112.0 | 85.6 |
| CoLk 12206 | 82.9 | 87.3 | 100.0 | 78.5 |
| CoLk 07201 | 85.6 | 85.3 | 107.3 | 79.7 |
| CoLk 04238 | 89.4 | 91.5 | 126.3 | 82.68 |
| LG 06605 | 83.1 | 108.3 | 89.5 | 117.3 |
| LG 04439 | 128.2 | 102.0 | 67.7 | 84.9 |
| LG 05350 | 86.5 | 100.3 | 68.2 | 79.4 |
| LG 05020 | 90.6 | 129.4 | 97.1 | 67.6 |
| LG 03040 | 97.1 | 102.7 | 68.3 | 95.7 |
| A-46-11 | 92.1 | 97.0 | 66.7 | 85.9 |
| B-44-12 | 91.7 | 95.7 | 59.2 | 78.3 |
| A-27-12 | 109.5 | 90.4 | 59.6 | 70.8 |
| D-12-9 | 97.9 | 112.3 | 68.2 | 72.9 |
| D-6-13 | 77.3 | 93.8 | 79.5 | 82.0 |
| S 5085/11 | 97.1 | 84.6 | 106.9 | 82.2 |
| S5087/11 | 76.8 | 65.2 | 134.0 | 114.1 |
| S 5090/11 | 130.5 | 90.4 | 107.5 | 92.1 |
| Mean | 92.4 | 96.13 | 89.9 | 87.6 |

Table 6: Correlation between tolerance indices of investigated plant parameters

| | Tolerance indices | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameters | Leaf dry wt | Leaf sheath dry wt | Stalk dry wt | Root dry wt | Whole clump dry wt | Chl a | Chl b | Total chl | SPAD | Carotenoids | SLW | P | K |
| Leaf dry wt | 1 | | | | | | | | | | | | |
| Leaf sheath dry wt | 0.440 | 1 | | | | | | | | | | | |
| Stalk dry wt | 0.493 | 0.447 | 1 | | | | | | | | | | |
| Root dry wt | 0.072 | -0.004 | 0.460 | 1 | | | | | | | | | |
| Whole clump dry wt | 0.632 | 0.619 | 0.968 | 0.429 | 1 | | | | | | | | |
| Chlorophyll a | 0.295 | -0.041 | 0.288 | -0.017 | 0.275 | 1 | | | | | | | |
| Chlorophyll b | 0.308 | 0.036 | 0.263 | -0.091 | 0.271 | 0.988 | 1 | | | | | | |
| Total chlorophyll | 0.299 | -0.024 | 0.283 | -0.034 | 0.274 | 0.999 | 0.993 | 1 | | | | | |
| SPAD | 0.031 | -0.002 | 0.148 | 0.514 | 0.162 | 0.140 | 0.103 | 0.133 | 1 | | | | |
| Carotenoids | 0.290 | -0.012 | 0.304 | -0.029 | 0.292 | 0.992 | 0.983 | 0.992 | 0.157 | 1 | | | |
| SLW | 0.011 | 0.410 | 0.262 | 0.112 | 0.281 | -0.359 | -0.349 | -0.358 | 0.034 | -0.277 | 1 | | |
| P | 0.061 | 0.006 | -0.194 | -0.270 | -0.159 | 0.218 | 0.245 | 0.225 | -0.090 | 0.139 | -0.550 | 1 | |
| K | 0.135 | 0.153 | -0.079 | -0.064 | -0.019 | -0.167 | -0.156 | -0.165 | -0.145 | -0.208 | -0.271 | 0.294 | 1 |

were used (Fig. 2, Table 5). As shown in Table 5, tolerance index for specific leaf weight of tested genotypes varied between 65.2 and 129.4, the highest tolerance index was recorded for LG 05020 followed by CoLk 94184 and CoS 97264 D-6-13 genotype showed highest tolerance index for stalk dry weight. While highest tolerance indices for chlorophyll a (varied between 46.2 and 205.6), chlorophyll b (varied between 47.7 and 220.7), total chlorophyll (varied between 46.6 and 208.7) and carotenoid contents (varied between 55.1 and 187.0) was recorded in S 5085/11 genotype. Genotype, S 5087/11 showed lowest tolerance index for different plant parts i.e., leaf dry weight, leaf sheath dry weight, stalk dry weight, root dry weight and whole clump dry weight.

There was a significant and positive correlation between tolerance index for whole clump dry weight with stalk dry weight, leaf dry weight, leaf sheath dry weight and root dry weight. Similarly, tolerance index for total chlorophyll showed positive correlation with chlorophyll a, b and carotenoids content (Table 6).

## CONCLUSIONS

Findings obtained indicated variability among genotypes for waterlogging tolerance based on stalk, leaf and whole clump dry weight. D-6-13, S 5090/11 and S 5085/11 genotypes had greater tolerance indices for stalk and whole clump dry weight and S 5085/11, B-44-12 and CoS 767 for chlorophyll a, b total chlorophyll and carotenoids contents.

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