Plant Archives Vol. 21, No. 2, 2021 pp. 624-631 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2021.v21.no2.095

BIOCHEMICAL AND PHYSIOLOGICAL RESPONSES OF SUGARCANE CULTIVARS AGAINST WATER DEFICIT STRESS

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(Date of Receiving : 04-05-2021; Date of Acceptance : 13-08-2021)

ABSTRACT

Sugarcane is one of the extremely important crops grown in tropical and subtropical areas. Water deficit stress is the major problem affecting the yield, millable quality and sucrose content of the crop. The objective of the present study is solely based on the impact of lack of water on physiological changes of twenty-three genotypes of sugarcane at various stages of its growth. Water stress was imposed by withholding irrigation after 60 days of normal growth. SPAD index, photosynthetic pigment such as chlorophyll a, chlorophyll b, and total chlorophyll, relative water content and water retention capacity was calculated at different time intervals of water deficiency (T1, T2) which were designated as moderate and severe water stress and they were analyzed in the leaves followed by the relief, of water deficit stress (T3). As a result, seven genotypes (Co 09004, Co 14011, Co 95020, Co 08020, Co 85019, Co 05001, and Co 671) significantly showed higher SPAD index, photosynthetic pigment such as chlorophyll a, chlorophyll b and total chlorophyll content, relative water content and water retention capacity, which might be due to their tolerance to water deficiency. Through these physiological parameters, PCA based cluster analysis was further carried out to ascertain those sugarcane genotypes which are resistant to water deficient conditions.

Keywords: Chlorophyll content, Relative water content, SPAD index, Sugarcane, Water deficit stress, Water retention capacity

INTRODUCTION

Sugarcane of genus *Saccharum* is the most important crop worldwide which is distributed in tropical and sub-tropical regions of the world. It plays a major role in the economy of many countries. Sugarcane is mainly grown for sugar production all over the world. The biomass obtained from it is used as a source of bioethanol (Jangpromma *et al*., 2012). Water deficit stress is the major abiotic stress caused due to climatic change. When this stress reaches a certain extent, it damages the physiological status of crop, directly affecting the growth rate and development of the crop which in turn affects the biomass production (Graca *et al.*, 2010; Medeiros *et al*., 2013; Zhao *et al*., 2013). Generally, severe stress in early and mid-growth stages leads to the reduction of cane yield which affects the crop quality by lowering the sugar yield. However moderate stress during the late growth stages may aid the crop to improve the sucrose content of the stalk. Thereby the effect of drought directly depends upon the degree and duration of stress (Zhao & Li, 2015). An increase in temperature and water stress both are in combination with each other hence chlorophyll fluorescence (Fv/Fm ratio) acts as quantitative measures to the photochemical efficiency of the PSII complex reported by (Kohila & Gomati, 2018). Certain modification such as reduced leaf water potential, relative water content, gas exchange, and photosynthesis was seen in plants with water deficit stress (Medeiros *et al*., 2013). Through different adaptive mechanism and reorganization of certain metabolic pathway plants conserve water for later use, to repair the damage caused by stress, which permit them to increase the overall yield of the crop (Vankova *et al*., 2012). Shortage of water leads to negative effect on physiological and biochemical aspect that was verified from all parts of the plant identified by (Silva *et al*., 2013).

According to Toppa *et al*. (2010) reduction in temperature, moderate drought and nitrogen content present in the soil play an important role in the maturation of crop, this process involves complex metabolic pathway begin with the photosynthetic capacity in the chloroplast of the leaf, and ends with accumulation of carbohydrates in the stem (Fernanda *et al*., 2018).

MATERIALS AND METHODS

In the present study twenty-three genotypes of sugarcane were grown in Yargatti Farm of S. Niglingappa Sugarcane Institute, Belagavi, Karnataka, India. The seeds were sowed in February 2019. With a plot size 1.2cm × 6m × 6 line, twenty-three varieties were grown with 1.2cm distance between the rows and the auto whether unit was installed to measure the climatic parameters during the crop season,

through this rainfall and air temperature was measured. Twenty three Genotypes of sugarcane include Co 09004, Co 14011, Co 0303, Co 13003, Co 98017, Co 95020, Co 93009, Co 92013, Co 12007, Co 07015, Co 08020, Co 85019, Co 86032, Co 90003, Co 13006, Co 92002, Co 06015, Co 92020, Co 94005, Co 98008, Co 05001, and Co 10033, Co 671.The plants were under treatment from 60-120 days of their growing period followed by irrigation. Data was recorded at 60th day considering the reading as plants under controlled conditions further there was water stress induced from 60-120 days of planting and similar observations was made followed by relief of water stress, and data was documented on 150th day of planting. Frequent field visit was done for data analysis and interpretation during the month of February to December.

About 10 feet distance the plants were selected to record data at different time intervals where 60 days as (control-T_0), 90 days (T_1), 120 days (T2) and 150 days (T3). The important traits such as chlorophyll 'a', chlorophyll 'b', Total chlorophyll, SPAD reading relative water content and water retention capacity were considered to estimate the tolerant varieties of sugarcane. Pearson correlation coefficient (Table 2) analysis was carried out for the correlation between various traits (Alemu *et al*., 2018; Jakhar & Kumar, 2018; Ambiger *et al*., 2019). Figure 2 depicts the study of the gradual change among the various sugarcane varieties. PCA was carried out to substantiate the relation between photosynthetic pigments, SPAD index, RWC and WRC. Dendrogram analysis was done with grouping pattern of various sugarcane varieties resulting in two main clusters.

Measuring chlorophyll content via SPAD index

The estimation of chlorophyll content was determined using a SPAD chlorophyll meter and an average of three reading in leaf +2 of each plant were used and SPAD index was calculated.

Pigment content analysis

Chlorophyll a (Chl a), chlorophyll b (Chl b) and total chlorophyll (Totchl) concentration were analyzed following the method of (Hiscox & Israelstam, 1979; Anamiel *et al*., 2018). The processed sampled was analyzed at optical density of 663 and 645 nm. The chlorophyll 'a', chlorophyll 'b' and total chlorophyll content was computed with standard formula as follows

Chlorophyll 'a' = (12.7 × A663) – (2.69 × A645) × (v/1000 × W)

Chlorophyll 'b' = (22.9 × A645) – (4.68 × A663) × (v/1000 x W)

Total chlorophyll = (20.2 × A645) + (8.02 x A663) × (v/1000 × W)

Relative water content (RWC)

Fresh weight (FW) of the sample was measured immediately after cutting, turgid weight was obtained by immersing the leaf in deionized water for 24h and subsequently, dry weight was measured by drying the leaf in a preheated oven at 80° for 48 h. relative water content was calculated by using the formula according to (Medeiros *et al*., 2013) and WRC was calculated using the formula suggested by (Tetsushi & Karim, 2007).

RWC = FW – DW/TW – DW × 100

WRC = Turgid/Dry weight

RESULTS AND DISCUSSION

Biochemical and physiological characterization

Generally, sugarcane yield depends on mainly some of the important physiology characters such as chlorophyll a, chlorophyll b, total chlorophyll, SPAD index, relative water content, and water retention capacity. Table 1 depicts the same and was recorded for different time intervals at T_0 (60 days), T_1 (90 days), T_2 (120 days) and T_3 (150 days) respectively. Under water deficit stress genotypes Co 671 and Co 09004 resistance to stress showed higher value of chlorophyll 'a' content at T_0 and reduction was seen at T_1 in genotypes Co 671 (1.89 mg g^{-1} FW), and Co 09004 (1.86 mg g^{-1} FW) and at T_2 in Co 09004 (1.63 mg g^{-1} FW) and Co 671 (1.65 mg g^{-1} FW). Whereas genotypes Co 98017 and Co 07015 which were susceptible to stress showed reduction in chlorophyll content at T_0 followed by decrease at T_1 and T_2 found in genotypes Co 98017 (1.68 mg g^{-1} FW) and Co 06015 (1.66 mg g^{-1} FW), (1.55 mg g^{-1} FW) and Co 07015 (1.46 mg g^{-1} FW).Similar observation were recorded with chlorophyll 'b' content and thus the genotypes Co 671 and Co 09004 were resistant to stress showed higher chlorophyll 'b' values at T_0 and the reduction was observed at T_1 in genotype Co 671 (0.35 mg g^{-1} FW), Co 09004 (0.34 mg g^{-1} FW) and at T_2 in genotypes Co 09004 (0.14mg g^{-1} FW), Co 671 (0.20 mg g^{-1} FW) was noticed. Whereas, genotypes Co 98017 and Co 06015 which were susceptible to stress showed low levels of chlorophyll content at T_0. Further reduction was seen at T_1 and T_2 in the genotypes Co 98017 (0.105 mg g^{-1} FW), Co 06015 (0.031 mg g^{-1} FW) and at T_2 in genotypes Co 98017 (0.045 mg g^{-1} FW), Co 06015 (0.016 mg g^{-1} FW). Higher level of total chlorophyll was observed at T_0 in genotypes Co 671 and Co 09004, Further decrease in Total chlorophyll was seen at T_1 and T_2 in genotypes Co 671 (2.252 mg g^{-1} FW), Co 09004 (2.212 mg g^{-1} FW) and Co 09004 (1.746 mg g^{-1} FW), Co 671 (1.699 mg g^{-1} FW) respectively. The genotypes Co 98017 and Co 06015 were susceptible to stress had great reduction in Total chlorophyll at T_0. Later at T_1 and T_2, the genotypes Co 98017 (1.792 mg g^{-1} FW), Co 06015 (1.694 mg g^{-1} FW) and Co 98017 (1.622 mg g^{-1} FW), Co 06015 (1.325 mg g^{-1} FW) shows reduction in total chlorophyll. SPAD index was higher in genotypes resistant to stress at T_0 further reduction was observed at T_1 in genotypes Co 671 (40.270 mg g^{-1} FW), Co 09004 (39.850 mg g^{-1} FW) and with a slight increase at T_2, inCo 671 (41.850 mg g^{-1} FW), Co 09004 (35.340 mg g^{-1} FW) respectively. Greater reduction in SPAD index was seen at T_1 and T_2 in genotypes Co 98017 (35.50 mg g^{-1} FW), Co 06015 (37.35 mg g^{-1} FW) and Co 98017 (33.45 mg g^{-1} FW), Co 06015 (32.47 mg g^{-1} FW) respectively. The RWC and WRC value was higher in genotypes Co 671 and Co 09004 and lowest in genotypes Co 06015 and Co 98017 respectively. According to the results loss of chlorophyll is linked with water deficit thus change in the chlorophyll content and SPAD index was used to assess the consequence of stress on sugarcane. Further the genotypes such as Co 09004 and Co 671 which were tolerant to stress showed higher chlorophyll content. Hence, reduction in chlorophyll content and SPAD was found in genotypes Co 98017 and Co 06015. Similar observation recorded by (Kohila & Gomati, 2018; Medeiros *et al*., 2013).

Pearson correlation coefficient analysis

Physiological effect under control (T_0), water stress (T_1 and T_2) and stress relief (T_3) was studied and the Pearson correlation coefficient analysis (Table 2) indicated that water retention capacity at (T_1 and T_2) was negatively correlated with chlorophyll content (r = -0.012, -0.007, -0.063), SPAD (r = -0.116, -0.062, -0.046, -0.245) and RWC (r = -0.180). The plants which are susceptible to water stress have lesser chlorophyll content and RWC. Whereas Relative water content was significantly positively correlated to chlorophyll content (r = 0.656^{**}, 0.699^{**}, 0.624^{**}, 0.681^{**} respectively), SPAD (r = 0.632^{**}, 0.631^{**}, 0.626^{**}, 0 .540^{**}, 0.584^{**}). A study by Surendar *et al*. (2013) on ratoon crop of banana shows similar results where two subplot treatments S1 and S2 showed highest RWC value as S1 (81.1) and S2 (80.4%). Hence RWC was highly correlated with yield. Similarly, SPAD value was also highly significantly correlated with chlorophyll r = 0.694^{**}, 0.531^{**}, 0.699^{**}, 0.759^{**} respectively. However similar results were seen Jangpromma *et al*. (2010) observed that significant reduction in chlorophyll content and SPAD reading, thus according to their findings reduction in the chlorophyll content was greater compared to SPAD index. Silva *et al*. (2018) also reported reduction in SPAD index during different time interval and the largest decrease in SPAD index was seen in variety RB855453.In addition to this reduction was also seen in RWC and chlorophyll content of plants. Variation in the chlorophyll content in sugarcane during drought was identified (Cha-um & Kirdmanee, 2009). According to Silva *et al*. (2007) the susceptible genotypes showed a great reduction in the SPAD chlorophyll meter reading values. Zhao *et al*. (2015) suggested chlorophyll content of the sugarcane leaf also plays an important role in identifying the stress tolerant varieties.

Principal component analysis

Among the twenty-four traits of sugarcane, PCA (Table 3) provides three principal components with the cumulative variance accounted for 83.369%. The resultant PC1 and PC2 together contributed to 75.02% whereas 73.47% of variance was contributed by PC1 and PC3. Thus, it is clear from PC1 that total chlorophyll at T_1, chlorophyll 'b' at T_1 were found to be most effective variable contributing 0.985 and 0.973% respectively whereas water retention capacity at T4 with 0.897% was better explained by PC2. Similarly, water retention capacity at T_2 (0.759%) and water retention capacity T_1 (0.590%) were most effective variables of PC3. According to Kohila & Gomati, (2018) biochemical characterization was undertaken with 5 sugarcane genotypes and two *S. Spontaneum* spp. under heat stress the genotypes which were tolerant to stress maintained high RWC and chlorophyll content while sensitive genotypes decrease in RWC chlorophyll content with a cumulative percentage of PC1 and PC2 as 95.5%.

It is clear from scree plot of principal component analysis the first three components showed more than one Eigen values hence there are well demonstrated whereas the component 4-24 indicates eigen values less than 1 thus they do not secure more importance (Fig. 1).

The genotype I and IV were having the lowest dissimilarity index which is equal to 17.148. Followed by 9.575 as the lowest dissimilarity for genotype II and genotype V. Successively it was 14.218 with respect to genotype III and VII respectively. Thus, these genotypes were found to be resistant towards water deficit stress (Table 4).

Cluster analysis of twenty-three sugarcane varieties

On the basis of twenty-four physiological characters, the genetic distance of twenty-three sugarcane varieties and prominent traits were predicted. The dendrogram analysis (Fig. 2) indicates two main clusters at 7% and 8% level of the cut made into seven genotypes of sugarcane varieties namely, Co 14011, Co 08020, Co 85019, Co 09004, Co 95020, Co 671 and Co 05001 respectively. Further, these two clusters classified at less than 5% level of the point made into the sub cluster are also named as groups. The first group (G1) is considered as cluster classified at 4% level varieties of sugarcane viz Co 0303, Co 92013, and Co 90003, Co12007, Co 94005 these five lines revealed 22% of total varieties. The second group G2 made at 3% level classify the sugarcane varieties and were grouped with five genotypes with 22% having Co 93009, Co 98008, Co 10033, Co 13003, Co 86032.Followed by that of third group (G3) was classified at 3% level exhibiting six lines with 26%, sugarcane varieties having genotypes Co 98017, Co 92020, C0 07015, Co 13006, Co 92002, and Co 06015.Finally, the fourth group (G4) classified at the 7% level have seven genotypes viz., Co 14011, Co 08020, Co 85019, Co 09004, Co 95020, Co 671, Co 05001 with 30% of the total respectively. A study on screening of sugarcane for salt tolerance Cha-um *et al*. (2013) reported through cluster analysis that '(A3) AE1-11' and 'KK3' were salt tolerant cultivars.

CONCLUSION

When the plants are subjected to water stress mainly the photosynthetic pigments are been affected as a result of it usually reduction in chlorophyll content such as chlorophyll a/b and total chlorophyll and relative water content. The varieties of sugarcane which were tolerant to stress, Co 09004, Co 14011, Co 95020, Co 08020, Co 85019, Co 05001, and Co 671 alter their development to water deficit stress and showed a greater recovery after rewatering when compared to Co 98017, Co 07015, Co 92020, Co 13006, Co 92002, Co 06015 which showed susceptibility. As a result, by having two different groups as depicted in the cluster analysis with respect to (G3 and G4) it could clearly indicate that the plants which were susceptible to stress had no recovery after rewatering and were clustered in a different group. Thus, based on the experimental results these significant variations of diverse characters of different groups are helpful for a future breeding programme.

Table 1 : Recorded mean values of physiological traits studied for 23 sugarcane varieties cultivated at Northern Karnataka in India

Geno-type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
I	2.3669	1.8629	1.6309	2.1692	0.4029	0.3498	0.1417	0.3377	2.7692	2.2122	1.7460	2.5064	46.6500	39.8500	35.3400	40.4500	259.6774	149.6296	107.0707	186.7347	1.1887	2.2162	1.8462	1.1431
II	2.3596	1.8265	1.6471	2.0508	0.2588	0.2975	0.1073	0.3638	2.6178	2.1235	1.7965	2.4141	48.3800	38.5200	33.5300	42.7500	229.2818	148.9796	114.7651	177.6536	1.3285	1.9533	1.5665	1.3214
III	2.2385	1.8992	1.6427	2.0721	0.2552	0.2575	0.1549	0.1303	2.4932	2.1563	1.7306	2.2020	43.0500	37.9500	33.5600	39.3500	206.6038	148.2143	103.8095	174.6411	1.4149	2.0228	1.9417	1.4074
IV	2.1468	1.8051	1.6288	2.1596	0.2496	0.3141	0.0877	0.1506	2.3959	2.1188	1.7020	2.3098	42.2500	37.1500	32.4500	39.0800	275.2381	146.4286	109.1228	186.3636	1.1620	2.1966	2.2232	1.1698
V	2.1585	1.8721	1.6370	2.1246	0.3154	0.3333	0.0694	0.3147	2.4734	2.2049	1.6980	2.4388	49.5100	40.0400	36.2300	42.5500	236.5854	145.9732	110.8787	179.3651	1.1855	2.2016	1.9637	1.1906
VI	2.1532	1.8760	1.6355	2.1361	0.2779	0.3099	0.0611	0.2579	2.4306	2.1855	1.7085	2.3935	42.5300	37.6400	35.0500	38.3500	232.0988	146.6926	107.4219	174.7191	1.2908	2.2786	2.2673	1.3260
VII	2.1825	1.8851	1.6352	2.0746	0.3591	0.3263	0.0744	0.3572	2.5411	2.2109	1.7214	2.4313	45.1200	40.4500	36.7900	39.5500	193.3333	148.5149	104.5198	176.7045	1.3433	1.9573	1.7832	1.3099
VIII	2.2328	1.8920	1.6577	2.1136	0.3756	0.3084	0.0793	0.3560	2.6079	2.2000	1.8518	2.4691	47.0500	40.9700	40.1400	41.1700	296.5517	146.4602	100.9804	176.8182	1.1950	1.9339	1.7907	1.4418
IX	2.3281	1.8988	1.6563	2.2192	0.4434	0.3541	0.2046	0.3368	2.7710	2.2524	1.6990	2.5555	49.4500	40.2700	41.8500	43.4500	262.8571	148.6188	86.2857	183.5821	1.2418	1.5403	1.5193	1.3888
X	2.0794	1.7733	1.5496	1.9602	0.2131	0.1396	0.0687	0.1934	2.2920	1.9126	1.6099	2.1532	40.2700	36.2500	32.3800	38.4400	180.6084	145.7711	88.7324	170.2811	1.6383	1.6223	1.5201	1.5900
XI	2.0906	1.7872	1.5583	1.9824	0.2834	0.1148	0.0567	0.1699	2.3735	1.9016	1.6309	2.1519	40.3500	34.3300	28.7500	36.4500	182.9268	119.2771	98.9305	163.2813	1.2541	1.7124	1.9167	1.2678
XII	2.0423	1.7916	1.5638	1.9445	0.1566	0.1395	0.0722	0.1620	2.1985	1.9307	1.6397	2.1061	40.9500	34.4500	28.5500	36.7500	179.5699	146.9697	89.0173	168.6486	1.4143	1.4907	1.5227	1.4102
XIII	2.1410	1.8089	1.5467	2.0150	0.1027	0.0542	0.0829	0.1404	2.2433	1.8628	1.5970	2.1550	41.6500	35.2500	30.4800	37.6500	175.7962	133.8624	97.8610	168.3077	2.4338	1.8077	1.7924	2.4908
XIV	2.0913	1.8039	1.5739	1.9781	0.3182	0.1174	0.0378	0.2482	2.4090	1.9209	1.5973	2.2258	41.2500	34.8200	31.2500	37.4900	171.9355	135.8824	83.5294	169.1558	1.8986	1.6667	1.6667	1.8928
XV	2.1530	1.7960	1.5529	2.0427	0.2692	0.1532	0.0302	0.1740	2.4217	1.9488	1.5788	2.2163	41.0500	35.5500	30.9100	38.4500	185.8621	139.3258	98.1818	164.6688	1.9831	1.6520	1.4015	2.1241
XVI	2.1365	1.7609	1.5420	2.0149	0.1613	0.1420	0.0299	0.1623	2.2974	1.9025	1.5635	2.1768	40.8400	35.7500	31.8500	38.2500	191.0377	128.7958	94.2122	162.6556	1.5287	1.9502	2.4952	1.6010
XVII	2.0236	1.7865	1.5507	2.0354	0.3256	0.1107	0.0179	0.1635	2.3488	1.8968	1.5946	2.1985	41.1900	35.2500	30.5800	37.5500	198.4925	120.1149	82.2222	152.7778	1.5209	1.7945	2.0274	1.5654
XVIII	2.0170	1.6874	1.5536	1.8728	0.0411	0.1055	0.0453	0.0066	2.0577	1.7926	1.6228	1.8790	37.6300	35.5000	33.4500	36.4200	158.0247	127.4725	88.0866	154.0373	1.2765	1.8426	2.3512	1.2752
XIX	2.0331	1.6756	1.4678	1.8670	0.0483	0.0507	0.1032	0.0043	2.0810	1.7261	1.5727	1.8710	38.5100	34.5500	32.8500	36.5200	155.2941	133.7349	84.5118	146.6667	1.1396	1.7511	2.5469	1.1478
XX	2.0387	1.6644	1.4789	1.8477	0.0111	0.0636	0.1013	0.0027	2.0495	1.7277	1.5638	1.8501	38.5800	35.2500	33.4600	36.8500	155.2632	122.1429	81.8182	148.9474	1.4492	1.5447	1.8132	1.4481
XXI	2.0497	1.6818	1.4824	1.8776	0.0005	0.0397	0.0825	0.0070	2.0499	1.7212	1.5020	1.8843	39.0900	34.1500	33.5600	38.5800	165.0718	134.9650	90.4348	139.5604	1.4456	1.5885	1.3010	1.3848
XXII	2.0436	1.6778	1.4818	1.8606	0.0006	0.0631	0.0148	0.0176	2.0438	1.7406	1.4964	1.8779	39.5300	36.0800	34.3500	37.6500	167.5497	146.7290	83.5714	142.5926	1.3107	1.3934	1.5147	1.3333
XXIII	1.9257	1.6634	1.4767	1.8536	0.0112	0.0312	0.0167	0.0049	1.9366	1.6942	1.3255	1.8581	39.3800	37.3500	32.4700	38.5900	154.7826	124.0310	78.7879	125.2874	1.3100	1.4831	1.2472	1.7016

Traits: 1:Chla-T0, 2:Chl a-T1, 3:Chl a-T2, 4:Chl a-T3, 5:Chl b-T0, 6:Chl b-T1, 7:Chl b-T2, 8:Chl b-T3, 9:Total-T0, 10:Total-T1, 11:Total-T2, 12:Total-T3, 13:SPAD-TO, 14SPAD-T1, 15:SPAD-T2, 16:SPAD-T3, 17:RWC-T0, 18:RWC-T1, 19:RWC-T2, 20:RWC-T3, 21:WRC-T0, 22:XWRC-T1, 23:WRC-T2, 24:WRC-T3. GP: Genotypes, I:CO 09004, II:CO 14011, III:CO 13003, IV:CO 95020, V:CO 08020, VI:CO 85019, VII:CO 86032, VIII:CO 05001, IX:CO 671, X:CO 0303, XI:CO 93009, XII:CO 92013, XIII:CO 12007, XIV:CO 90003, XV:CO 94005, XVI:CO 98008, XVII:CO 10033, XVIII:CO 98017, XIX:CO 07015, XX:CO 92020, XXI:CO 13006, XXII:CO 92002, XXIII:CO 06015.

Table 2 : Pearson's Correlation coefficient among different physiological characters studied for twenty-three sugarcane varieties of Northern Karnataka in India

TRS	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
A	1																							
B	.775**	1																						
C	.805**	.936**	1																					
D	.798**	.909**	.899**	1																				
E	.713**	.894**	.849**	.881**	1																			
F	.817**	.859**	.939**	.900**	.808**	1																		
G	.685**	.464*	.479*	.483*	.365	.529**	1																	
H	.792**	.881**	.868**	.827**	.901**	.841**	.342	1																
I	.908**	.908**	.895**	.911**	.941**	.877**	.549**	.920**	1															
J	.829**	.950**	.971**	.936**	.873**	.976**	.520*	.888**	.921**	1														
K	.793**	.808**	.880**	.741**	.726**	.830**	.528**	.776**	.816**	.850**	1													
L	.832**	.936**	.923**	.950**	.933**	.908**	.427*	.961**	.958**	.953**	.795**	1												
M	.835**	.813**	.835**	.817**	.770**	.863**	.535**	.882**	.862**	.873**	.720**	.890**	1											
N	.694**	.699**	.759**	.707**	.636**	.852**	.452*	.734**	.715**	.818**	.617**	.754**	.854**	1										
O	.531**	.435*	.501*	.485*	.404	.629**	.524*	.472*	.498*	.569**	.452*	.500*	.654**	.822**	1									
P	.769**	.638**	.703**	.699**	.596**	.772**	.536**	.725**	.727**	.743**	.547**	.746**	.928**	.842**	.729**	1								
Q	.748**	.759**	.837**	.885**	.748**	.874**	.464*	.741**	.808**	.857**	.773**	.846**	.800**	.757**	.606**	.737**	1							
R	.656**	.624**	.650**	.573**	.444*	.717**	.466*	.590**	.582**	.703**	.607**	.609**	.632**	.626**	.505*	.614**	.590**	1						
S	.699**	.681**	.748**	.683**	.508*	.750**	.287	.635**	.641**	.748**	.733**	.688**	.631**	.540**	.198	.530**	.641**	.560**	1					
T	.807**	.878**	.902**	.876**	.812**	.862**	.523*	.829**	.875**	.900**	.870**	.890**	.739**	.584**	.339	.565**	.771**	.666**	.732**	1				
U	-.118	-.029	-.215	-.128	-.115	-.407	-.244	-.087	-.126	-.261	-.252	-.111	-.245	-.410	-.443*	-.278	-.369	-.189	-.162	-.052	1			
V	.523*	.600**	.677**	.673**	.492*	.699**	.204	.509*	.546**	.682**	.651**	.613**	.481*	.500*	.223	.359	.621**	.350	.818**	.645**	-.251	1		
W	-.012	.043	.109	.138	.030	.127	-.007	-.063	.012	.096	.257	.033	-.116	-.062	-.046	-.245	.111	-.180	.197	.180	-.258	.585**	1	
X	-.157	-.043	-.226	-.119	-.114	-.410	-.294	-.094	-.144	-.269	-.331	-.111	-.211	-.312	-.350	-.207	-.311	-.244	-.234	-.143	.948**	-.314	-.328	1

TRS:Traits, A:Chla-T0, 2:Chl a-T1, 3:Chl a-T2, 4:Chl a-T3, 5:Chl b-T0, 6:Chl b-T1, 7:Chl b-T2, 8:Chl b-T3, 9:Total-T0, 10:Total-T1, 11:Total-T2, 12:Total-T3, 13:SPAD-TO, 14SPAD-T1, 15:SPAD-T2, 16:SPAD-T3, 17:RWC-T0, 18:RWC-T1, 19:RWC-T2, 20:RWC-T3, 21:WRC-T0, 22:XWRC-T1, 23:WRC-T2, 24:WRC-T3

Table 3 : Contribution of Twenty-four physiological traits to the total variation in the first three Principal Component Analysis of Twenty-three Genotypes.

Traits	Component		
	PC-1	**PC-2**	**PC-3**
Chlorophyll a (T0)	.889	.102	-.089
Chlorophyll a (T1)	.919	.253	.106
Chlorophyll a (T2)	.957	.056	.114
Chlorophyll a (T3)	.931	.136	.124
Chlorophyll b (T0)	.863	.220	.077
Chlorophyll b (T1)	.973	-.146	.016
Chlorophyll b (T2)	.569	-.166	-.287
Chlorophyll b (T3)	.904	.237	-.022
Total chlorophyll (T0)	.944	.181	.002
Total chlorophyll (T1)	.985	.018	.055
Total chlorophyll (T2)	.871	-.069	.216
Total chlorophyll (T3)	.959	.198	.049
SPAD (T0)	.917	.047	-.249
SPAD (T1)	.836	-.177	-.315
SPAD (T2)	.614	-.330	-.520
SPAD (T3)	.805	-.026	-.451
Relative water content (T0)	.892	-.115	-.002
Relative water content (T1)	.707	-.019	-.235
Relative water content (T2)	.753	-.019	.357
Relative water content (T3)	.899	.165	.239
Water retention capacity (T0)	-.275	.906	.118
Water retention capacity (T1)	.669	-.210	.590
Water retention capacity (T2)	.080	-.441	.759
Water retention capacity (T3)	-.283	.897	-.008
Total	15.633	2.374	2.002
Percent of Variance	65.138	9.890	8.341
Cumulative percent	65.138	75.028	83.369

Table 4 : Dissimilarity matrix of twenty-three varieties of sugarcane varieties of Northern Karnataka in India

GP	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII
I	0.000	32.857	54.746	17.148	25.080	30.667	67.199	39.120	22.652	83.318	86.941	84.855	88.267	93.982	78.720	77.199	80.426	111.247	115.678	117.595	108.473	105.229	127.704
II		0.000	26.164	47.760	9.575	11.536	37.864	69.111	45.254	56.595	60.278	57.902	59.639	67.871	50.114	51.052	59.648	83.523	87.959	90.838	80.540	78.299	101.549
III			0.000	69.874	32.248	25.869	14.218	90.435	60.698	30.684	40.038	32.192	35.423	42.638	25.677	29.489	42.692	59.218	63.556	67.037	57.811	54.635	79.686
IV				0.000	40.421	44.802	82.860	26.708	29.287	98.164	99.639	99.507	102.534	108.379	92.943	90.502	91.898	124.975	129.452	130.973	121.780	119.087	140.261
V					0.000	11.306	44.200	61.033	36.785	61.961	64.835	63.584	65.417	72.671	55.977	55.307	61.625	88.788	93.397	95.579	86.058	83.721	106.160
VI						0.000	39.216	65.314	40.043	55.106	58.584	56.515	59.148	66.066	49.037	48.410	54.598	81.816	86.104	88.623	78.636	76.042	98.867
VII							0.000	103.386	72.618	22.858	36.186	25.039	26.883	34.607	20.080	27.663	44.592	50.758	55.436	59.332	51.473	48.291	73.864
VIII								0.000	37.635	117.358	118.653	118.867	122.448	127.159	112.331	108.793	106.826	142.909	146.584	147.876	138.131	135.072	154.562
IX									0.000	84.688	90.341	86.596	91.746	94.291	82.177	79.217	78.595	112.242	115.938	117.288	109.283	104.797	126.346
X										0.000	29.691	5.158	16.153	14.379	13.916	22.070	36.511	33.513	37.051	41.372	36.228	31.150	57.146
XI											0.000	30.100	17.318	26.029	20.622	13.956	25.274	30.359	38.439	36.036	35.070	41.124	51.901
XII												0.000	16.506	14.841	14.440	23.255	37.192	33.105	35.971	40.961	35.139	29.874	56.175
XIII													0.000	15.061	12.099	17.565	34.524	26.186	32.991	34.820	31.916	33.500	52.630
XIV														0.000	21.033	23.969	34.998	23.126	28.315	29.860	31.373	29.290	48.944
XV															0.000	12.660	30.442	33.988	38.665	41.990	33.998	33.282	56.007
XVI																0.000	19.366	34.930	40.783	40.945	35.644	37.405	54.580
XVII																	0.000	41.840	45.924	43.633	39.952	42.307	52.030
XVIII																		0.000	10.767	10.141	18.187	24.902	30.809
XIX																			0.000	12.189	13.772	18.566	24.485
XX																				0.000	20.682	28.321	24.132
XXI																					0.000	14.365	24.010
XXII																						0.000	31.731
XXIII																							0.000

GP- Genotypes, I:CO 09004, II:CO 14011, III:CO 13003, IV:CO 95020, V:CO 08020, VI:CO 85019, VII:CO 86032, VIII:CO 05001, IX:CO 671, X:CO 0303, XI:CO 93009, XII:CO 92013, XIII:CO 12007, XIV:CO 90003, XV:CO 94005, XVI:CO 98008, XVII:CO 10033, XVIII:CO 98017, XIX:CO 07015, XX:CO 92020, XXI:CO 13006, XXII:CO 92002, XXIII:CO 06015.

Fig. 1 : Scree plot analysis of Twenty-three sugarcane varieties using 24 traits

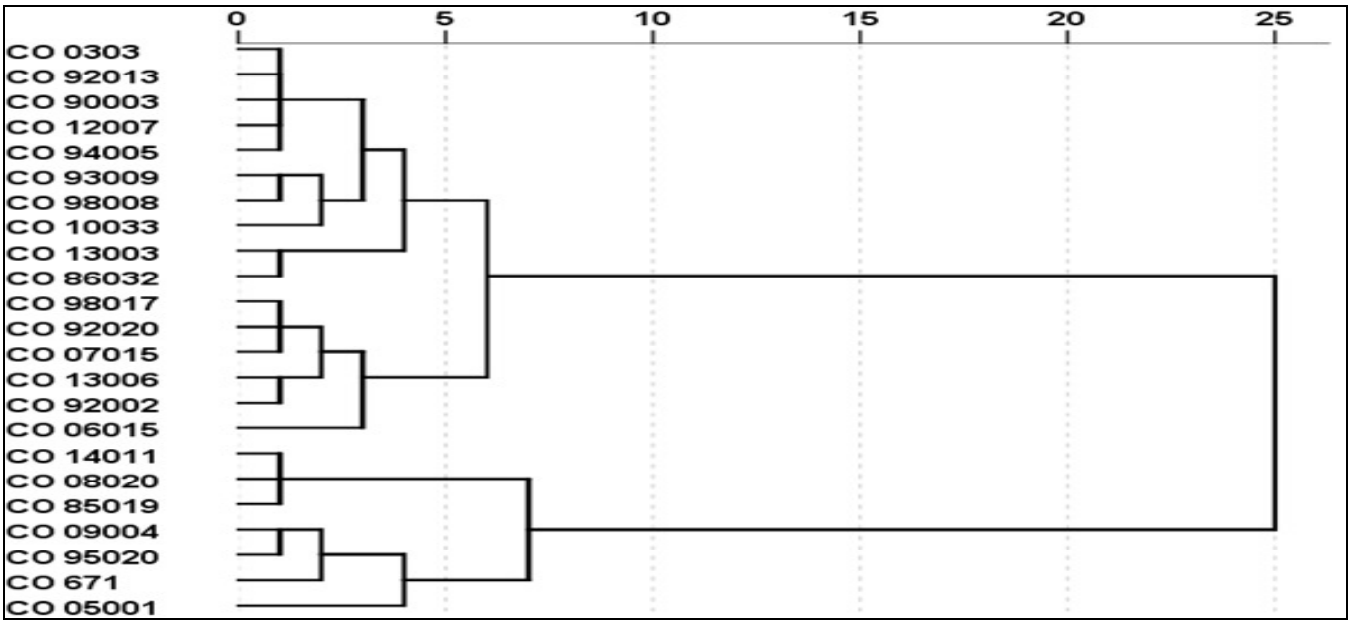

Fig. 2 : Dendrogram using Average Linkage (between groups) of Twenty-three varieties using 24 parameters of sugarcane cultivars

Acknowledgements

First author SJ, wish to thank the Directorate of Minority, Government of Karnataka for providing financial assistance to carry out research work in the form of Minority Fellowship (DOM/FELLOWSHIP/CR-21/2018-19).

Compliance with ethical standards

The authors declare that there is no conflict of interest.

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