



Adaptation behavior of sugarcane varieties against high temperature stress in subtropical India

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Abstract: High temperature stress has emerged as a widely occurring problem in sugarcane growing tracts, in general and in subtropical India, in particular, affecting growth and development of sugarcane in early pheno-phases of establishment and shoot formation. Seventy one sugarcane varieties from Peninsular, North-west, North-central and North-eastern sugarcane zones of the country were screened for their tolerance to high temperature stress. The tolerance has been assessed on the basis of drying of leaf-tips and margins (leaf injury) and rolling of leaves. Some varieties have the potential to escape high temperature stress and some other varieties were able to tolerate high temperature induced stress. Some of the varieties suffered from excessive leaf injury and leaf rolling, indicating thereby their inability to tolerate high temperature stress. The leaf rolling during formative phase of the crop showed qualitative impact on the tonnage of the crop at harvest. These varieties may further be explored for their use in breeding programmes.

Key words: Escape mechanism, High temperature stress, Leaf burning, Leaf injury, Leaf rolling, Sugarcane, Tolerance

Introduction

The high temperature stress due to global warming has detrimental effects on growth of all the crops and has its adverse implications on the crop production systems worldwide. Manifestations of high temperature stress are mediated through generation of reactive oxygen species damaging various biomolecules in different crop plants (Bhattacharjee, 2009; Srivastava *et al.*, 2012; Wilson *et al.*, 2014). Sugarcane, one of the most important agro-industrial crops in India is also one amongst such crops. Sugarcane cultivation in India is usually exposed to favorable as well as stressful weather patterns and climatic conditions during the growth and development and sugar accumulation particularly in the context of climate change. The thermal stress conditions encountered by the crop during establishment, formative phase vary from excessively high temperature during April to June (>38-40°C) in sub-tropical India to low temperature stress (<10°C) during harvest span (November- January) which seriously affect the yield and quality of early varieties and also the succeeding ratoon crop, primarily due to poor sprouting of stubble buds. The ever-changing weather condition due to climate change, with special reference to maximum temperature during summer months has necessitated the demand for new sugarcane varieties capable to acclimatize and withstand the heat stress and to yield *at par* with normal conditions. In the present study, an attempt has been made to identify sugarcane varieties having tolerance and adaptation potential to high temperature stress during formative phase, particularly in subtropics. Seventy-one promising sugarcane varieties developed for various agro-climatic zones of India were evaluated for their tolerance and avoidance to escape high temperature stress.

Materials and Methods

Seventy-one varieties of sugarcane, belonging to various agro-climatic zones of India, *viz.*, six varieties from Peninsular zone, fifty-seven from North-west zone and eight from North-central and North-eastern zones were evaluated for their response to high temperature and adaptation mechanism to high temperature stress at IISR farm during spring season of 2007 (table-1). These varieties were rated for leaf injury and leaf rolling during the formative phase. The details of methodologies adopted for the study are as follows. **Screening for heat injury:** Above mentioned varieties were screened for heat tolerance/injury induced due to high temperature stress at early growth stage on a 0-4 point scale as detailed below: 0- No damage to leaf; 1- up to 2 cm leaf tip and leaf margin drying; 2- 2-4 cm leaf tip and leaf margin drying; 3- 4-6 cm leaf tip and leaf margin damage/drying and 4-more than 6 cm leaf drying. If more than 25% of leaves were affected in a particular variety, the corresponding rating as narrated above was assigned to that variety. **Leaf rolling:** Leaves, the site of interaction of plant with ambient environment, are the worst effected part due to prolonged high temperature stress at early stage. High temperatures, invariably lead to drought stress. There are various escape mechanisms in plants against high temperature stress and leaf rolling and curling is one of them (Cheng and Shih, 1948; Gilani *et al.*, 2008; Ishaq *et al.*, 2008). In order to assess the impact of heat stress on leaf rolling, number of total leaves and the number of rolled leaves were counted in 6 m row length of each variety. The per cent rolled leaves were calculated with respect to the total number of leaves produced per genotype at the time of observation. The leaf rolling in varieties was characterized and graded in 0-4 point scale as follows: 0- No leaf

rolling; 1- 0-25% leaves rolled; 2- 26-50% leaves rolled; 3- 51-75% leaves rolled and 4- > 76% leaves rolled. The daily maximum and minimum temperature from 15th April to 15th June, 2007 was also collected from met yard of the Institute.

Catalase and ascorbate peroxidase activity: The catalase and ascorbate peroxidase activity (in terms of total integrated density) in sugarcane leaves affected due to exposure to high diurnal temperature was also determined by the method described by Srivastava *et al.* (2012).

Results and Discussion

Temperature and Rainfall Pattern: The daily temperature pattern in formative phase of the crop from April 15 to June 15, 2007 is shown in fig. 1 (a). The maximum temperature varied from 27.1 to 44.0°C with a mean of 38.4 °C during the formative phase. The maximum temperatures exceeded 40°C for 22 days during this span. The minimum temperatures ranged from 21 to 30°C with a mean of 25°C. It remained higher than 25°C for 23 days. The rainfall received this period is shown in fig. 1(b). The total rainfall received was 78 mm out of which, 60.7 mm was received on 14th and 15th June, 2007.

Heat injury to leaf tip margins during formative phase: Integrated agrotechniques for growth attributes of pigeonpea The above-mentioned varieties responded differently to high temperature stress during formative phase at the location (Plate 1). There was no damage at all in 13 varieties. Most of the varieties suffered from leaf tip damage up to 2 cm (46 out of 71 varieties), followed by 8 varieties showing leaf tip damage of 2-4 cm length and showing symptoms of drying of leaf margins. Three varieties showed damage of leaf tips and margins up to 4-6 cm along with drying of leaves. Drying of more than 6 cm of leaves was rare and was found in only one genotype.

Ten out of fifty-seven varieties (17.54 %) of North-west zone were severely affected by heat injury. This was followed by varieties developed for Peninsular zone wherein one out of six varieties (16.67 %) was severely affected, however, no variety of North-central and North-eastern zones showed severe heat injuries. On the other hand, 11 varieties of North-west zone (18.97 %) did not register any high temperature injury. The number of varieties of Peninsular zone showed no leaf injury. Two out of seven (28.57 %) varieties of North-central and North-eastern zones, respectively did not show any damage to leaf tip due to high temperature stress. There was a perceptible difference in the response of high temperature stress on the injury pattern of the early and mid-late varieties (Figs 2a, 2b and 2c). Apparently, there is no consistent trend in crop yield due to leaf injury. This may possibly be attributed to pattern of leaf emergence in this vegetatively propagated crop.

Leaf rolling due to high temperature stress: These varieties were also scored for leaf rolling /curling due to high temperature stress at formative phase (tables- 2, 3, 4). The results indicated that 36 varieties did not show leaf rolling, followed by 14 varieties showing leaf rolling up to 25%. Six varieties suffered from 26-50% leaf rolling followed by eight varieties showing 51-75% leaf rolling and seven varieties exhibited > 75% leaf rolling. The pattern showed variable response of sugarcane varieties due to high temperature stress. Three out of six varieties (50%) of Peninsular zone showed

Table 1: Sugarcane varieties used in the study

Zone	Variety
Peninsular zone (6)	CoC 90063, CoA 93081, Co 86249, Co 93009, CoV 94104, CoLk 8001
North-west zone (57)	CoLk 8102, CoLk 04238, CoLk 9616, CoLk 9617, CoLk 9705, CoLk 9707, CoLk 9709, CoLk 9412, CoLk 9606, CoS 88230, CoS 96268, CoS 99259, CoS 95255, CoS 8436, CoS 96275, CoS 767, CoS 01268, CoS 02264, CoS 00221, CoS 2191, CoS 98259d, CoS 96258, CoS 2252, CoS 97258, CoS 2252, CoS 97248, CoS 95258, CoS 95222, CoS 94257, CoSe 92423, CoSe 00421, CoH 110, CoH 119, CoH 92201, CoH 92202, CoJ 64, CoJ 83, CoJ 20193, CoJ 99192, Co 99016, Co 99015, Co 00240, Co 00241, Co 89003, Co 0238, Co 0237, Co 0120, Co 0230, CoPant 84212, CoPant 90223, CoPant 02217, CoPant 84211, CoPant 2218, CoPant 99213, CoPant 99214, CoPant 98224, CoPk 59, CoPk 112, CoPk 78
North-central and North-east zone (8)	BO 128, BO 130, Co 89029, CoSe 95422, CoP 9301, CoP 9206, BO 91, CoLk 94184

severe leaf rolling. This was followed by varieties of North-central and North-eastern zones with three out of seven varieties showing severe leaf rolling, whereas, only 10 out of 58 varieties (17.24 %) of North-west zone showed severe leaf rolling. On the other hand, 33 varieties of North-west zone (57.89 %) did not suffer from leaf rolling. The number of varieties showing no leaf rolling was zero in Peninsular zone and four (50 %) in case of North-central and North-eastern zones. The leaf rolling pattern differed amongst early and mid-late varieties (Figs. 3a, 3b, and 3c).

It is clearly seen from the above data that group of varieties with no rolling gave relatively lower yield in early and mid-late varieties. This could possibly be attributed to the fact that leaf rolling or curling is a known mechanism in plant to ward off impact of water and heat stress in many plant species (Kadioglu, 2012).

Differential behaviour of sugarcane varieties towards high temperature stress: The varieties of different agro-climatic zones responded differently for tolerance to high temperature as reflected by leaf injury. The varieties of North-west zone were comparatively more tolerant to high temperature stress than that of North-central and Peninsular zones. The varieties have shown differential response to leaf injury *vis-à-vis* protective mechanism as leaf rolling and cane yield. Tolerance to heat injury with no leaf rolling coupled with high yield was observed in early maturing varieties such as CoLk 9707 and Co Pant 02217 and mid late varieties like CoLk 04238 and CoS 96275. Co 0238, an early maturing variety possessed high yield with maximum susceptibility to heat injury and moderate leaf rolling, indicating strong compensatory mechanism. CoPant 00217 and CoSe 00421 exhibited maximum leaf rolling and no leaf injury due to high temperature, indicating success of protective mechanism. CoPant 02218 gave highest yield in spite of moderate heat injury and leaf rolling.

In general, most of the varieties reflected some degree of tolerance to high temperature stress, especially of those developed for North-west zone. Seven varieties of this zone viz., CoLk 04238,



Plate- 1: Sugarcane leaf burning due to high temperature stress

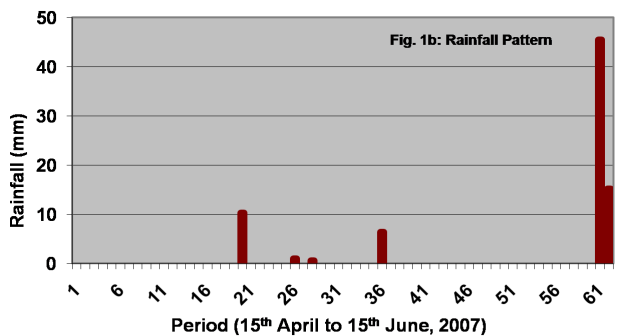
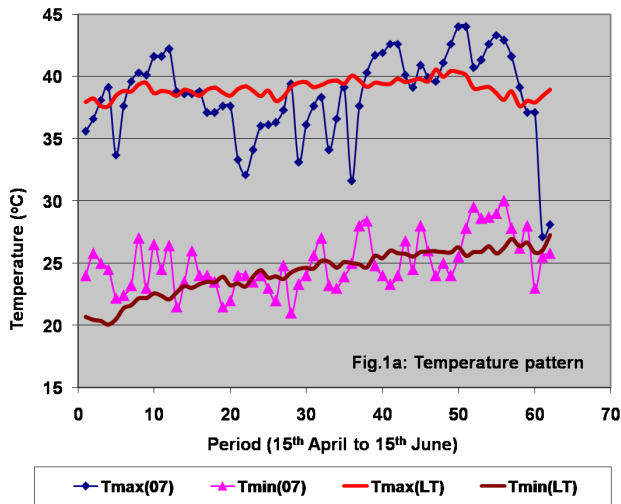


Fig. 1: Daily temperature (a) and rainfall (b) pattern in formative phase of the crop from April 15 to June 15, 2007

CoLk 9707, CoS 99259, CoS 95258, CoH 92202, CoS 96275 and Co 0120 neither suffered from any leaf injury nor any leaf rolling, indicating thereby their inherent tolerance to high temperature stress. Besides, one variety (CoP 9206) of North-central and North-east

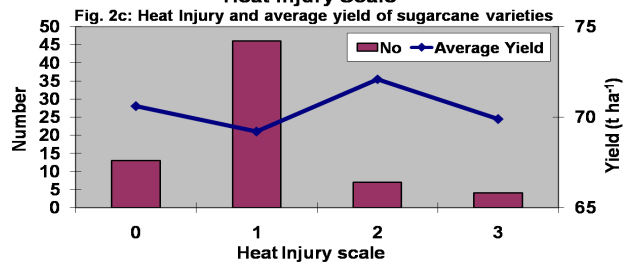
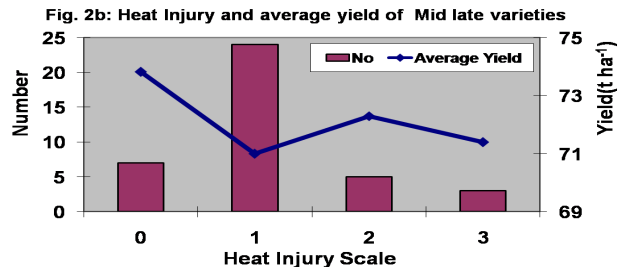
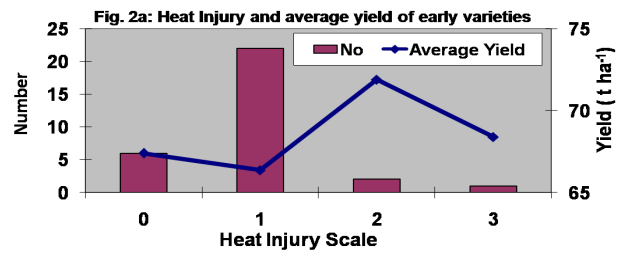


Fig. 2: Difference in the response of heat stress on the injury pattern of the early and mid-late varieties (Figs 2a, 2b and 2c)

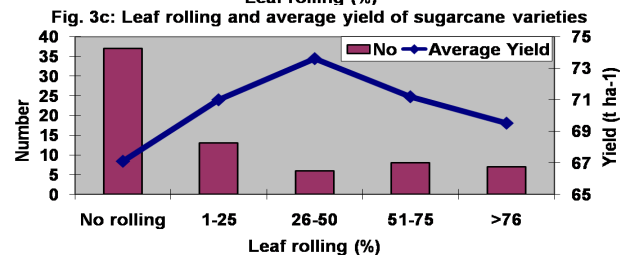
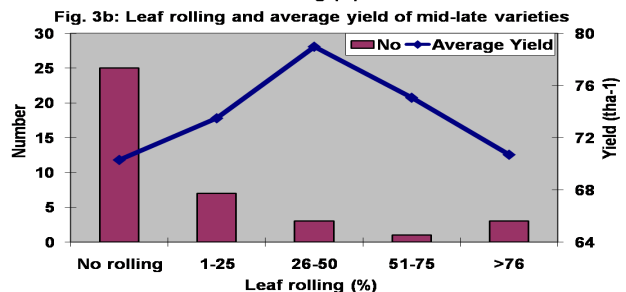
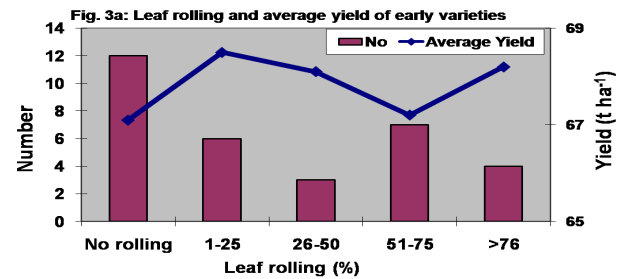


Fig. 3: Difference in the response of high temperature stress on leaf rolling pattern of the early and mid-late varieties (Figs. 3a, 3b, and 3c).

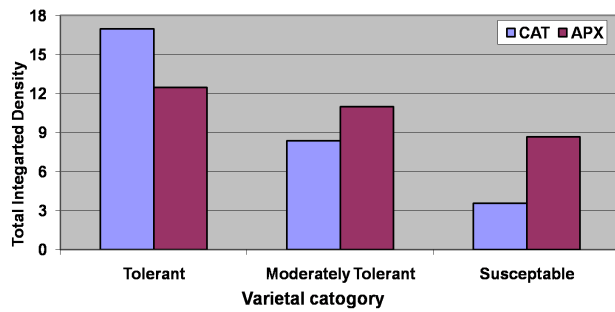


Fig. 4: Activity Pattern of catalase and ascorbate peroxidase isoenzymes in sugarcane varieties due to high temperature stress

zone also did not suffer due to leaf injury and/or leaf rolling. On the other hand, all the varieties of Peninsular zone suffered from heat injury/leaf rolling. However, the effect of high temperature stress was not very severe. Two varieties of North-west zone, (Co 0238 and CoS 02191) were the worst affected ones and suffered from excessive leaf injury and leaf rolling, indicating their inability to tolerate high temperature stress. Some varieties of North-western zone such as CoPant 02217, CoPant 99213, CoPk 78, CoSe 00421, CoJ 64, CoJ 83, CoS 2252, CoS 97248 and CoS 767 suffered from only marginal leaf injury as these appeared to have escaped high temperature stress through more than 50% rolling of their leaves. Similarly, CoC 90063 and Co 93009 of Peninsular zone and BO 128 and BO 130 of North-central and North-eastern zone also escaped severe heat injuries due to excessive leaf rolling. On the other hand, CoLk 94184, CoLk 9617 and CoS 96268 did not show any leaf rolling but suffered from drying of 4-6 cm leaf tips and leaf margins and consequent damage. The study shows that some sugarcane varieties like CoPant 02217, CoPant 99213, CoPk 78, CoSe 00421, CoJ 64, CoJ 83, CoS 2252, CoS 97248, CoS 767, CoC 90063, Co 93009, BO 128 and BO 130 have potential to escape high temperature stress and some other varieties like CoLk 04238, CoLk 9707, CoS 99259, CoS 95258, CoH 92202, CoS 96275, Co 0120 and CoP 9206 are able to tolerate high temperatures, hence these varieties may further be explored for their economic attributes, following high temperature stress in order to use them in breeding programmes.

Catalase and ascorbate peroxidase activity: The catalase and ascorbate peroxidase activity due to high temperature stress were assayed. The activity patterns are presented in fig. 4. It is seen that the activities of both the enzymes is gradually reduced from high temperature stress tolerant to susceptible sugarcane varieties. Wilson et al. (2014) studies effect of heat stress on *Brassica juncea*. Fifty genotypes of *B. juncea* were classified as tolerant or susceptible in terms of their survival percentage after heat shock treatment at 45° C for 4.5 h; ten genotypes were registered as tolerant, twenty moderately tolerant and rest of the twenty as susceptible. The activity of Catalase was also decreased after heat shock but the extent of decrease was less in tolerant genotypes (1.3 fold) as compared to susceptible genotypes (1.6 fold). Activities of catalase and ascorbate peroxidase decreased significantly under heat stress in *Amaranthus lividus* L. also during early germination (Bhattacharjee, 2009).

Table 2: Heat injury and leaf rolling rating in varieties of North-west zone

Variety/Genotype	Heat injury rating	Leaf rolling rating
CoLk 8102	1	0
CoLk 04238	0	0
CoLk 9616	1	0
CoLk 9617	3	0
CoLk 9705	1	0
CoLk 9707	0	0
CoLk 9709	2	0
CoLk 9412	1	1
CoLk 9606	1	1
CoS 88230	1	0
CoS 96268	3	0
CoS 99259	0	0
CoS 95255	1	0
CoS 8436	1	0
CoS 96275	0	0
CoS 767	1	4
CoS 01268	2	1
CoS 02264	1	0
CoS 00221	1	1
CoS 2191	3	4
CoS 98259	1	0
CoS 96258	1	1
CoS 2252	1	3
CoS 97248	1	3
CoS 95258	0	0
CoS 95222	1	0
CoS 94257	1	2
CoSe 92423	1	0
CoSe 00421	0	3
CoH 110	2	0
CoH 119	2	0
CoH 92201	1	0
CoH 92202	0	0
CoJ 64	1	3
CoJ 83	1	3
CoJ 20193	1	0
CoJ 99192	0	1
Co 99016	1	1
Co 99015	2	0
Co 00240	1	0
Co 00241	1	0
Co 89003	1	0
Co 0238	4	3
Co 0237	0	1
Co 0120	0	0
Co 0230	1	0
CoPant 84212	1	0
CoPant 90223	1	0
CoPant 02217	0	4
CoPant 84211	1	2
CoPant 2218	2	2
CoPant 99213	1	4
CoPant 99214	1	0
CoPant 98224	1	0
CoPk 59	1	2
CoPk 112	1	1
CoPk 78	1	4

Table-3: Heat injury and leaf rolling rating in varieties of peninsular zone

Variety	Heat injury rating	Leaf rolling rating
CoC 90063	1	3
CoA 93081	1	1
Co 86249	1	1
Co 93009	1	4
CoV 94101	2	1
CoLk 8001	1	2

The two enzymes in question, *i.e.*, ascorbate peroxidase and catalase belong to two different classes of hydrogen peroxide-scavengers. Hydrogen peroxide, a reactive oxygen species (ROS) gets accumulated in plants due to heat induced oxidative stress (Foyer *et al.* 1994). Ascorbate peroxidase (APX) is found in many parts of plants such as present in chloroplasts, apoplast, mitochondria, cytosol and peroxisomes. This is one of the most important antioxidant enzymes of plants that detoxifies hydrogen peroxide and catalase (CAT) present in peroxisomes which is responsible for the removal of excess reactive oxygen species during stress conditions (Noctor and Foyer 1998). High activity of catalases and ascorbate peroxidases in high temperature stress tolerant sugarcane varieties as compared to the susceptible ones indicates that these varieties are more efficient to protect themselves from reactive oxygen species (ROS) such as hydrogen peroxide, superoxide, and hydroxyl radicals produced after exposure to high temperature.

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Table-4: Heat injury and leaf rolling rating in varieties of North-central and North-east zone

Variety	Heat injury rating	Leaf rolling rating
BO 130	1	3
BO 128	1	4
Co 89029	0	2
CoSe 95422	1	0
CoP 9301	1	0
CoP 9206	0	0
BO 91	1	1
CoLk 94184	3	0

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