Journal of Sugarcane Research (2013) 3(1) : 1-8

RESEARCH ARTICLE

AN ASSESSMENT OF HIGH TEMPERATURE TOLERANCE POTENTIAL OF ELITE GENOTYPES OF SUGARCANE (*SACCHARUM* SPP.) EVALUATED IN THE PENINSULAR ZONE OF INDIA

G. Hemaprabha*, S.P. Adhini, T.S. Sarath, S. Alarmelu and R.M. Shanthi

Abstract

A steady increase in global temperature is a matter of alarm to agriculture and development of climate resilient sugarcane varieties is an anticipatory approach for sugar sustenance. This study was conducted to assess the relative performance of elite genotypes under low and high temperature regimes. For this, data on temperature and mean CCS t/ha of two plant and one ratoon crops of the advanced varietal trials under All India Co-ordinated Research Project (Sugarcane) from 1997- '98 to 2009-'10 in the Peninsular zone of India were examined. Mean maximum temperature during the 13 years ranged from 34.0^{O}C at Thiruvalla to 42.2^{0}C at Akola. The centres were categorized into low temperature region, with a mean of 35.36^{0}C comprising four centres viz. Thiruvalla, Mandya, Navasari and Coimbatore and high temperature region with a mean of 39.54^{0}C including Akola, Rudrur, Pune, Sameerwadi, Padegaon and Sankeshwar. Mean CCS yields of 61 clones based on two plant and ratoon crops at the two temperature regimes showed that 33 clones exhibited increased sugar yield at high temperature regime in contrast to 28 clones at low temperature. Twelve clones viz. Co 90010, Co 91005, CoG 93076, Co 94012, Co 92001, Co 91003, Co 0310, Co 85012, Co 92024, Co 93018, Co 95016 and CoC 92061 registered significant superiority and showed promise as high temperature tolerant clones. Twenty three clones registered high CCS with insignificant difference at the two temperature regimes indicating their stability in performance as thermoinsensitive genotypes. CoC 671, Co 7201, Co 740, Co 7717 and Co 658, and the wild species, Saccharum robustum, appeared more frequently in the parentages of these genotypes. Low coefficients of coancestry values (below 0.05) of 27 clones with increased CCS at higher temperature measured their less common descent and hence higher genetic diversity. Hence the parental combinations of these clones could be effectively tried in breeding for high temperature tolerance for the zone. This study could give a definite indication on varietal response to temperature and the parents involved in their evolution to serve as the foundation for developing climate resilient varieties through conventional and biotechnological means.

Key Words: Sugarcane, temperature tolerance, CCS t/ha, AICRP(S), varietal response, coefficient of coancestry.

Introduction

Plants are incredibly temperature sensitive and can perceive changes of as little as one degree Celsius (Lobell et al. 2008). For the same reason agriculture is extremely vulnerable to climate change. FAO posited that 'a genetically diverse portfolio of improved crop varieties, suited to a range of agro-ecosystems and farming practices, and resilient to climate change' is key to sustainable production intensification (Chikelu Mba et al. 2012). Rising temperature and altered rainfall reduce yields of desirable crops while encouraging weed and pest

G. Hemaprabha*, S.P. Adhini, T.S. Sarath, S. Alarmelu and R.M. Shanthi
Division of Crop Improvement, Sugarcane Breeding Institute, Coimbatore- 641007
*email : hemaprabha@sify.com

proliferation. Developing countries, particularly South Asia will be hard hit by climate change through direct effects of climate change on crop yields as well as indirect effects through changes in irrigation water availability for most crops without CO_2 fertilization (Nelson et al. 2009, Long et al. 2006). Among the extreme weather events including heat waves, drought, strong wind and heavy rains, drought is more damaging because of the long-term lack of water available to the plants. Droughts cause wilting resulting in different morpho-anatomical, physiological and biochemical changes in plants. Studies related to comparing responses to heat of contrasting species indicated that photosystem II of a cool season species, wheat, is more sensitive to heat than photosystem II of rice and pearl millet, which are warm season species adapted to much higher temperatures (Al-Khatib and Paulsen 1999). Heat stress tolerance can be mitigated by breeding plant varieties that have improved levels of thermo-tolerance using different conventional or advanced genetic tools (Hall, 1992).

The steady increase in temperature is a matter of alarm for sugarcane crop, more so because of reducing arable land and the preference for cereal crops in the available arable area especially in India with its vast population depending on climate sensitive sectors like agriculture and forestry for livelihood. Hence development of climate resilient sugarcane varieties is an anticipatory approach for sugar sustenance. Climate models do not do a good job of predicting how extreme weather events might change under global warming (Hall 1992). Though sugarcane is basically a drought tolerant species, improved varieties differ in their reaction to drought (Venkataramana et al. 1986). In sugarcane, varietal evaluation trials are conducted in five agroclimatic conditions through All India Co-ordinated research project (AICRP) under Crop Improvement. Peninsular zone is the largest among the five zones spread across the states of Gujarat, Maharashtra, Madhya Pradesh, Karnataka, Interior Andhra Pradesh, Tamil Nadu and Kerala, where a set of common entries are tested in 16 to 18 centres every year. The advantage of this testing is that a set of elite genotypes is tested in replicated trials following similar cultural practices and protocols of proper field experimentation. The only difference is the macroenvironment that decides variation in the final yield of the genotypes evaluated in the centres. The information on the data on weather parameters and sugar yield of the entries tested in all the centres of Peninsular Zone under AICRP on Sugarcane from 1997-98 to 2009-10 (Principal Investigator's Report, Crop Improvement, AICRP(S), 1997-98 to 2009-10) were examined in this study to evaluate the varietal response at high and low temperature locations in the zone.

Materials and methods

The data from the All India Co-ordinated Research Project (Sugarcane) over a period of 13 years from 1997- '98 to 2009-'10 of 14 varietal testing centres in the Peninsular zone of India, published in the Annual Reports of Crop Improvement under AICRP were examined. Common sets of entries were tested in the centres along with a set of identified zonal standards in randomized block design in two plant crops and a ratoon crop under early and midlate maturity groups. Mean data of two plant crops and a ratoon crop at each centre and monthly mean maximum temperature were tabulated. The maximum mean temperature during the period from 1997-98 to 2009-10 are presented in Table 1. Data on mean commercial cane sugar yield (CCS t/ha) of the test entries and standards at higher and lower temperature regions were compared and better genotypes were identified based on standard protocols (Panse and Sukhatme 1954). Percent increase in CCS of each entry at higher temperature over that at low temperature was calculated to identify the best genotypes at both temperature regimes, at low temperature and at high temperature and inferences made.

Coefficient of coancestry (CoC) of the best performing clones was estimated. CoC is the degree of descent between two individuals that estimates

Table 1. Mean maximum temperature at AICRP Centres of Peninsular zone

Sl.No.	Centre	State	Mean maximum temperature (^{0}C)
1	Rudrur	Andhra Pradesh	40.06
2	Navasari	Gujarat	35.96
3	Mandya	Karnataka	34.84
4	Sankeshwar	Karnataka	38.13
5	Sameerwadi	Karnataka	38.21
6	Thiruvalla	Kerala	34.02
7	Sehore	Madhya Pradesh	41.30
8	Padegaon	Maharashtra	37.88
9	Pravaranagar	Maharashtra	36.89
10	Pune	Maharashtra	38.33
11	Akola	Maharashtra	42.18
12	Coimbatore	Tamil Nadu	36.01
13	Melalathur	Tamil Nadu	42.10
14	Pugalur	Tamil Nadu	38.92

genetic relationship (Martin et al. 1991). The method suggested by Falconer and Mackey (1989) was employed for the estimation of CoC based on the full pedigree information traced back to the founding parents.

Coefficient of co-ancestry:

$Fx = \Sigma [(1/2) n1 + n2 + 1 (1 + FA)]$

where:

Fx = coefficient of co-ancestry of the cross to be known

FA = inbreeding coefficient of common parent A

n = number of generations (path) connecting the parents of x through their common ancestor.

Σ = overall paths of relationship.

Results and discussion

A study of this nature with a uniform set of genotypes evaluated in different environments with uniformity of experimentation would enable generating information on the adaptability of the elite genotypes to normal conditions and at relatively high temperature conditions. The advantage of this approach lies in the fact that agro-ecological systems are subject to multiple stresses and interaction of such stresses would be often nonlinear. For the same reason, experimental results and crop simulation models used in agricultural impact studies could not be designed to correctly quantify multiple stresses under wide range of environmental conditions (Goudriaan and Van Laar 1994). The present study revealed that the 14 varietal testing centres spread over seven states exhibited variation in temperature and varietal performance. Maximum mean temperature during 13 years was relatively low at Thiruvalla (34.0 ^{0}C), Mandya (34.5 ^{0}C), Navasari (35.9 ^{0}C) and Coimbatore (36.0 ^{0}C), in contrast to Akola (42.2^{0}C), Rudrur (40.1^{0}C), Pune (38.3^{0}C), Sameerwadi (38.2^{0}C), Sankeshwar (38.13^{0}C) and Padegaon (37.9^{0}C) experiencing relatively high temperatures. Examination of 61 clones for CCS t/ha for two plant and ratoon crops showed a grand mean CCS of 13.98 t/ha in the zone and differences among the entries could facilitate selection of the best genotypes.

Based on the mean maximum temperatures, the centres were grouped into two categories with a difference of about four degrees in mean temperature. The low temperature region, with a

Table 2. Centres with low and high mean maximum temperature during the period of study in the Peninsular zone

Centre	Low mean maximum temperature ^{0}C	Centre	High mean maximum temperature ^{0}C
Coimbatore	36.10	Rudrur	40.06
Navasari	35.96	Sameerwadi	38.21
Thiruvalla	34.02	Pune	38.33
Mandya	35.36	Akola	42.20
		Sankeshwar	38.13

mean of 35.36^{0}C comprised four centres (Thiruvalla, Mandya, Navasari and Coimbatore) and high temperature region with a mean of 39.54^{0}C comprised six centres (Akola, Rudrur, Pune, Sameerwadi, Padegaon and Sankeshwar) (Table 2). Sugar yield values ranged from 7.33 t/ha in Co 90010 to 19.61t/ha in Co 95007 in low temperature regime and from 10.38 t/ha in Co 94008 to 19.39 t/ha in Co 95012 under warm regime. Among the promising genotypes, 28 types recorded higher CCS at low temperatures, while 33 clones registered an increased sugar yield at high temperature (Fig 1). However, as the data pertained to different years and majority of clones were selections from a particular time period ie. 1994 and 1995, this high *per se* performance might be due the better standard of experimentation and the ideal conditions of growth during these testing periods. Hence percent improvement of the clones at high temperature over that at low temperature was estimated as a better way of comparing genotypes. In all, 33 clones exhibited increased sugar yield at high temperature regime with an improvement of 0.43 (in Co 95012) to 52.35 (in Co 90010) (Fig 2). Among these, 12 clones viz. Co 90010, Co 91005, CoG 93076, Co 94012, Co 92001, Co 91003, Co 0310, Co 85012, Co 92024, Co 93018, Co 95016 and CoC 92061 registered significant superiority and showed promise as high temperature tolerant clones. Three among these, viz. Co 92001, Co 91003 and Co 93018 are backcross hybrids involving *S. robustum* indicating that this species might prove as a potential donor for high temperature tolerance.

A few genotypes viz. CoG 93078, CoC 671, Co 2001-15, Co 0218, Co 92002, Co 0314, CoM 9516, Co 2001-13, CoM 0265, Co 99012, Co 86032, Co 2000-12, Co 2000-10, Co 0212, Co 99004, Co 99006, Co 2000-03, Co 2000-02, Co 95003, Co 94019, Co 95005, Co 95012 and Co 95007 produced high CCS (> GM

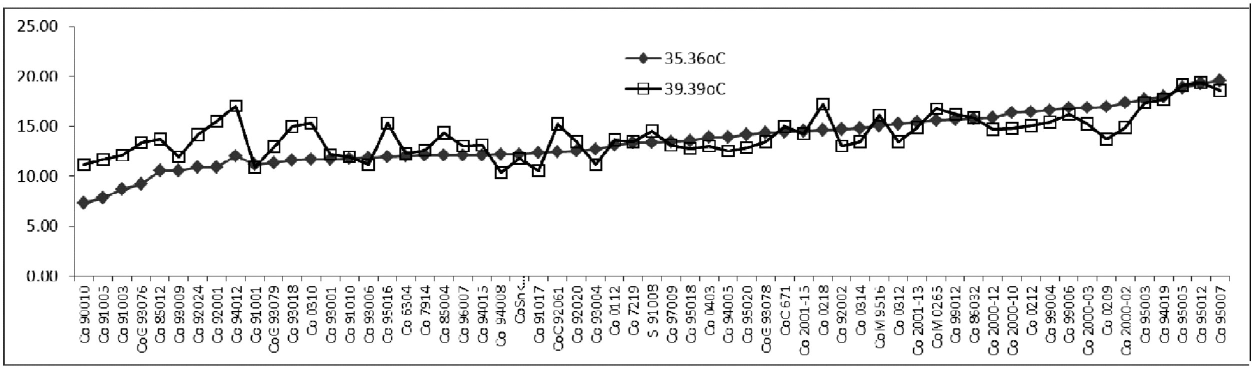

Fig 1. Relative performance for CCS t/ha of 85 genotypes evaluated in centres with low and high temperature in Peninsular zone during 1997-98 to 2009-2010

= 13.98 t/ha) and exhibited insignificant differences in performances at low and high temperature, reflecting their stable performance with wide adaptability, and behavior as thermoinsensitive genotypes. It was also observed that the best genotypes at low temperature viz. Co 95007, Co 95012, Co 95005, Co 94019, Co 95003, Co 99006, Co 86032, Co 99012 and CoM 0265 performed well at high temperature as well (Fig 1). The list included varieties viz. CoC 671, Co 86032, Co 91010, Co 99004, Co 2001-13, Co 2001-15, Co 0218 and CoM 0265 commercialized for the zone. The success of the wonder variety viz. Co 86032 in the peninsular zone and the spread of a recent release CoM 0265 could be attributed to their stability of high sugar yield in the zone. A newly identified genotype Co 99006 can be projected as stable variety yielding high CCS independent of temperature variation observed in tropical India. A look into the parentages of these genotypes indicated that in general, the genotypes developed from the parents viz. CoC 671, Co 7201, Co 740, Co 7717, Co 62174 and Co 658, apart from *S. robustum* performed better at high temperature and as thermo- insensitive types. Genetic diversity and its potential for adaptation are important in genetic improvement for high temperature tolerance. For this purpose, CoC of the clones exhibiting better performance at high temperature (except four clones for which pedigree could not be traced) was examined (Table 3). CoC is one of the estimates extensively used in many crops to identify the genetic diversity between the parents (Martin et al, 1991; Chang 1996; Babu 2004). CoC values range from 0 in cases with no common pedigree to 1 when there is complete similarity. Generally CoC between full sibs and between parent -offspring would be 0.25 and that between second cousins 0.0625. Among the genotypes, all, barring Co 2001-15 (CoC = 0.2859) revealed values below 0.06 indicating less common descent and hence higher genetic diversity. Co 2001-15 has Co 775 as its male parent and the female parent viz Co 85002 again has Co 775 in its immediate pedigree reflecting its high consanguinity. This observation of low CoC of the clones studied was in contrast to the study of Chang (1996) who observed higher CoC values of sugarcane parents, indicating genetic relatedness as full sib or half sibs involving a few common ancestors. However an Indian work with 39 biparental crosses involving new interspecific derivatives and commercial hybrids by Babu (2004)

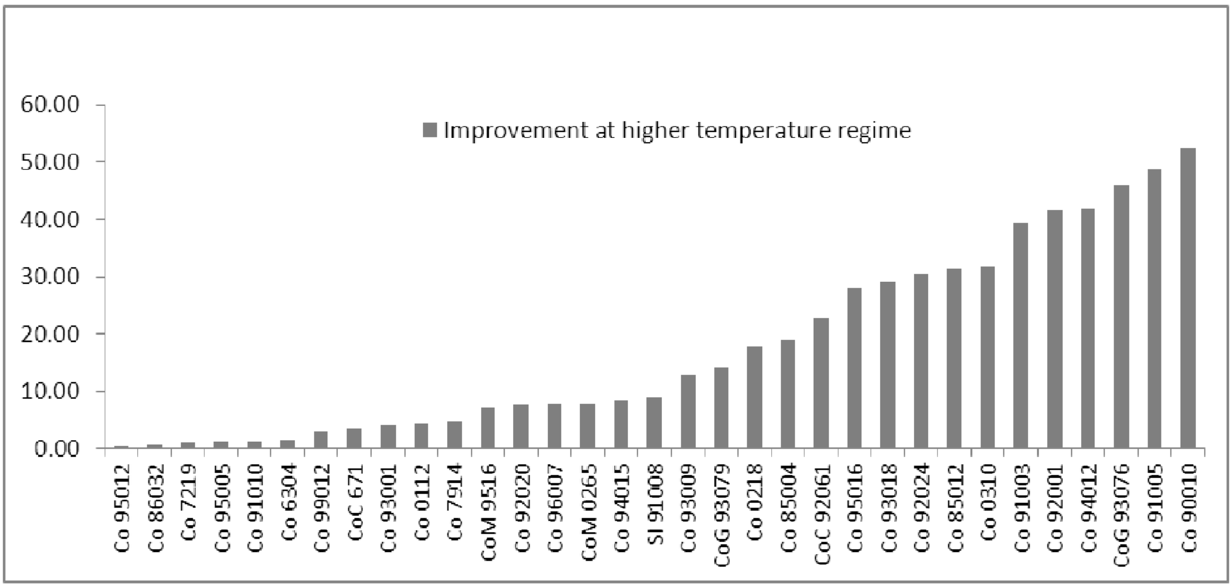

Fig 2. Enhanced performance of 33 genotypes with increase in mean CCS t/ha at high temperature regime

Table 3. Coefficients of parentage of clones that performed better at high temperature and selected clones with stable performance

Sl. No.	Genotype	Parentage	CoC
1	Co 6304	Co 419 x Co 605	0.00781
2	Co 7914	Co 6804 x Co 6304	0.03766
3	Co 85004	Co 6304 x Co 740	0.01623
4	Co 86032	Co 62198 x CoC 671	0.04814
5	Co 90010	Co 7717 PC	0.12988
6	Co 91003	CoC 671-EM 398 x (57 NG 110 X NG 77-28)	0.01562
7	Co 91005	Co 7201 x Co 62174	0.00886
8	Co 91010	Co 312 x Co 775	0.01953
9	Co 92001	[Co 7201 x [CoC 671 X (57 NG 110 X NG 77-28)]	0.00980
10	Co 93001	Co 7201 x Co 7717	0.02069
11	Co 93018	{Co 7201 x [CoC 671 X(57NG 110x *S. robustum*)]}	0.00980
12	Co 94012	CoC 671 somaclone	0.00830
13	Co 95005	[(58NG 45 x Co62174) x (Mont 1555 x NG 77-221)]	0.00027
14	Co 95016	CoC 772 x MS 6847	0.02893
15	Co 99012	CoC 671-TC-1103-2240	0.00830
16	Co 0112	Co 7201 x Co 85002	0.00836
17	Co 0310	CoC 90063 x Co 88013	0.08716
18	CoG 93076	CoC 772 x Co 419	0.05530
19	Co 7219	Co 449 x Co 658	0.00276
20	CoC 671	Q 63 x Co 775	0.00879
21	CoM 9512	?	
22	Co 0218	Co 8353 x Co 86011	0.04809
23	Co 92020	Co 7201 x Co 1307	0.02735
24	CoM 0265	Co 87044 GC	0.04809
25	Co 96007	Co 7201 x Co 775	0.05688
26	Co 94015	Co 6806 x CoC 671	0.00421
27	Si 91008	?	
28	Co 93009	Co 678 x Co 775	0.04736
29	CoG 93079	?	
30	CoC 92061	?	
31	Co 92024	Co 740 x Co 775	0.04809
32	Co 85012	Co 62198 x CoC 671	0.04814
33	Co 95012	Co 88006 x Co 62174	0.01385
34	Co 93006	Co 7201 x Co 775	0.05688
35	Co 95007	Co 88006 x Co 62174	0.01385
36	Co 99006	(BO 91 x Co 62175) x Co 775	0.05127
37	Co 2001-13	Co 7806PC	0.00390
38	Co 2001-15	Co 85002 x Co 775	0.28588
39	CoSnk 03632	Co 8013 polycross	0.01196
40	Co 95020	Co 7407 x (CP 44101 x NG77-94)	0.01250

estimated CoC values to range from 0.0083 to 0.2505. The progeny evaluation of crosses with high and low CoC values led him to conclude that there existed a relationship between the extent of parental divergence of crosses in terms of coancestry and their progeny performance. In this study, the crosses involving the parents of 27 elite clones with CoC below 0.05, as given in Table 3, could be repeated to derive better selections combining increased CCS and high temperature tolerance suitable for the zone.

Further, studies conducted in related crops have clearly showed the role of physiological mechanisms to contribute to heat tolerance in the field. These tolerant mechanisms include higher photosynthetic rates, stay-green and membrane thermo-stability, or heat avoidance as indicated by canopy temperature depression (Cushman and Bohnert, 2000; Fokar et al. 1998; Rosyara et al 2008). Two strategies to be implemented for achieving higher temperature tolerance in sugarcane genotypes include use of temperature tolerant genotypes, including a few elite types identified in the present study and adoption of a physiological breeding strategy with the screening of the populations for physiological and morphological traits such as canopy temperature, leaf chlorophyll, stay green canopy, leaf conductance, number of canes, and biomass etc. than merely breeding for yield *per se.* Studies in wheat have shown that such a strategy increased the probability of productive crosses achieved through additive gene action to tolerate high temperature (Rosyara et al. 2008). Thus the present study while clearly pointing out the varietal response to temperature, identified elite clones with better performance at higher temperature and stable varieties at the two temperature regimes to offer a platform to plan a breeding strategy to develop future sugarcane varieties to address the challenges of global warming.

Acknowledgements

The authors acknowledge the Principal Investigators (Crop Improvement) of AICRP (S) and teams of scientists who compiled the results of the reports from 1997-98 to 2009-2010. Thanks are also due the breeders of the AICRP centres of Peninsular zone for conducting the trials and making available the data for compilation.

References

Al-Khatib, Paulsen (1999) High-temperature effects on photosynthetic processes in temperate and tropical cereals. Crop Sci. 39: 119-125.

Babu C (2004) Family performance of sugarcane (*Saccharum* sp hybrids) for yield, quality and red rot (*Colletotrichum falcatum* Went) resistance and its relationship with genetic diversity based on STMS markers and coancestry of crosses. PhD. Thesis Tamil Nadu Agricultural University, Coimbatore, India

Chang YS (1996) Implication of inbreeding coefficient and coancestry in sugarcane breeding program. Proc. Int Soc Sugar Cane Technol. 22:307-310.

Chikelu Mba, Elcio P Guimaraes EP, Ghosh K (2012) Re-orienting crop improvement for the changing climatic conditions of the 21st century. *Agriculture & Food Security* 1:7.

Cushman JC, *Bohnert HJ (*2000) *Genomic approaches to plant stress tolerance.* Curr. Opin. Plant Biol, 3117-*124.*

Falconer DS, Mackey TFC (1996) Introduction to quantitative genetics. Fourth Edition. Longman Gp Ltd. UK.

Fokar M, Nguyen HT, Blum A (1998) Heat tolerance in spring wheat. I. Genetic variability and heritability of cellular thermotolerance. Euphytica 104:1-8.

Goudriaan J, Van Laar HH (1994) Modelling Potential Crop Growth Processes: Textbook With Exercises Springer, Science pp 238.

Hall AE (1992) Breeding for heat tolerance. *Plant Breed. Rev.* 10: 129-168.

Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL (2008). "Prioritizing climate change adaptation needs for food security in 2030". Science 319 (5863): 607–10.

Long SP, Ainsworth E A, Leakey ADB, Nosberger J, Ort DR (2006) Food for thought: Lower-than-expected crop yield stimulation with rising CO_2 concentrations. Science 312(5782): 1918–1921.

Martin JM, Blakes TK, Hockett (1991) Diversity among North American spring barley coltivars basaed on coefficient of parentage. Crop Sci. 31:1137-1149.

Nelson GC, Rosegrant MW, Jawoo Koo, Robertson R, Sulser T, Zhu T, Ringler C, Msangi S, Palazzo A, Batka M, Magalhaes M, Valmonte-Santos R, Ewing M, Lee D (2009) Climate Change:Impact on Agriculture and Costs of Adaptation. International Food Policy Research Institute. Food Policy report. Washington DC.

Panse VG, Sukatme PV (1954) Statistical methods for agricultural workers. Published by ICAR.

Rosyara UR, Vromman D, Duveiller E (2008) Canopy temperature depression as indication of correlative measure of spot blotch resistance and heat stress tolerance in spring wheat. J. Plant Path. 90:103–107.

Venkataramana S, Gururajrao P, Naidu KM (1986) The effects of water stress during the formative phase on stomatal resistance and leaf water potential and its relationship with yield in ten sugarcane varieties. Field Crops Res. 13 : 345-353.