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Research Article

Sugarcane Disorders Associated with Temperature Extremes and Mitigation Strategies

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Abstract: Sugarcane (*Saccharum* spp.) is an important agro industrial cash crop, providing raw material for different sugar industries and plays crucial role in the economy of several countries. It requires optimum temperature for economic production and causes reduced cane and sugar yields otherwise. Extreme temperatures either low or high causes abiotic disorders like cold / banded chlorosis and sunburn during initial and mid season crop establishment led to yield reduction in sugarcane by affecting its physiology, biochemistry and quality leading to poor agronomic produce in subtropical conditions. Low temperature during winter (December-January) for autumn planting and high temperature during summer (May-June) for spring planting also affects the germination percentage, seedling establishment and ratoonability of early harvested (Nov-Dec) crop. Several breeding and genomics based studies have been conducted to improve the sugarcane production under different stresses in this crop in many areas of the world. The studies on abiotic disorders caused by high and low temperature extremities and their mitigation strategies are scanty. An attempt has been made in this appraisal report to explore sugarcane clones/ cultivars that contribute to adaptation in era of climate change by discovering and introducing desirable genes for agronomic traits using basic breeding methodologies, physiological approaches and new technologies of molecular biology that can mitigate the negative effect of extreme temperature and improve sugarcane yields, productivity and sustainability.

Keywords: Sugarcane, Cold chlorosis, Sunburn, Temperature, Mitigation strategies.

INTRODUCTION

Ever-increasing variability in world climate is threatening the crop production globally due to temperature extremes, drought stress and irregular rainfall patterns. More than 50% yield reductions in arable crops have been accounted due to aforementioned stresses worldwide (Boyer, 1982). Sugarcane is tropical grass widely grown in both hemispheres in over 120 countries worldwide. It is an important agro industrial cash crop, providing raw material for different sugar industries and plays crucial role in the economy of several countries. It requires optimum temperature for economic production and causes reduced cane and sugar yields otherwise. Extreme temperature, more importantly, high temperature causes serious yield reduction in sugarcane by affecting its physiology, biochemistry and quality leading to poor agronomic produce in subtropical conditions. However, low temperature during spring (Feb-March) and autumn (October) planting also affects the germination percentage, seedling establishment and ratoonability of early harvested (Nov-Dec) crop especially in Indian subcontinent. Similarly, high temperature in summer (May-June) cause sunburn disorder that hampers crop growth during tillering and grand growth stages in sprin planted sugarcane. Sugarcane is considered a cold-sensitive plant (Tai and Lentini, 1998) and occupies the tropical and subtropical areas where frost is not a usual phenomenon. Its production is severely affected due to these abiotic and several biotic stresses, thus resulting in reduced cane yields and inferior harvest quality. Having indeterminate growth habit, it bears a complex set of growth pattern which is considered to be severely prone to climatic interactions as well as management techniques with differential response (Neumeister, 2010). Sugarcane plant responds to various stresses differently, depending upon the stress severity and the developmental stage. Among various aforementioned stresses, temperature extremes (high and low temperatures) and water stresses in sugarcane are of key importance as it may cause drastic impact during germination, early growth season, and flowering and maturity stages (Tao *et al.*, 2006, Sanghera and Kumar 2018). As the change in global climate is inclined to cause increase in average temperatures, therefore, high temperature may impact the crop in the form of longer growing seasons, more or fewer rainfalls, and thus a shorter growing period. Whereas, low temperature during the planting time impairs the germination process, oppositely high temperature is also an undesirable feature during planting time. Air temperature is directly related to sugarcane growth and ripening processes. Burr *et al.*, (1957) observed a reduction of 84 % in the rate of sugarcane photosynthesis when air temperature was reduced from 23.0 to 13.6 °C. Waldron *et al.,* (1967) showed that the photosynthetic efficiency decreased linearly with a decrease in air temperature in the range from 34 to 5 °C. The effects of air temperature on the photosynthesis rate and on the efficiency of this process are directly related to crop vegetative development (Alexander, 1973). Accordingly, Stender (1924) demonstrated a close relationship between stalk length and diameter and air temperature, with a reduction in stalk growth rates during the winter to one-third of those observed in the summer. The reduction in stalk growth rates, either in length or diameter, is followed by an increase in the rate of sucrose accumulation (Mamet and Galwey, 1999). Temperature stress in terms of both cold and heat stress induces differential metabolic and physiological responses in sugarcane, through alterations in plant photosynthetic performance, oxidative balance, normal protein synthesis, stomatal closure, membrane damage, lipid peroxidation and carbohydrate production (Roy *et al.,* 1996, Levitt, 1980, Bibi *et al.,* 2008). In consequence, various stress responsive mechanisms are triggered by molecular networks to stabilize the internal homeostasis by protecting and repairing of damaged membranes and proteins (Reddy *et al.,* 2004). Meanwhile, certain heat shock proteins and antioxidant enzymes get activated to combat with induced oxidative and membrane damage within the plant body, resulting in plant tolerance to imposed stress. Still a number of key molecular and physiological mechanisms involved in this homeostasis stabilizing process are under way to find. Several breeding and genomics based studies have been conducted to improve the sugarcane production under high and low temperature stress in this crop. Here an attempt is made to explore recent advances in breeding and physiological approaches coupled with new technologies of molecular biology that can mitigate the negative effect of extreme temperature in sugarcane crop.

Sugarcane Climatic Requirements and Phenology

Sugarcane requires large sunny days, which should synchronise with the sufficient amount of water, with an optimum temperature on a reasonably longer growing period. Crop need about 33-38 °c temperature, 56 % relative humidity and winds, which are neither desiccating nor very cold for the successful germination. The south Indian conditions are favourable for the year round planting but in North India the conditions required for germination can be met during spring and autumn seasons (Sanghera and Sharma, 2011). For optimum grand growth, relative humidity must increase above 60 to 70 percent and the differences in diurnal temperature should not exceed 10 to 15°C. However for optimum maturity, the diurnal differences may be above 20° C, subject to the lower limit at 8 to10^0 C. Temperatures below this point effects the recovery of sugar from cane adversely. It being a C_4 photosynthetic plant is known to utilize the greater amount of solar radiation and ranks high in dry matter production and yield. However the nature of response to the intensity of the sunlight depends upon the incidence and duration of light, crop age and other environmental factors. Development of sugarcane model of crop growth requires quantitative understanding of the key parameters which driving the phonological development. Temperature is the primary factor which driving shoot emergence, leaf appearance and stalk elongation of sugarcane (Inman·Bamber, 1994). The most important stages of the phonological development in sugarcane are shoot emergence and stalk appearance. Emergence covers the period from planting until shoot appearance above ground and is characterized by the biochemical conversions of carbohydrate reserves in the cuttings.

The time required for this phase varies and depends on the air temperature and soil moisture (McMahon *et al.,* 199). There is no carbon assimilation during this period. After the emergence and before the appearance of any stalk, carbohydrates produced in the photosynthesis are mainly partitioned to develop leaves and root systems. After stalk appearance, carbohydrates are increasingly partitioned into structural dry matter and sugar accumulation in the stalks. Thus carbon-partitioning coefficients in the sugarcane growth model vary as a function of the phonological development of crop (Wyseure *et al.,* 1994). Development of leaf canopy in sugarcane is slow compared to canopy development of annual grain crops. The development of the sugarcane ratoon canopy may be viewed as a process of development depends on the emergence of tillers from the soil and leaves from the whorl of each tiller canopy development thus depends on the rates of tillering, leaf appearance, leaf extension and size of the each leaf. Various methods have been used for modelling the crop phenology. Thermal time has been used to predict the leaf appearance in sugarcane crop in a variety of ways. Bacchi and Sousa (1977) obtained a base temperature of 19 degree Celsius from stalk height measurements. Stalk elongation was delayed 100 days when sugarcane was subjected to 18 degree instead of 30 degree constant temperature. Barnes (1974) noted a base temperature of 12°C for germination. Ferraris *et al.,* (1994) used a base temperature of 15°C to determine the TT requirement for leaf emergence in sugarcane (also known as the phyllochron interval or index, PI). This requirement increased with the increase vapour pressure deficit and water stress. The most commonly used method is the calculation of thermal time, the accumulation of the mean daily temperature above the base temperature.

Critical Growth Stages of Sugarcane

Although sugarcanes produce seeds, modern commercial sugarcane cultivation relies on vegetative propagation through stem cuttings which has become the most common reproduction method. Sugarcane has essentially four-growth phase's viz., germination phase, tillering (formative) phase, grand growth phase, maturity and ripening phase. A brief understanding of these growth phases would help in better management of the crop. Under field conditions germination starts from 7 to 10 days and usually lasts for about 30-35 days after planting (DAP). In sugarcane, germination denotes activation and subsequent sprouting of the vegetative bud. The germination of bud is influenced by both external as well as internal factors. The external factors are the soil moisture, soil temperature and aeration. The internal factors include the bud health, sett moisture, sett reducing sugar content and sett nutrient status. Tillering starts from around 40 DAP and may last up to 120 days. Tillering is a physiological process of repeated underground branching from compact nodal joints of the primary shoot, providing the crop with appropriate number of stalks required for a good yield. Various factors viz., variety, light, temperature, irrigation (soil moisture) and fertilizer practices influence tillering. Early formed tillers give rise to thicker and heavier stalks. Late formed tillers either die or remain short or immature. Cultivation practices such as spacing, time of fertigation, water availability and weed control influence tillering. Encouraging good tillering is important to build adequate population. Grand growth phase starts from 120 DAP and lasts up to 270 days in a 12-month crop. During the early period of this phase tiller stabilization takes place. Out of the total tillers produced only 40-50% survives by 150 days to form millable cane. This is one of the most important phase of the crop where in the actual cane formation and elongation and thus yield build up takes place. Under favourable conditions stalks grow rapidly almost 4-5 internodes per month. Ripening and maturation phase in a twelve-month crop lasts for about three months starting from 270-360 days. Sugar synthesis and rapid accumulation of sugar takes place during this phase and vegetative growth is reduced. As ripening advances, simple sugars (monosaccharide viz., fructose and glucose) are converted into cane sugar (sucrose, a disaccharide). Cane ripening proceeds from bottom to the top and hence bottom portion contains more sugars than the top portions. Ample sunshine, clear skies cool nights and warm days (i.e., more diurnal variation in temperature) and dry weather are highly conducive for ripening.

Climate Change and Crop Growth Alterations

Climate variability and its impact on economy are now under serious national and international political dialogue. To address this problem effectively there is a detailed understanding of the adverse effect of climate change and climatic variability on agriculture is essential. Moreover, timing, magnitude and special variability of these adversities is also having paramount importance, because of the high heterogeneity exists across different agro-ecosystems. As we know agro-ecosystem is a man made ecosystem evolved by the interaction, modification and adaptation among the three major sub sets, physical, biological and socio-economical. A sustained increase in temperature along with a high inconsistency in inter-intra seasonal temperature is modifying the physical environment of agro-ecosystems. So it is necessary to evaluate and understand the likely hood changes that taking places or going to takes place in the inter-phase of these sub sets. The rising temperatures and carbon dioxide and uncertainties in rainfall associated with global climatic change may have serious direct and indirect consequences on crop production and hence food security (Sinha and Swaminathan 1991). We recently witnessed such an impact of climatic events on food availability in 1998 in the form of a crisis of onions, potatoes, cauliflower and tomato, which triggered some unprecedented social and political impact. This crisis has once again demonstrated how little we understand the integrated relationships of weather and agriculture and how little we have developed the backup for policy support in such unfortunate and unforeseen circumstances. It is, therefore, important to have an assessment of the direct and indirect consequences of global warming on different crops contributing to our food security. Agricultural productivity can be affected by climate change in two ways: one, directly, due to changes in 'temperature, precipitation or CO_2 levels and two, indirectly, through changes in soil, distribution and frequency of infestation by pests, insects, diseases or weeds (**Fig 1**). In tropical Asia, although wheat crops may be sensitive to an increase in maximum temperature, rice crops might be vulnerable to increased minimum temperature. It is known that CO_2 influences the photosynthetic processes, whereas the temperature influences all aspects of crop growth, development and water and nutrient use (Baker and Allen 1993). CO_2 is vital for photosynthesis, and the evidence is that increases in CO_2 concentration would increase the rate of plant growth.

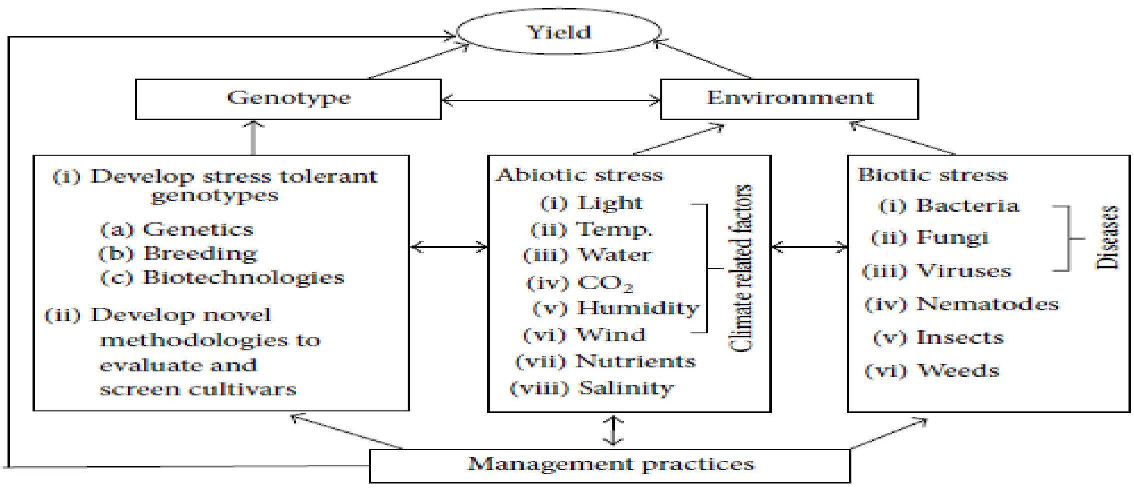

Fig 1: A flow chart with major factors (genotype, environment, and management practices) and their interactions influencing sugarcane yield.

Photosynthesis is the net accumulation of carbohydrates formed by the uptake of CO_2, so it increases with increasing CO_2. A doubling of CO_2 may increase the photosynthetic rate by 30 to 100%, depending on other environmental conditions such as temperature and available moisture. More CO_2 enters the leaves of plants due to the increased gradient of CO_2 between the external atmosphere and the air space inside the leaves. This leads to an increase in the CO_2 available to the plant for conversion into carbohydrate (Acock and Allen 1985). The difference between photosynthetic gain and loss of carbohydrate by respiration is the resultant growth just as important may be the effect that increased CO_2 has on the closure of stomata, small openings in leaf surfaces through which CO_2 is absorbed and through which water vapour is released by transpiration. This tends to reduce the water requirements of plants by reducing transpiration (per unit leaf area) thus improving what is termed water use efficiency (the ratio of crop-biomass accumulation to the water used in evapotranspiration).

Effects of Temperature Stress on Sugarcane

Sugarcane requires optimum temperature for economic production and led to reduced cane and sugar yields otherwise. Extreme temperature, more importantly, high temperature causes serious yield reduction in sugarcane by affecting its physiology, biochemistry and quality leading to poor agronomic produce. Low temperature at planting also affects the germination percentage, seedling establishment and ratoonability of early harvested crop. Several studies have been conducted to improve the sugarcane production under high and low temperature stress in this crop. Air temperature is directly related to sugarcane growth and ripening processes. Waldron *et al.*, (1967) showed that the photosynthetic efficiency decreased linearly with a decrease in air temperature in the range from 34 to 5 °C. The effects of air temperature on the photosynthesis rate and on the efficiency of this process are directly related to crop vegetative development.

Accordingly, Stender (1924) demonstrated a close relationship between stalk length and diameter and air temperature, with a reduction in stalk growth rates during the winter to one-third of those observed in the summer. The reduction in stalk growth rates, either in length or diameter, is followed by an increase in the rate of sucrose accumulation (Mamet and Galwey, 1999). Alexander (1973) described the process of sugarcane physiological ripening as dependent on the seasonal reduction of air temperature, which slows growth rates. However, this reduction in growth rates occurs without significantly affecting the photosynthetic process, so that there are more photosynthates converted into sucrose to be stored in plant tissues. Cardozo (2012) noted an inversely proportional relationship between air temperature and sugarcane ripening, with higher correlation coefficients observed when the air temperature was averaged in the last 120 to 150 days before sampling, which agrees with Clement (1962) findings. Glasziou *et al.*, (1964) showed that high sugar content was produced when the air temperature was reduced over a long period of time. According to Glasziou *et al.*, (1964), the sugar concentration did not exceed 12 % of the fresh weight when the air temperature was constant or when small daily temperature variations occurred. However, when the average air temperature was reduced for a long period of time, i.e., three to six months, sugar concentration reached 17 % of the fresh weight.

There is no consistency regarding the thermal parameters of sugarcane, primarily related to base temperatures, since there are numerous base temperature values proposed, which may vary according to the location, cultivars and phenological phase (Scarpari and Beauclair, 2004, 2009). Barnes (1964) found that the base temperature for shoot emergence is 12 °C, while Inman-Bamber (1991, 1994) found a base temperature of 16 °C for tillering. Bacchi and Souza (1977) reported values between 18 and 19 °C for the internode elongation process. Cardozo (2012) evaluated eight sugarcane cultivars and found variation of their base temperature, with the earliest cultivars (SP91-1049 and SP86-155) exhibiting higher values, between 20 and 21 °C, while the middle (RB867515) and late ripening cultivars (SP83-2847) exhibited smaller values, between 18 and 19 °C. According to Cardozo (2012), this fact explained the precocity of some cultivars in relation to others because the higher the base temperature, the smaller the growth under low air temperatures. Late cultivars are less sensitive to low air temperature than the early ones; thus, they continue their growth for longer periods, delaying their ripening. Sugarcane being evolved in tropics is sensitive to low temperature injury (10-15^{0}C). Generally, the tropical species when grown in warm climates i.e. temperature ranging from 25^{0}C-35^{0}C are more prone to chilling than temperate species. Chilling and freezing both affect plant growth and development (Thomashow 2010, Sanghera and Sharma 2011). The optimum temperature for sugarcane growth is 35^{0}C (Grantz *et al.*, 1987). In some sugarcane growing countries like USA, north India, Pakistan and Australia the crop receives low temperature (< 20^{0}C) which severely reduced the growth of sugarcane plant. Low temperatures changes hormone production in plants. Out of different hormones cytokinins have a large effect on senescence of plant parts (Mikkelsen *et al.*, 2004) and involved in change of metabolism and morphological characters in response to environmental stimuli (Sakakibara 2006).

Sugarcane Growing Seasons and Temperature Extremes with Special Reference to Punjab

In Northern India, April marks the beginning of summer season and it goes on until June. During peak season, the minimum temperature the state experiences is around 29°C and the maximum it touches is 45°C. The corresponding figures in Punjab remain around 42^{0}C and 26^{0}C, respectively (**Fig 2**). One can deduce the summers are extreme here and it is wise to avoid late planting of sugarcane in Punjab during the crop season. If one happens to go for late planting in Punjab at the beginning of the season, they might be able to witness the severe sun burn disorder in sugarcane in May-June months. Similarly, winter season starts taking over the monsoon season from October onwards, and it lasts until mid March.

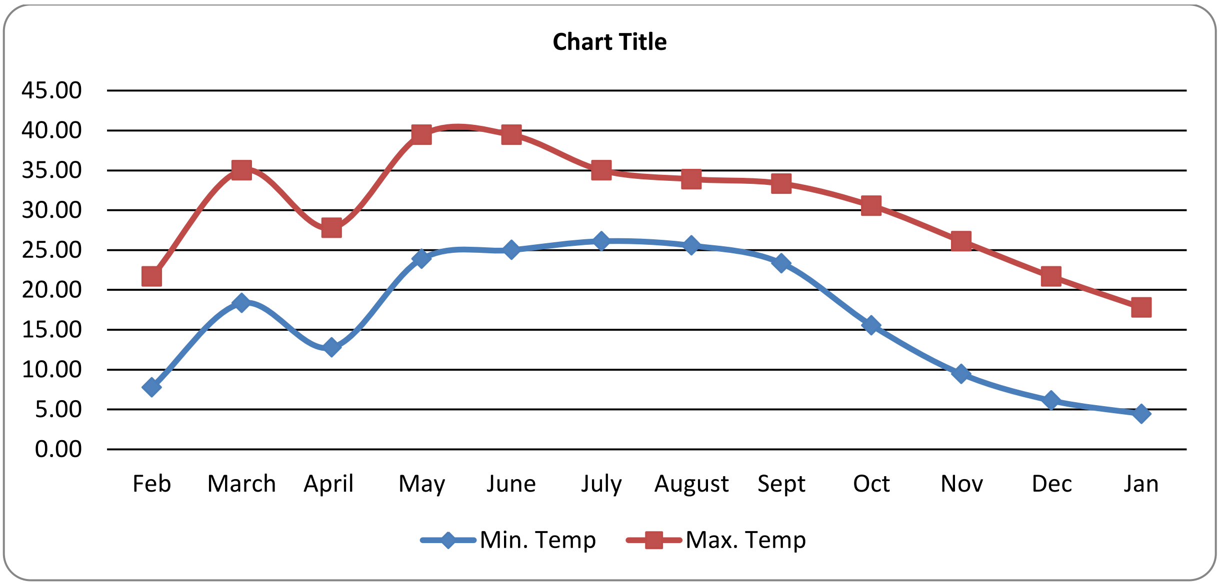

Fig 2. Mean monthly temperature (max. and min.) during 2019-20 crop seasons in Punjab

The weather remains soothing and pleasant at the beginning of the season facilitating sugarcane planting after harvesting of paddy crop. The day-time temperature stays around 26°C while during the night; it drops down to less than 10°C. Sometimes different regions of the state also experience less than 5°C especially sugarcane growing districts Amritsar, Gurdaspur, Hoshiarpur and Jalandhar. Farmers who explore autumn season as comparatively better time for planting of sugarcane in Punjab experience problem of cold/ banded chlorosis in sole and inter cropped sugarcane crop.

Abiotic Disorders in Sugarcane

Sugarcane is a long durational crop, which experiencing extreme weather conditions throughout its life cycle in sub tropical part of India. There are various biotic and abiotic stresses faced by this crop during their growth period and maturity. Many diseases caused by fungi, bacteria, viruses and phytoplasmas as well as environmental and physiological stresses cause immense quantity and quality loss of this crop worldwide. The climate change will lead to more extreme events for rainfall patterns and change in temperature patterns (Nelson *et al.*, 2010). The changes in temperature, rainfall and solar emission patterns affect the productivity and sugar content of sugarcane in both up and down stream. Tremendous change in environmental temperature (low or high) effects to physiological mechanism in sugarcane and symptoms of any stresses firstly appears on leave. The two important physiological / abiotic disorders of sugarcane crop manifested as result of extremities in temperature include cold or banded chlorosis and sun burn or sun scald are described.

Manifestation of Banded or Cold Chlorosis

The banded or cold chlorosis or cold injury is especially a physiological disorder which appears due to cold temperature. Its symptom first appeared in the research farm of Guneid, Sudan on the cane variety B 47419 during the year of 1999 (Marchelo *et al.*, 1999). It occurs on cane leaves due to both high as well as low temperature (Martin *et al.*, 1964). Banded chlorosis has been noticed earlier in tropical region of Maharashtra, India during 2nd week of March 2011, when the minimum temperature ranged from 10^0C to 12^0C in throughout December-January resulted in such abnormality as the most popular tropical commercial cultivars Co 86032 and CoC 671 affected by banded chlorosis (Web report of VSI, Pune). Under subtropical conditions, the minimum temperature remained below 5^0C from last week of December to third week of January (Fig 3) during 2019-20 winter seasons, which resulted in such abnormalities.

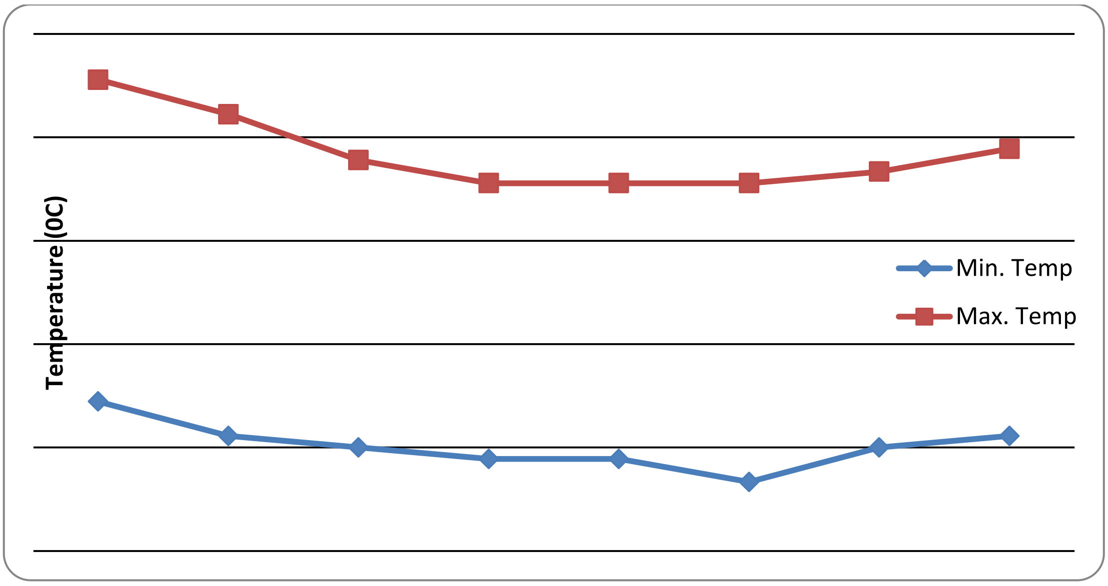

Fig. 3 Average weekly temperatures (max. and min.) during crop seeason in months of December-January (2019-20)

Symptoms generally consist of chlorotic tissues extending across the leaf on both sides of the midrib. The colour varies from yellow green to white, and in some cultivars a pinkish tinge may develop. The area ranges from narrow stripes on each margin of leaf to bands of 50 to 100mm broad. The symptom of the disorder appears on cane leave due to the low temperature (8-10^{0}C) during January to March in autumn planted crop. The chlorotic bands are possible near the base of older leaves **(Fig 4)** and progressively closer to the tips of the successively younger leaves, indicating that injury occurred in spindle before the affected leaves unrolled. These types of symptoms were first observed in Puerto Rico on the leaves of sugarcane variety PR 1059 at Central Aguirre. The prominent bands of chlorosis on the sugarcane leaves termed as "cold chlorosis" (Faris, 1926) or "sectional chlorosis" (Newcomb and Lee, 1927) but in general the broadly termed as "banded chlorosis".

Fig 4: Effect of low temperature showing banded/ cold chlorosis in CoJ 88 sugarcane variety during Dec-Jan 2020

It is caused primarily by injury due to cold weather and is indicated by narrow bands of pale green to white tissue across the leaves. Waraitch and Kanwar (1977) reported firstly in sugarcane clone from North India in the state of Punjab. They observed the symptoms of banded chlorosis on a sugarcane clone S-98/70 due to severity of low temperature (minimum 0.5^{0}C). None of the other clones or varieties was affected by this symptom in 1977.

In Punjab state, 9 sugarcane varieties namely CoPb 92, Co 0118, CoJ 85, CoJ 64 (in early group) and CoPb 93, Co 0238, CoPb 91, CoPb 94 and CoJ 88 (midlate group) have been recommended for commercial cultivation. Farmers are planting these varieties in both autumn and spring seasons irrespective of maturity group. Variable response commercial varieties to cold / banded chlorosis were reported in different command areas of sugarmills running in the state. Of the nine cultivars, Co 0238 exhibited severe cold/ banded chlorosis symptoms in Gurdaspur, Pathankot and Hoshiarpur districts adjoining shivalik foothills followed by CoJ 88, CoJ 85, CoPb 94. It was observed that the broad leaved and fast growth habit varieties showed more leaf burning than narrow leaved varieties like CoPb 92, Co 0118 and CoJ 64. Further, autumn planted crop showed pronounced effect of cold chlorosis. In autumn planted cane, the cold damage was observed from 3 to 4 leaf stage. It was found that the varieties CoPb 92 and Co 0118 having anthocyanin pigmentation in leaves (Fig.6) were not prone to this disorder.

Fig 5: Differential response of sugarcane varieties toward banded/ cold chlorosis

Earlier, Singh *et al.,* 2017 also observed such abnormalities of banded chlorosis on commercial cultivars at Sugarcane Research Institute, Shahjahanpur (UP), representing sub-tropical region of India. In general, it was observed that earlier among different varieties grown in Punjab, early maturing varieties like CoPb 92 and Co 0118 have tolerance to cold and advised for autumn planting and varieties Co 0238, CoPb 93 and CoPb 94 for spring planting. Further, Brar *et al.,* (2018) documented some physiological and biochemical indicators for cold tolerance in sugarcane and reported significant differences in chlorophyll content, leaf colour and bud necrosis before and after cold stress. They reported that clones selected as cold sensitive showed significant decline in chlorophyll and carotenoids content in comparison to tolerant genotypes. Differential behaviour of physiological and biochemical parameters indicated that these parameters may serve as novel screening criteria for selecting tolerant and sensitive genotypes under cold stress. Since the sugarcane crop is harvested during wither months, cold chlorosis may affect the ratoon during initial establishment of crop. Hence, there is need to have a separate breeding Programme for cold tolerance along with some mitigating strategies for this disorder needs to be advised to tackle consequences.

Manifestation of Sunburn or Sunscald

There are two main kinds of sun damage in the plant world: sunburn (also called leaf scorch), which affects the foliage, and sunscald, which affects the bark. Sunburn occurs in plants for like it does in people – too much light and heat, with increased risk when dehydrated. But unlike us, the sunburned plants don't immediately turn pink. Sunburn injury on sugarcane leaves is an abiotic disorder caused by high temperature combined with hot waves during summer. It is evident from data presented in **Fig 5** that maximum weekly temperature prevailed more than 39^{0}C for a period of three weeks thereby causing severe sunburn disorder in sugarcane crop as it coincide with beginning of grand growth stage of the crop.

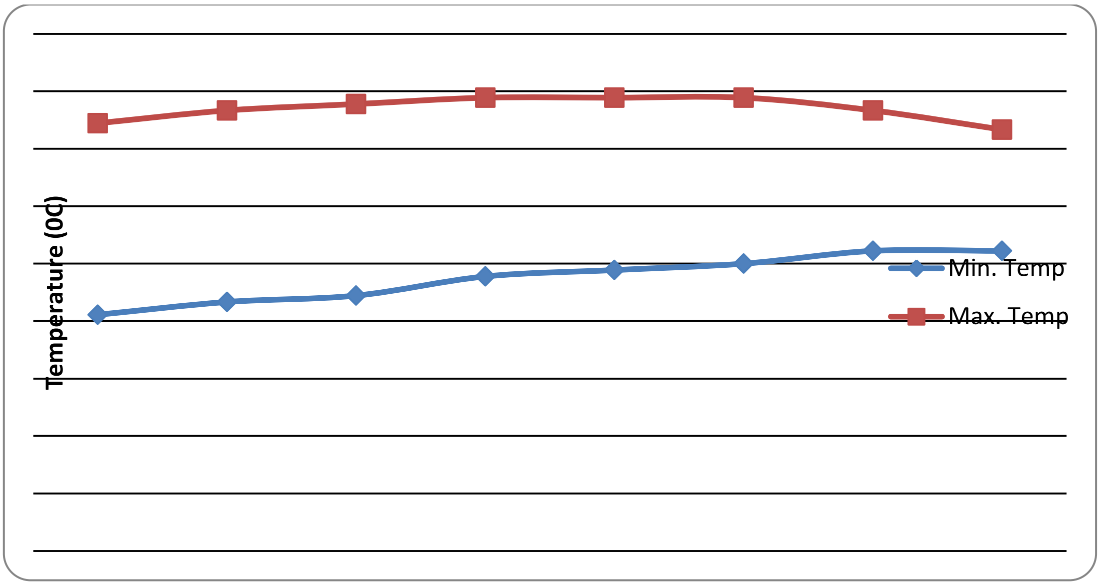

Fig 6. Average weekly temperatures (max. and min.) during crop seeason in months of May-June 2019

Sunburn symptoms includes drying of leaf lamina initially on the leaf apex of newly unfurled leaf i.e. on the first top visible leaf and then progressed towards the middle of leaf lamina (Fig. 6). Initial drying of fully expanded young leaves is higher than on the newly emerged folded leaves. The affected leaf lamina remained pale green for 2–3 days and then parched. In the injured leaves, drying appeared from leaf apex to near bottom. Often the bottom one fifth portion of injured leaf lamina did not dry and remained green. Under continued high temperature and hot waves without rainfall, the newly emerging unfurled leaf which is just above the already injured leaf gets dried in the same manner. The injured leaves did not regain hence the injury was irreversible. The sunburn symptom described above is different from 'sugarcane leaf scorch' caused by *Leptosphaeria* (Kaiser and Hawksworth 1979) and 'leaf scald' caused by *Xanthomonas albilineans* (Roh 1994) but resemble the photo-oxidative sunburn injury of apple (Felicetti 2008). Further, in subtropical states (Punjab, Haryana and UP) the incidence of sunburn appeared from 3rd or 4th week of May provided if the maximum air temperature was above 39 ^{0}C and if no precipitation during the two preceding and succeeding weeks. However, if the mean maximum temperature subsided below 39 ^{0}C or one or two precipitation occurred, as happened in the last week of June to 1st week of July, the newly opened leaf did not manifest injury. Sunburn injury in cucumber and paprika fruits was reported to occur if the air temperature is 38-40 ^{0}C and 40.5-42.5 ^{0}C, respectively (Piskolczi and Racsko 2004). The threshold temperature for sugarcane sunburn reported in the present study (39 ^{0}C and above) corroborate with previous reports. The damage can take longer to become apparent, and results in yellow or brown foliage. If the damage progresses, the leaves die off starting in the areas between the leaf veins.

Fig 7. Effect of high temperature showing tip sun burn in Co 0238 variety in Punjab during June

Differential response commercial varieties to sunburn were noticed during survey in different command areas of sugarmills running in the state. Of the nine cultivars mentioned above (in banded chlorosis section), Co 0238 exhibited severe sundurn symptoms. It was observed that the broad leaved and fast growth habit varieties Co 0238, CoPb 93and CoPb 91 experienced more leaf burning than narrow leaved varieties like CoPb 92, Co 0118 and CoJ 64. Further, plant crop showed pronounced effect of sunburn as compare to ratoon crop. In autumn and spring planted cane, the sun burn damage was obseved from 6 to 8 leaf stage and continued till the crop attained 10–12 leaf stage. In earlier study, Karuppaiyan et al (2014) evaluated one hundred twenty clones and categorized them as tolerant, moderately tolerant and susceptible showing the variable response of varieties for sunburn disorder. Among different varieties grown in Punjab, only one variety Co 0238 showed high extent this disorder, hence, there is no need to have a separate breeding Programme, and however some mitigating and adaptation Strategies for this disorder needs to be advised to tackle consequences of monoculture of such commercial variety.

Mitigation and Adaptation Strategies

Since climate change is projected to reduce sugarcane yields in the next century, it is vital to come up with mitigation strategies that can lower the effects. A number of mitigation measures can be drawn from understanding the potential effects of climate change relying much on climate models. However, the projections of climate change using models are uncertain because of errors that may be encountered in these models (Mall *et al.,* 2004). Several breeding and genomics based studies have been conducted to improve the sugarcane production under adverse conditions in this crop. There an attempt is made to explore different agronomical cum physiological approaches to mitigate the harmful effects of extreme climatic conditions coupled with multiple breeding and molecular approaches to enhance the genetic potential of sugarcane for tolerance through marker assisted selection or transgenic approaches.

Agronomical Strategies

To adopt abiotic stresses, strategies should be applied according to site-specific conditions. Like, growing the verities of thick cuticle and waxy surfaces that can reflects solar radiation to reduce the impact of heat stress (Bonnett *et al.,* 2006). Water stress generated by high temperatures and low rainfall can be mitigated by growing varieties that are tolerant or resistant to drought. Inman-Bamber *et al.,* (2012) reported that sugarcane cultivar differences in drought adaptation exist. Researchers should therefore continue to breed sugarcane varieties or cultivars that adapt to drought conditions or greater water use efficiency (Matthieson 2007). Irrigation scheduling based on plant-needs accessed with canopy temperature sensors can also play a crucial role in ameliorating the negative impact of temperature and drought stress (White and Raine 2008). So, adaptation strategy to low rainfall due to climate change is to invest in irrigation infrastructure like dams, canals and pumps (Matthieson 2007, Parry *et al.,* 2004) and drip irrigation (Koehler *et al.,* 1982). India like other developing countries is trailing behind in irrigation development as most of its infrastructure is not working after its land reform. However, investment in irrigation development will reduce the likely competition of water resource between sugarcane production and other sectors. Besides increasing irrigation infrastructure, it is essential to increase the efficiency of irrigation (Matthieson 2007). High irrigation efficiency will save water in the midst of low rainfall and also reduce cost of production when yields are expected to be low due to moisture stress. Exogenous application of natural and synthetic plant growth regulators (Waqas *et al.,* 2017) is an important and quick agronomic approach to reduce the negative impact of temperature stress.

Some mitigation and adaptation strategies for climate change in sugarcane production in Zimbabwe have recently been proposed (Chandiposha 2013) and these mitigation strategies included planting drought tolerant varieties, investing irrigation infrastructure, improving irrigation efficiency and drainage systems, and improving cultural and management practices. Sugarcane breeders and other scientists can develop computer data base to design hybridization (within or between species) for special requirement in the breeding programs, use growth and physiological traits to screen elite clones for resistance/tolerance to biotic and biotic stresses (Inman-Bamber *et al.,* 2012, Sanghera and Kumar 2018), and use tissue culture, molecular biology, and gene transformation technologies to improve breeding and selection efficiencies (Sanghera *et al.,* 2016). Studies have shown that some genotypes/ cultivars are better than others in tolerance to water deficit (Inman-Bamber *et al.,* 2012, da Silva *et al.,* 2012, Zhao *et al.,* 2013, Sanghera *et al.,* 2018) and low temperature (Sanghera and Sharma 2011) stresses, in radiation use efficiency [De Silva and De Costa 2012), and in nutrient use efficiency (Robinson *et al.,* 2007, Zhao *et al.,* 2014). Based on pot and field studies with intensive measurements of physiological, growth, and yield traits, it has been reported that some sugarcane genotypes are more tolerant to stress environment than others (Zhao *et al.,* 2013, 2014, 2015).

Physiological Approaches

Sugarcane is an important industrial crop and the world's major C_4 crops that mainly grown in the tropical and sub-tropical regions for sugar and bioenergy. Weather and climate related events (i.e., growth environment of atmospheric CO_2, temperature, precipitation, and other extreme weather) are the key factors for sugarcane production worldwide, especially in many developing countries. The potential negative impact of climate change, especially temperature and rainfall, on sugarcane production in Zimbabwe has been reviewed by Chandiposha (2013). By using crop simulation models, Marin *et al.,* (2013) reported that climate change improved sugarcane water use efficiency and cane yield in some areas of Brazil. They predicted that cane yield in 2050 could be 15–59% higher than that at the current average level. Studies have also indicated that elevated CO_2 under controlled environment increased sugarcane photosynthesis, water use efficiency, biomass, and productivity (Vu and Allen 2009, de Souza *et al.,* 2008). Improved water use efficiency of sugarcane under elevated CO_2 is mainly associated with the reduced stomatal conductance (Vu and Allen 2009a, b). Although these findings from the controlled environment are important for better understanding of physiological mechanisms of sugarcane plant response to elevated CO_2, they may not completely reveal the interactions of CO_2 and other climate factors under field conditions. The most significantly positive effect would be on reduced incidence of frost, which is a major limitation on production (Chakraborty *et al.,* 1998) in most regions, such as Louisiana of USA, Punjab Haryana, UP and Rajasthan states of India where growing season is short. When realizing these benefits, however, serious consideration for long-term negative impact on nutrient levels, soil moisture, water availability, and other conditions. A negative effect of increased temperature may occur in the tropical regions where cool winters are required to slow plant growth and increase sucrose storage. Brar *et al.,* (2018) practised selection on the basis of significant differences in chlorophyll content, Brix° content (total soluble sugars), leaf colour and bud necrosis before and after cold stress and reported genotypes selected as cold sensitive showed significant decline in chlorophyll and carotenoids content, proline content, total soluble sugars and free amino acids in comparison to tolerant genotypes. They suggested that differential behaviour of physiological and biochemical parameters may serve as novel screening criteria for selecting tolerant and sensitive genotypes under cold stress.

Biotechnological Approaches

Sugarcane is cultivated in tropical and subtropical regions where cold stress is not very common, but lower yields and reduced industrial quality of the plants are observed when it occurs. Further, it being a typical glycophyte, exhibits stunted growth or no growth under adverse conditions like salinity, with its yield falling to 50% or even more as compared to its true potential (Akhtar and Rasul 2003, Wiedenfeld 2008). High adversities in environment significantly affects plant growth due to alterations in water relations, ionic and metabolic perturbations, generation of reactive oxygen species (ROS), and tissue damage (Patade *et al.*, 2011a), enzymes involved in sugar metabolism (Gomathi and Thandapani 2005) and respond with an altered expression of stress responsive genes, which may ameliorate the detrimental effects. Therefore construction of cDNA libraries enriched for differentially expressed transcripts is an important first step in attempting to study stress responsive genes.

Endogenous level of cytokinin was increased in sugarcane plant by transforming it with isopentenyl transferase gene (*ipt* gene) under control of cold inducible gene promoter COR15a and plant response as evaluated by subjecting it to low temperatures. Chlorophyll content, lipid peroxidation and ion leakage were used to evaluate the effect of the enhanced transcription of the *ipt* gene in sugarcane leaves under low temperatures. Total chlorophyll content in leaves of transgenic plants was higher than non transgenic plants. Which indicate that senescence was reduced in transgenic plants due to enhanced transcription of *ipt* gene. The damage to cell wall was measured by evaluating the concentration of malondialdehyde (MDA) and electrolyte leakage. Lower malondialdehyde content and electrolyte leakage indicated less damage induced by cold in transgenic plants (Belintani *et al.,* 2010). The expression of cold related genes can be regulated at transcription or translational level.The transcription of cold responsive genes can be regulated by C-repeat binding factors (CBFs) which activate the downstream genes by binding to dehydration responsive elements (DREs) in promoter region of genes. This pathway is called as ICE (inducer of Crepeat binding factor expression 1)-CBF-COR pathway. Reports are available on role of miRNA in cold tolerance.RNA interference has emerge as a novel mechanism for gene regulation. MicroRNA are the central components of this regulatory pathway. MiRNAs are small endogenous RNAs (having length of 20-25 nucleotides), (Zhang *et al.,* 2006) which regulate the expression of gene by cleavage of mRNA thereby repressing the translation (Rubio-Somoza *et al.,* 2009). This type of gene regulation is essential for normal plant growth and development (Rubio-Somoza *et al.,* 2009) as well as their adjustments to different stress conditions (Ding *et al.,* 2009). The plants modifies the abudance of mRNA in the cell by up or down regulating the related miRNAs thereby regulating the plant's response to the different stresses (Saini and Sunkar 2009). The repression of miRNA could enhance accumulation of mRNA of target gene resulting in positive regulation of stress tolerance (Sunkar and Zhu 2004). Thiebaut *et al.*, (2012) studied the differential expression of 12 miRNAs by subjecting the sugarcane plants to low temperature (4^0C). Stem-loop RT-PCR was used to study the expression assay of these miRNAs. It was shown that miR319 was upregulated in both roots and shoots of sugarcane plant exposed to low temperature. Two target sites of miRNA319 were identified as *Myb* transcription factor (*GAMyB*) and a TCP transcription factor (PCF5) using a 5-RACE PCR.

Up regulation of miRNA319 and down regulation of these two genes were observed when two sugarcane cultivars tolerant and sensitive to cold stress were subjected to 4°C. In cold tolerant variety the changes in expression were delayed as compared to sensitive variety. These observations led to the conclusion that that time differences and expression levels of miRNA and its targets could be used as markers for selection of cold-tolerant sugarcane cultivars. Yang *et al.*, (2017) provided a global view of response of sugarcane to low temperatue stress by associating it with miRNA expression.

In the study of various tissue-specific EST libraries sequence data of Indian subtropical sugarcane variety (CoS 767), 25 water-deficit stress-related clusters showed greater than twofold relative expression during 9 h dehydration stress (Gupta *et al.*, 2010). Further, recently Prabu *et al.*, (2010) based on sqRT-PCR analysis showed higher transcript expression of WRKY, 22-kDa drought induced protein, MIPS and Ornithine-oxo-acid amino transferase at initial stages of stress induction with a gradual decrease in advanced stages. Analysis of the expression of these stress responsive genes in sugarcane plants under water deficit stress revealed a different transcriptional profile compared with sucrose accumulation. Prabu *et al.*, (2010) identified differentially expressed transcripts in response to water deficiency stress in sugarcane cv. Co740 using PCR-based cDNA suppression subtractive hybridization technique. Of the sequenced 158 cDNA clones based on Dot blot, 62% showed similarity with known functional genes, 12% with hypothetical proteins of plant origin, while 26% represented new unknown sequences. Annotation of these differentially ESTs indicated their possible function in cellular organization, protein metabolism, signal transduction, and transcription.

Molecular marker-assisted selection (MAS) is preferred over visual selection because it is time and cost effective. MAS is a powerful strategy to accelerate the crop breeding for tolerance against biotic and abiotic stresses (Mantri *et al.*, 2010, 2014). Study and development of molecular markers that are linked to the chosen traits (Ashraf *et al.*, 2010, Delannay *et al.*, 2012) and utilization of indirect selection of required loci using molecular markers is a proficient selection tool. Numerous markers have been developed in the recent past like restriction fragment length polymorphism (RFLPs), random amplified polymorphic DNA (RAPDs), amplified fragment length polymorphism (AFLPs), and simple sequence repeats (SSRs) to be utilized in breeding programs via MAS (Mantri *et al.*, 2014). Usually molecular markers are not developed from the desired genes. On the other hand, development of functional markers (FMs) is generally based on observed polymorphism in transcribed regions of the functional target genes, which make these markers suitable to develop a complete correlation with gene function. Functional markers enable precise selection of target genes (Andersen and Lübberstedt, 2003). Development of new sugarcane cultivars that can contribute to adaptation to climate change by discovering and introducing desirable genes for agronomic trait development (Burke *et al.*, 1988) and using basic breeding (Sanghera *et al.*, 2016), physiological screening (Gupta *et al.*, 2010, Sanghera *et al.*, 2018), and new technologies of molecular biology (Hoang *et al.*, 2015, Sanghera *et al.*, 2016) can mitigate the negative effect of climate change (temperature) and improve sugarcane yields, productivity, and sustainability.

"As the mercury rises or falls and the days get longer or shorter, it's time to protect your plants and yourself from the sunburn or cold!"

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