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Chapter

Sugarcane Production under Changing Climate: Effects of Environmental Vulnerabilities on Sugarcane Diseases, Insects and Weeds

Sadam Hussain, Abdul Khaliq, Umer Mehmood, Tauqeer Qadir, Muhammad Saqib, Muhammad Amjed Iqbal and Saddam Hussain

Abstract

Sugarcane is an important crop for bioenergy and sugar, contributing to Gross Domestic Product (GDP) of Pakistan. Global warming and increasing greenhouse gas emission result in the increased intensity and frequency of extreme weather events. Temperature stress is a major environmental stress that limits the sugarcane growth, productivity and metabolism worldwide. Numerous biochemical reactions are involved in plant development, and these biochemical reactions are very sensitive to temperature stress. Now a day, temperature stress is a major concern for sugarcane production and approaches for high yield of sugarcane under temperature stress are important agriculture goals. Sugarcane plant adapts a number of acclimation and avoidance mechanism against different environmental stress. Plant survival under different stresses depends on ability to generate and transmit the signal and biochemical and physiological changes. In future, climate change is an important consequence for sugarcane production in the world because of its relative low adaptive capacity, poor forecasting system and high vulnerable to natural hazard. In this review we briefly describe climate change effects on sugarcane, sugar production in several countries especially in Pakistan, future challenges for sugar production under changing climatic scenario and propose strategies for mitigation negative impacts of climate change.

Keywords: climate change, diseases, drought, high temperature, weeds, sugarcane

1. Introduction

Natural process and anthropogenic activities result in global climate change and variability that affect the world during twenty-first century. According the fourth assessment report of intergovernmental panel on climate change (IPCC), estimate of temperature increase in the range 1.8–4°C in 2090–2099 relative to 1980–1999

and extreme events such as floods and drought are projected in future [1]. Due to combustion of fossil fuel, industrial processes and deforestation, atmospheric CO₂ concentration has increased by 30% since mid of eighteenth century [2] and projection indicates that CO₂ concentration would be double in high emission scenario by the end of this century. Increases in concentration of CO₂ and air temperature can be beneficial for some plant [3]. Abiotic stresses, change in rainfall pattern, frequency of extreme low and high temperature, flood and drought are projected in future [1].

Changing climatic conditions influences the population dynamics, life cycle duration and overall occurrence of majority of insects, pathogen and weeds of sugarcane. Weeds, pathogen and insects are among the agriculture pest that will be influence by climate change. Changes in temperature, rainfall and CO₂ levels, will affect pathogen, insects and weeds distribution and their competitiveness with wheat crop. C3 cultivars are performing well under high CO₂ concentration than C4 cultivar. Agriculture sector is sensitive to temporary weather changes and seasonal, annual and long term variation in climate. Agronomic practice, soil, seed, pest and diseases have significant influence on crop yield. Human induced climate change and environmental problems, provides a limiting factor. Sugarcane is a C4 crop, mainly grow in tropics and subtropics regions and important source of bioenergy and sugar in the world. Sugarcane is perennial crop cultivated on 20 million ha in subtropical and tropical region [4] with annual yield app. 1325 million tons stalks for sugar, energy, rum and chemicals [5]. Sugarcane is one of the world's major food-producing crops, providing about 75% of sugar produced in the world for human consumption [6]. Sugarcane is cash crop of Pakistan and makes contribute in 0.6% in total GDP. During 2015–2016, sugarcane crop cultivated on 1132 thousand hectares as compared 1141 thousand hectares previous year, with production of 65,475 thousand tons [7]. Decline in area is due to shifted sugarcane area to other crops. Total cultivated area and production of sugarcane in Pakistan is given in **Figure 1**.

Sugarcane mostly propagated by placing cutting and whole stalks in furrows. After each harvest, ratoons mostly grows from stubble and it is possible to harvest 20 successful ratoon crop from a single plantation [8] but environmental related factor such as pathogen infection, low winter temperature, weed competition, stalk borer injury and water deficit condition reduce the production one season to next [9]. Climate related and weather events such as temperature, precipitation and atmospheric CO₂ are the key factor for sugarcane production in the world [10].

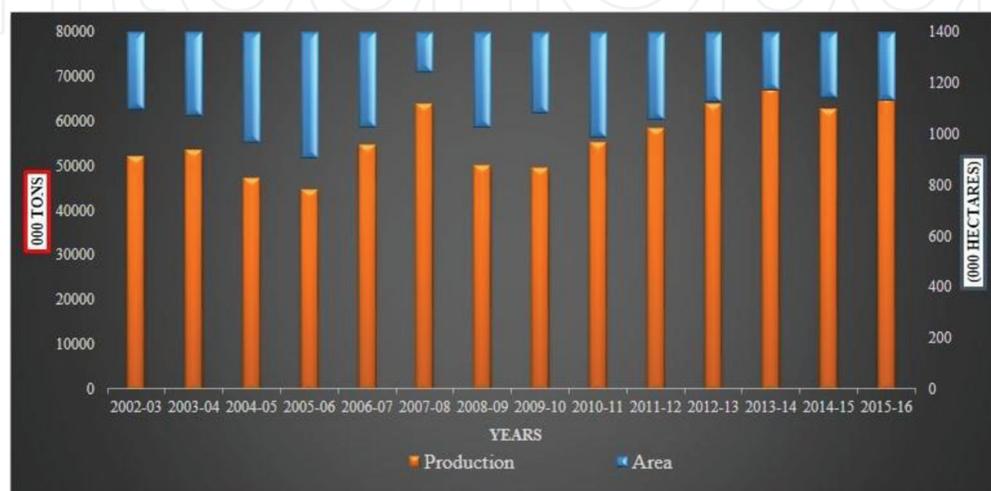


Figure 1. Total area and production of sugarcane in Pakistan 2002–2016 (Pakistan Bureau of Statistics, 2016).

2. Temperature stress and sugarcane production

Sugarcane is a C₄ species; increase in temperature in the range of 8–34°C increases the carbon dioxide assimilation and improve cane growth during winter but low temperature limit the photosynthesis and leaf growth rate ([11]; **Table 1**). Low temperature below 15°C limited the cultivation of sugarcane but temperature increase under changing climatic condition during low temperature period improve the sugarcane yield [19]. High temperature likely reduce the incidence and severity of frost and extending the growth during winter months, frost known to poor quality in sugarcane [20, 21]. However high temperature has negative effect on sprouting and emergence of sugarcane and ultimate low plant population [22]. Temperature above 32°C result in increased number of nodes, short internodes, higher stalk fiber and lower sucrose [23]. High night temperature usually more number of flowering and flowering in sugarcane ceases the growth of internodes and leaves ultimately reduce the sucrose and cane yield [20]. Increase in temperature under changing climatic conditions also alter the daily evaporation, may cause water stress and more frequent irrigation cycle will be done to meet the demand of evaporation and crop. Frequent irrigation result in over irrigation and create water logging and salinity problem which can reduce the sugarcane yield [24]. Temperature changes also affect the ripening of sugarcane. During winter, low temperature is very important for natural ripening. Under changing climate, elevated temperature reduces the ripening and quality of sugarcane [11].

| Authors | Study traits | Effects |
|------------------------|---|--|
| Morales et al. [12] | High temperature and photosynthesis | Photosystem II activity greatly reduce under high temperature |
| Marchand et al. [13] | Heat stress and photosynthesis | Heat stress reduce the amount of photosynthesis pigments |
| Rodriguez et al. [14] | Temperature stress and sucrose phosphate activity | Temperature stress reduce the activity of sucrose phosphate synthase |
| Warland et al. [15] | Temperature stress and yield | Small increase in temperature significant reduce the yield of crops |
| Johkan et al. [16] | Temperature stress and germination stage | Heat stress exert have negative impact during germination stage |
| Srivastava et al. [17] | High temperature and photosynthesis rate | High temperature reduce the net assimilation rate (NAR) and relative growth rate (RGR) |
| Omae et al. [18] | Temperature stress and leaf morphology | High temperature stress damage the leaf tip and margins, drying the leaves and observed necrosis |

Table 1.
Temperature stress under changing climatic conditions and its effects on sugarcane crop.

3. Tolerance mechanism against high temperature stress

Plant response to temperature stress, vary with degree, duration and plant type. At high temperature, cell death or cellular damage may occur, which lead to catastrophic collapse of cellular organization [25]. Heat stress effect all the process includes germination, growth and yield [26] and the stability of various protein, cytoskeleton structure and efficiency of enzymatic reactions [24, 27]. Under high temperature stress, plant adopt various mechanism include long term phenological and morphological adaptations and short term avoidance mechanism such as transpirational cooling and

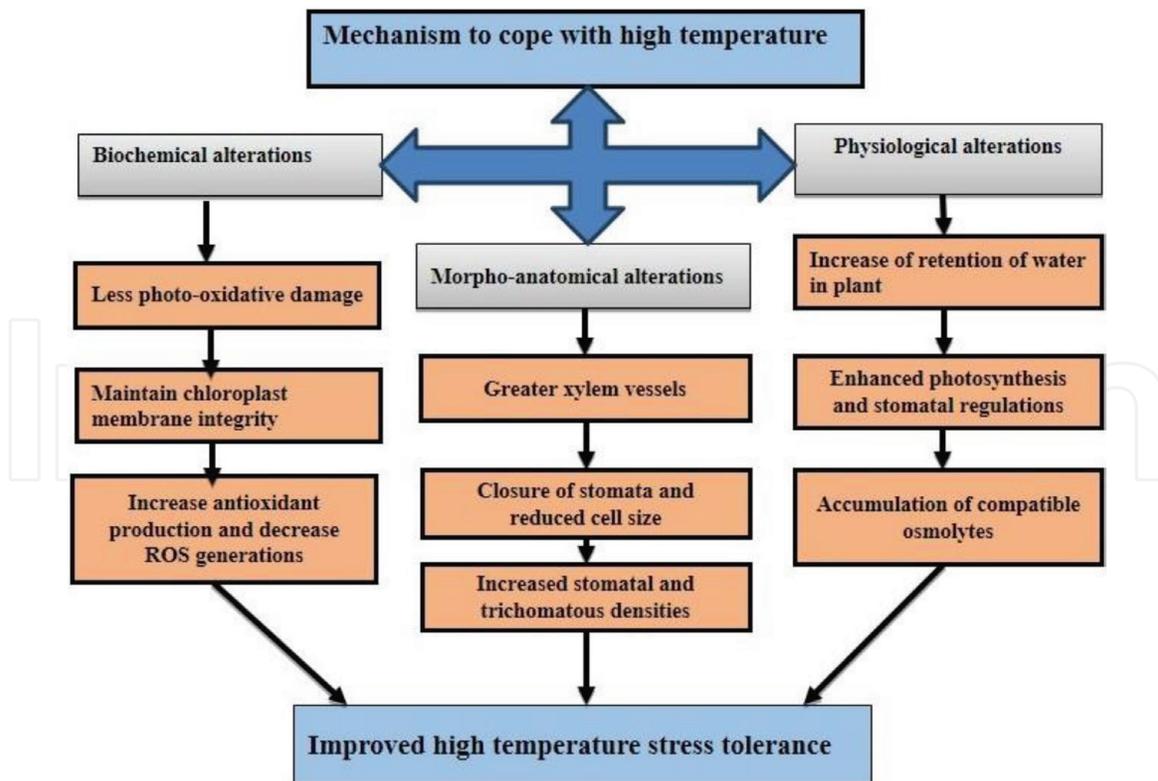


Figure 2.
Mechanism to cope with high temperature.

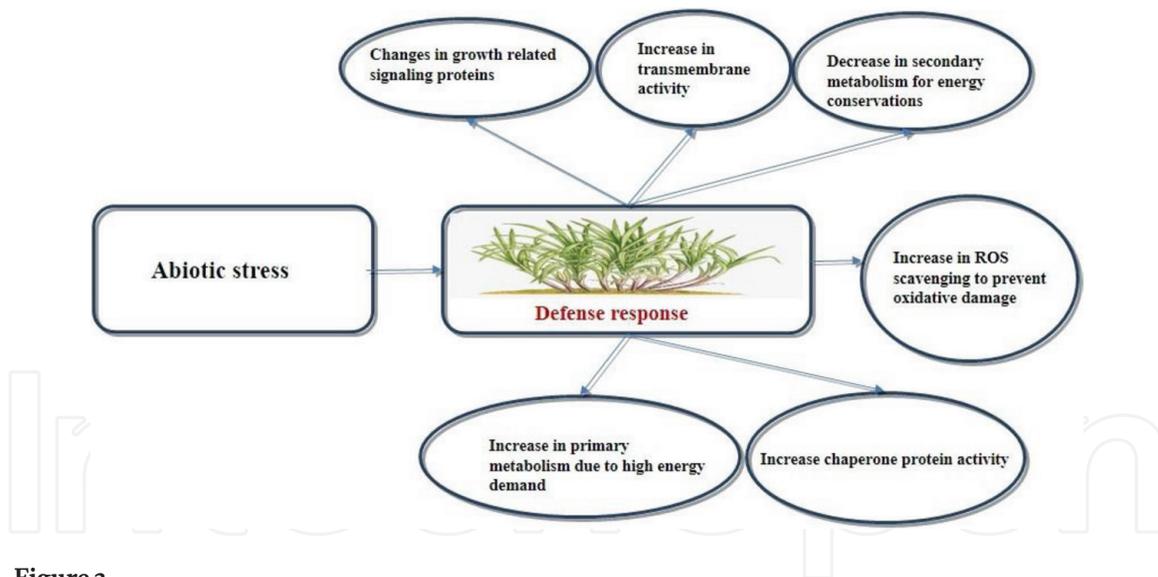


Figure 3.
Plant responses to abiotic stresses.

changing leaf orientations. Reduce water loss, closure of stomata, increased stomatal densities and alteration of membrane lipids compositions are the common feature which adopt by plant under stress [17], **Figure 2**. High temperature stress changes the degree of leaf rolling [28].

Low temperature affects the geographical distribution and planting seasons of crops, especially in tropical and subtropical regions [29]. Low temperature retard plant growth and development by reducing the metabolic process, leading to oxidative and osmotic stress [30]. Plant possesses the many strategies to response the temperature fluctuation such as cell remodeling and gene expression and metabolism reprogramming [20, 29]. Under low temperature stress, C-repeat binding factors, bind to dehydration responsive elements in gene promoters to active the COR

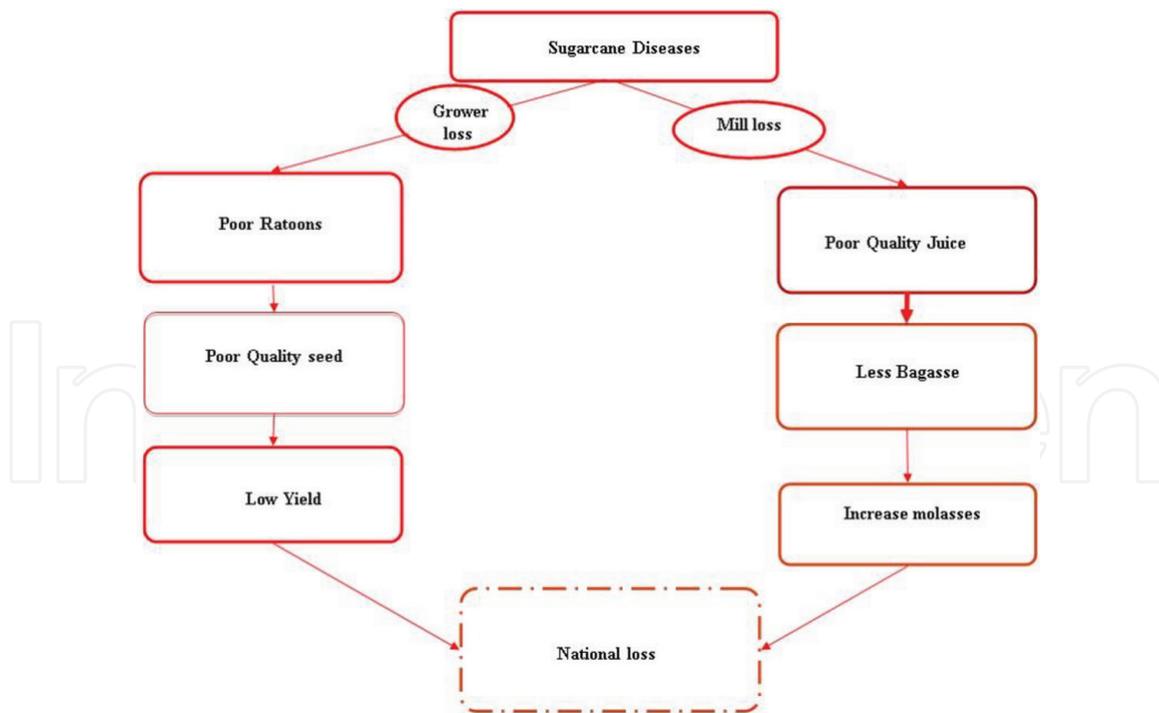


Figure 4.
National loss due to diseases of sugarcane.

(cold response genes), called as ICE-CBF-COR pathway [31, 32]. More study shows that miRNAs also play a critical role in this process [33, 34]. Ref. [19] observed the up-regulation of miR139 and down-regulation its target in both cold tolerant and sensitive varieties of sugarcane. Some other cold related miRNAs such as miR156K and miR394 has been reported [4, 35] (Figures 2–4).

4. Increase in CO₂ concentration and sugarcane production

Increases in CO₂ concentration directly affect the photosynthesis and stomatal physiology, increase growth rate in many plants [33]. High concentration with increase temperature will alter the plant ability to grow and modify the distribution of weeds across globe and their competitiveness in different habitat [36, 37]. In C₄ plants, internal mesophyll cell arrangement is different as compare to C₃ plant; help in efficient transfer of CO₂ and increase photosynthesis and reduce the photorespiration [33]. In future under increasing CO₂ condition, C₄ crop may become more vulnerable to increased competition from C₃ weeds. Double concentration of CO₂ may decrease 30–40% in stomatal aperture and 25–40% transpiration loss in both C₃ and C₄ plant. Double concentration of CO₂ may decrease 30–40% in stomatal aperture and 25–40% transpiration loss in both C₃ and C₄ plant. In long term field study, LAI (Leaf Area Index) did not increase in any species under elevated CO₂ conditions [33]. Bowes [38] discuss that under increasing cons. of CO₂, starch cons. Also increases in tissue reduce protein content. Elevated CO₂ cons. increase the growth and root-shoot ratio [39] and alter the photosynthesis activity in plants. Plants available nitrogen also reduces under elevated CO₂ [40]. Leaves carbon-nitrogen ratio increased under increasing CO₂.

5. Drought stress

Environmental stress reduces the crop productivity and plant growth and drought is the major abiotic stress, affecting crop productivity [41, 42]. Sugarcane

crop is highly sensitive to water deficit [43] and water deficit reduce the crop productivity up to 60% [44, 45]. Under water deficit conditions, sugarcane providing a key impetus to develop bio-technological strategies [43]. Under drought conditions, plant adopt various tolerant strategies such as modulation of growth, changes in life cycle, evolution of stress perception for rapid expression of stress tolerance and balance allocation of resources for stress adaptation and growth [25, 46, 47]. Molecular Breeding and biotechnology techniques are helpful tools to enhance crop productivity under water deficit conditions [25].

6. Morphological and physiological response of sugarcane to drought stress

Physiological and morphological response of sugarcane to drought stress varies according to duration, intensity of stress, type of tissue affected and genotype of plant [26, 48]. In sugarcane, common water responses are stomatal closure, inhibition of stalk and leaf growth, leaf rolling, reduce leaf area [26] and cell elongation and division are interrupted [49]. Stem and leaf elongation are most seriously affected [50]. Under water deficit conditions, root development also influence [51]. Sugarcane crop have C4 photosynthetic pathway and under water stress, decrease in transpiration rate, stomatal conductance and photosynthesis rate occurs [52, 53].

Water stress, decline the photosynthesis activity by decrease in phosphoenolpyruvate carboxylase and Rubisco activity [43]. Sugar accumulation in leaves also change the photosynthesis rate [54] and high sugar content moderates carbon fixation [55]. Under water deficit conditions, increase level of trehalose sugar, reducing the damage to cell membrane [34]. In reduce CO₂ fixation conditions, increase in starch hydrolysis helped in sustain carbon supply, which facilitate growth recovery after stress [56].

6.1 Changing rainfall pattern and sugarcane production

Climate change can affect agriculture through rise in temperature, variation in precipitation, increase in CO₂ concentration and weather vulnerabilities like flood, drought etc. Held et al. [57] predicted the more droughts in future; small changes in rainfall in future [58]. Extreme changes in rainfall have impact on sucrose yield [59] and frequent drought has negative effect on sugarcane as crop requires more water. Water stress also alters the photosynthesis, respiration and stomatal conductance [35]. For mitigate the drought conditions, farmer likely to more irrigate and increased the salinity problem and risen the water table. Reduce precipitation during harvesting period is likely to increase harvesting efficiency [60]. Nitrogen is the most limiting factor for sugarcane production [61]. Wetter years are likely to cause flood which may leach the nitrogen and farmer are use high rates of fertilizer during wetter years. Water logging may reduce the oxygen availability for root system and inhibit the uptake of nutrients [62]. Increased precipitation also reduces the quality of cane by inadequate “dry off” period. Changing in precipitation also has prevalence of weeds, diseases and insect pest. Termite and nematodes is expected to increase under warm and dry conditions. Some weeds such as *Cyperus* spp. may decrease under frequent drought conditions [20]. Effect of drought on sugarcane production depends upon plant growth stage and duration of stress. Drought at early and mid-growth stages mainly reduce sucrose yield. During the late growth stage, Moderate drought, increase the sucrose content in stalks. In china drought is the most important stress for production [63].

Environmental stress makes crops more vulnerable to insects and pathogen attack and less competitive with weeds [64]. Frequency and intensity of rainfall also changed under changing climatic conditions. After application of herbicides, precipitations wash out the herbicides and reduce its efficiency. For weed seeds germination, moisture is required, so weeds have more competitive advantage over crops. Increased rainfall and changed intensity will reduce the uptake of soil applied herbicides [65, 66].

Under water deficit conditions, efficacy of sethoxydim was lower in goosegrass [67] and *Urochloa plantaginea* (signalgrass) not effectively controlled by ACCase inhibiting herbicides when applied during later stages [68]. Patterson [64] discusses that under drought conditions, leaf pubescence and thickness increased and it will reduce the entry of herbicides into leaves. Water stress conditions affect the plant growth and efficacy of herbicides [69]. Most of studies done on impact of climate change on crop production but a little attention is given to identify the effects of climate change on weeds. Environmental stress changes the herbicides efficiency and contributes to loss in production. Under these changing climatic conditions it is necessary to understand how environmental conditions affect the herbicides performance.

7. Increases temperature conditions and different weeds, insects and diseases of sugarcane

Climate change affects the agriculture sector in different directions, directly by changing in temperature and/or precipitation as well as through indirect by changing pest pressure and availability of pollination service [31]. Diseases are a main threat to the food security and are responsible for 10% reduction in global food production [70], **Figure 4**. Many abiotic and biotic stresses such as weed competition, soil nitrogen and water deficit can exert stress on sugarcane and increase herbivore attacks. Among herbivorous arthropods, sugarcane borer, stalk insect borer and Mexican rice borer are the most important for sugarcane production [71]. A change in temperature under climate change conditions will have effects on some weeds, insects and diseases of sugarcane [10]. Smut disease (caused by *Sporisorium scitamineum*) is likely to increase under high temperature conditions [60]. But Sanguino [72] discusses different diseases of sugarcane, such as *Ustilago scitaminea* (Smut), *Sugarcane mosaic virus* (SCMV) and *Xanthomonas albilineans* (leaf scald disease) and told that all these diseases are systemic and only changed by direct human interference. However Chakraborty [30] told that leaf scald may spread by severe storms.

Extreme weather events have caused more disease pathogens and overwintering pests and also increased the input cost for controlling them. Sugarcane leaf and orange rust are big challenges for sugarcane production in Florida [32]. Reduced rainfall will also reduce the growth of crops and pasture and decrease canopy covers which favor weed infestation [73]. *Eoreuma loftini* is a major sugarcane pest [74]; drought results in greater abundance of dry leaf tissue and number of *E. loftini* eggs have been positively associated with number of dry leaves [75]. Under well water conditions sugarcane plants had 82.8–90.2% less *E. loftini* eggs than water deficit conditions [75]. In wet tropics, cyclones will disperse weed seeds through flood and wind. Moderate drought can increase the population of many herbivorous arthropods and cause injury in crop [76] drought also enhanced host plant suitability for herbivorous arthropods [77].

Summer weeds such as *Rottboellia cochinchinensis*, *Ipomoea plebeia* and *Digitaria sanguinalis* are expected to increase under high temperature conditions. Dormancy

of some summer weeds will have been broken under high temperature and these weeds may appear in winter. Insect pests such as *Heteronychus licas* and *Margarodes* spp. Will not be spared by temperature changes. Matthieson [60] told that temperature changes creates favorable condition for introduce new pests and diseases in sugarcane. Due to climate change, shift in temperature will have effect on diseases, weeds and insect pests [78]. Matthieson [60] discuss that attack of smut diseases is likely to increase under high temperature condition. High temperature induced the pollen sterility, poor anthesis and reduce the grain filling duration [79]. High temperature stimulates the stomata conductance and increases the permeability [80] and reduce the uptake of herbicides. Above discussion will help in identifying possible measure for weeds control under changing atmospheric conditions. So it is need to evaluate the climate change effects on weed flora and herbicides efficacy for adaptation and mitigation strategies.

8. Increasing concentration of CO₂ and weeds of sugarcane

Climate change is a continuous process, occur due to human and natural activities. Greenhouse gasses emission due to anthropogenic activities, accumulate the earth atmosphere and increase in concentration over time [81]. Concentration of CO₂ has risen to 387 $\mu\text{mol mol}^{-1}$ till 2007 and expected to reach 600 $\mu\text{mol mol}^{-1}$ till 2050 [27]. Modern agriculture techniques is main driving force which contribute in 30% of greenhouse gas emissions [82]. Weeds have negative effects on agriculture and public health. Weeds plants exert a variety of effects on sugarcane ecology under field conditions [83]. Uncontrolled annual summer weeds results 24% reduction in sugarcane stalks density, 19% in biomass and 15% reduction in commercial sugar production [84]. Under higher CO₂ concentration, C3 weeds generally increased their leaf area and biomass as compared with C4 weeds. Parthenium (*Parthenium hysterophorus*) is a C3 weed will be much more competitive under raised CO₂ environment [64]. Yield reduction due to weeds differ accordingly weeds density and species, when weeds emerge in high density, competitions will be highest. Crop and weeds competition affected by environmental conditions and have been shown to change with increasing CO₂. Temperature is a primary factor influencing the distribution of weeds at higher latitudes. Increase precipitation and temperature may provide suitable conditions for some species [37]. CO₂ enrichment reduce the effects of water stress and increased the leaf area in C4 grasses and increase the growth of C3 and C4 plants under stress. Increasing cons. of CO₂ from 300 to 600 ppm increased water use efficiency (WUE) in sunflower by 55%, in corn by 54%, in soybean by 48% and in redroot increased WUE by 76% [29] and greater stimulation of WUE in weeds than crops, provide competitive advantage to weeds. Rise in CO₂ concentration reduce the performance of many herbicides and plant growth, so it is needed to optimize herbicides application for better weed management in coming days. Climate also change the phenology and population of weeds. Most weeds species spread to new areas and researcher suggest that due to strong response of weeds to elevated CO₂, invasive species may become a threat in changing climate [85]. At elevated CO₂, C3 plant have higher photosynthesis rate and response more favorable than C4 weeds. Alberto [86] discuss the interaction between temperature and CO₂ and reported that elevated CO₂ favor the growth of barnyard grass at 37/29°C. It is essential to understand the factor that reduce the performance of any herbicides and insecticides, so for the successful management of chemicals it is necessary to understand its interaction with plants and environment. In plants, Herbicide absorption greatly depend on its interaction with environment. Soil

| Authors | Study traits | Effects |
|-------------------------|---|--|
| Rodenburg et al. [66] | Changing rainfall pattern and herbicides uptake | Increase in rainfall, reduce the uptake of soil-applied herbicides |
| Zanatta et al. [69] | Water stress and herbicides efficiency | Water stress conditions reduce the herbicides efficacy |
| Matthieson [60] | Elevated temperature and diseases of sugarcane | Attack of Smut disease is increased under high temperature conditions |
| Showler and Reagan [84] | Weeds in sugarcane | Uncontrolled annual summer weeds resulted in 15% reduction in commercial sugar production and 19% reduction in biomass |
| Singh et al. [85] | Climate change and weeds | Invasive species of weeds may become a threat |
| Alberto [86] | CO ₂ and different weeds | Elevated CO ₂ favor the growth of barnyard grass at 37/29°C |

Table 2.
Climate change and biotic stresses in sugarcane.

applied herbicides mainly influenced by soil temperature and moisture conditions. Environmental factor like temperature, humidity, moisture conditions and solar radiations also affects the efficacy of herbicides. Climate change also reduce the photosynthesis process which affects herbicides absorption and translocation (Table 2).

9. Conclusions

Environmental vulnerabilities are the major constraints for growth, development and productivity of sugarcane plant. The present rate of greenhouse gasses emission is believed responsible for gradual increase in temperature, changing rainfall pattern and environmental vulnerabilities and result in global warming. Plant response and adaptation to different stresses and effects of changing climatic conditions and weeds, insects and diseases, needs to be better understand for sugarcane crop. Sugarcane productivity under changing climatic conditions have been studied in recent years; however, a complete understanding of sugarcane production under changing climatic conditions remain elusive. Under different stress, sugarcane plant accumulate different mechanism and accumulate different metabolites such as antioxidant, osmoprotectants and heat shock protein and different metabolic process are activated.

10. Recommendations

- Under high temperature stress, exogenous application of protectant such as phytohormones and osmoprotectants, have beneficial effects on plants [87, 88].
- Soaking sugarcane nodal buds in exogenous pro (mM) and GB (20 mM) solution, restricted the H₂O₂ generation, improved the accumulation of soluble sugars and reduce the effects of heat stress on sugarcane crop [22].
- Managing the cultural practices, such as adequate sowing time and method, irrigation management and selecting the suitable cultivars, decrease the effects of different stresses.

- Under climate conditions, elevated temperature reduce the natural ripening, Chemical such as Ethrel, Fusillade super and round up may be helpful in ripening sugarcane.
- The effects of temperature and drought stress can be mitigated by growing the temperature and drought resistance varieties. A deep insight and research is need for new cultivars that adopt to temperature and drought stress conditions and greater water use efficiency.
- For mitigate the effects of climate change on sugarcane, scientist also use biotechnology for breeding the new cultivar to reduce the abiotic and biotic stresses.
- Health and environmental issue must also be given due consideration to address the new cultivar.
- Due to climate change, floods are projected in some areas, it is therefore important to adopt sugarcane production to such extreme conditions.
- Self-trashing varieties of sugarcane may be adopted, in order to complement harvesting without burning.
- Sugarcane residue may be used for weed suppression, increase the organic matter content in the soil and improve soil structure.
- Burning of sugarcane trash is a main cultural practice that effects of climate change. After harvesting trash is cleared from all ridges. Trash may use as mulch to control the water and wind erosion.

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References

- [1] Trenberth KE, Jones PD, Ambenje P, et al. Observations: Surface and atmospheric climate change: The physical science basis. In: Solomon S, Qin D, Manning M, et al., editors. Contribution of WG 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press; 2007. pp. 235-336
- [2] Houghton RA, Lawrence KT, Hackler JL, Brown S. The spatial distribution of forest biomass in the Brazilian Amazon: A comparison of estimates. *Global Change Biology*. 2001;7(7):731-746
- [3] Kimball BA. Carbon dioxide and agricultural yield: An assemblage and analysis of 430 prior observations. *Agronomy Journal*. 1983;75(5):779-788
- [4] FAO (Food and Agriculture Organization of the United Nations). Major Food and Agricultural Commodities and Producers. Available online: <http://www.fao.org/ess/top/commodity.html?lang=en&item=156&year=2005> [accessed on 1 July 2015]
- [5] Sharpe P. *Sugar Cane: Past and Present*. Carbondale, IL, USA: Southern Illinois University; 1998
- [6] Souza AP, Gaspar M, Silva EA, Ulian EC, Waclawosky AJ, Nishiyama MYJR, et al. Elevated CO₂ increases photosynthesis, biomass and productivity, and modifies gene expression in sugarcane. *Plant, Cell & Environment*. 2008;31(8):1116-1127
- [7] Government of Pakistan. Economic survey government of Pakistan. Finance Division, Economic Advisor's Wing, Islamabad. 2016. Available from: http://www.finance.gov.pk/survey/chapters_17/02-Agriculture.pdf
- [8] Blackburn F. *Sugar Cane*. New York, NY, USA: Longman; 1984
- [9] Edgerton CW. Stubble deterioration. *Proceedings—International Society of Sugar Cane Technologists*. 1939;6:334-341
- [10] Chandiposha M. Potential impact of climate change in sugarcane and mitigation strategies in Zimbabwe. *African Journal of Agricultural Research*. 2013;8:2814-2818
- [11] Gawander J. Impact of climate change on sugar-cane production in Fiji. *World Meteorological Organization Bulletin*. 2007;56(1):34-39
- [12] Morales D, Rodríguez P, Dell'Amico J, Nicolas E, Torrecillas A, Sánchez-Blanco MJ. High-temperature preconditioning and thermal shock imposition affects water relations, gas exchange and root hydraulic conductivity in tomato. *Biologia Plantarum*. 2003;47(2):203
- [13] Marchand FL, Mertens S, Kockelbergh F, Beyens L, Nijs I. Performance of high arctic tundra plants improved during but deteriorated after exposure to a simulated extreme temperature event. *Global Change Biology*. 2005;11(12):2078-2089
- [14] Rodríguez M, Canales E, Borrás-Hidalgo O. Molecular aspects of abiotic stress in plants. *Biotechnología Aplicada*. 2005;22(1):1-10
- [15] Warland JS, McDonald MR, McKeown AM. Annual yields of five crops in the family Brassicaceae in southern Ontario in relation to weather and climate. *Canadian Journal of Plant Science*. 2006;86:1209-1215
- [16] Johkan M, Oda M, Maruo T, Shinohara Y. Crop production and global warming. In: *Global Warming Impacts-case Studies on the Economy*,

Human Health, and on Urban and Natural Environments. InTech; 2011

[17] Srivastava S, Pathak AD, Gupta PS, Shrivastava AK, Srivastava AK. Hydrogen peroxide-scavenging enzymes impart tolerance to high temperature induced oxidative stress in sugarcane. *Journal of Environmental Biology*. 2012;**33**(3):657

[18] Omae H, Kumar A, Shono M. Adaptation to high temperature and water deficit in the common bean (*Phaseolus vulgaris* L.) during the reproductive period. *Journal of Botany*. 2012. Article ID 803413. 6 pages. DOI: 10.1155/2012/803413

[19] Ebrahim MKH, Vogg G, Osman MNEH, Kamor E. Photosynthetic performance and adaptation of *sugarcane* at suboptimal *temperatures*. *Journal of Plant Physiology*. 1998;**153**(6):587-692

[20] Clowes MJ, Breakwell WL. *Zimbabwe Sugarcane Production Manual*. Chiredzi, Zimbabwe: Zimbabwe Sugar Association; 1998

[21] Mathieson L. *Climate Change and the Australian Sugar Industry: Impacts, Adaptation and R & D Opportunities*. Australia: Sugar Research and Development Corporation; 2007

[22] Rasheed R, Wahid A, Farooq M, Hussain I, Basra SMA. Role of proline and glycine betaine pretreatments in improving heat tolerance of sprouting sugarcane (*Saccharum* sp.) bud. *Plant Growth Regulation*. 2011;**65**:35-45

[23] Bonnett GT, Hewitt ML, Glassop D. Effects of high temperature on the growth and composition of sugarcane internodes. *Australian Journal of Agricultural Research*. 2006;**57**(10):1087-1095

[24] Kahlow MA, Azam M. Individual and combined effect of water logging and

salinity on crop yields in the Indus basin. *Irrigation and Drainage*. 2002;**51**:329-338

[25] Hu H, Xiong L. Genetic engineering and breeding of drought-resistant crops. *Annual Review of Plant Biology*. 2014;**65**:715-741

[26] Inman-Bamber N, Lakshmanan P, Park S. Sugarcane for waterlimited environments: Theoretical assessment of suitable traits. *Field Crops Research*. 2012;**134**:95-104. DOI: 10.1016/j.fcr.2012.05.004

[27] IPCC. Assessment Report. 2007. http://www.ipcc.ch/pdf/assessmentreport/ar4/syr/ar4_syr_spm.pdf

[28] Sarijeva GE, Kenzhebaeva SS, Lichtenthaler HK. Adaptation potential of photosynthesis in wheat cultivars with a capability of leaf rolling under high temperature conditions. *Russian Journal of Plant Physiology*. 2010;**57**(1):28-36

[29] Carlson RW, Bazzaz FA. The effects of elevated CO₂ concentrations on growth, photosynthesis, transpiration and water use efficiency of plants. In: Singh JJ, Deepak A, editors. *Environmental and Climatic Impact of Coal Utilization*. New York: Academic Press; 1980. pp. 610-622

[30] Chakraborty S, Murray GM, Magarey PA, et al. Potential impact of climate change on plant diseases of economic significance to Australia. *Australasian Plant Pathology*. 1998;**27**:15-35

[31] Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL. Prioritizing climate change adaptation needs for food security in 2030. *Science*. 2008;**319**(5863):607-610

[32] Zhao D, Glynn NC, Glaz B, Comstock JC, Sood S. Orange rust effects on leaf photosynthesis and

related characters of sugarcane. *Plant Disease*. 2011;**95**(6):640-647

[33] Drake BG, González-Meler MA, Long SP. More efficient plants: A consequence of rising atmospheric CO₂? *Annual Review of Plant Physiology and Plant Molecular Biology*. 1997;**48**:609-639

[34] Delorge I, Janiak M, Carpentier S, Van Dijck P. Fine tuning of trehalose biosynthesis and hydrolysis as novel tools for the generation of abiotic stress tolerant plants. *Frontiers in Plant Science*. 2014;**5**:147. DOI: 10.3389/fpls.2014.00147

[35] Gardener FP, Pearce R, Mitchell R. *Physiology of Crop Plants*. 1st ed. Iowa: Iowa State University Press; 1984. p. 328

[36] Bunce JA. Weeds in a changing climate. In: BCPC Symp. Proc. No. 77: The World's Worst Weeds. 2001. pp. 109-118

[37] Parry ML. The impact of climate change on European agriculture. In: Lewis T, editor. *The Bawden Memorial Lectures 1973-1998, Silver Jubilee Edition*. UK: British Crop Protection Council, Surrey; 1998. pp. 325-338

[38] Bowes G. Photosynthetic responses to changing atmospheric carbon dioxide. In: Baker NR, editor. *Photosynthesis and the Environment. Advances in Photosynthesis*. Vol. 5. Dordrecht: Kluwer; 1996. pp. 387-407

[39] Ziska LH, George K. Rising carbon dioxide and invasive, noxious plants: Potential threats and consequences. *World Resource Review*. 2004;**16**:427-447

[40] Zhang W, Parker KM, Luo Y, Wan S, Wallace LL, Hu S. Soil microbial responses to experimental warming and clipping in a tall grass prairie. *Global Change Biology*. 2005;**11**:266-277

[41] Lobell DB, Schlenker W, Costa-Roberts J. Climate trends and global crop production since 1980. *Science*. 2011;**333**:616-620. DOI: 10.1126/science.1204531

[42] Wang W, Vinocur B, Altman A. Plant responses to drought, salinity and extreme temperatures: Towards genetic engineering for stress tolerance. *Planta*. 2003;**218**:1-14. DOI: 10.1007/s00425-003-1105-5

[43] Lakshmanan P, Robinson N. *Stress physiology: Abiotic stresses*. In: Moore PH, Botha FC, editors. *Sugarcane: Physiology, Biochemistry, and Functional Biology*. Chichester: John Wiley & Sons, Inc.; 2014. pp. 411-434

[44] Basnayake J, Jackson PAN, Inman-Bamber G, Lakshmanan P. Sugarcane for water-limited environments. Genetic variation in cane yield and sugar content in response to water stress. *Journal of Experimental Botany*. 2012;**63**:6023-6033. DOI: 10.1093/jxb/ers251

[45] Gentile A, Dias LI, Mattos RS, Ferreira TH, Menossi M. MicroRNAs and drought responses in sugarcane. *Frontiers in Plant Science*. 2015;**6**:58. DOI: 10.3389/fpls.2015.00058

[46] Hirayama T, Shinozaki K. Research on plant abiotic stress responses in the post-genome era: Past, present and future. *The Plant Journal*. 2010;**61**:1041-1052. DOI: 10.1111/j.1365-313X.2010.04124.x

[47] You J, Chan Z. ROS regulation during abiotic stress responses in crop plants. *Frontiers in Plant Science*. 2015;**6**:1092. DOI: 10.3389/fpls.2015.01092

[48] Bartels D, Sunkar R. Drought and salt tolerance in plants. *Critical Reviews in Plant Sciences*. 2005;**24**:23-58. DOI: 10.1080/07352680590910410

- [49] Machado R, Ribeiro R, Marchiori P, Machado D, Machado E, Landell M. Biometric and physiological responses to water deficit in sugarcane at different phenological stages. *Pesquisa Agropecuaria Brasileira*. 2009;**44**:1575-1582. DOI: 10.1590/S0100-204X2009001200003
- [50] Inman-Bamber N, Bonnett G, Spillman M, Hewitt M, Jackson J. Increasing sucrose accumulation in sugarcane by manipulating leaf extension and photosynthesis with irrigation. *Australian Journal of Agricultural Research*. 2008;**59**:13-26. DOI: 10.1071/AR07167
- [51] Smit M, Singels A. The response of sugarcane canopy development to water stress. *Field Crops Research*. 2006;**98**:91-97. DOI: 10.1016/j.fcr.2005.12.009
- [52] Basnayake J, Jackson PAN, Inman-Bamber G, Lakshmanan P. Sugarcane for water-limited environments. Variation in stomatal conductance and its genetic correlation with crop productivity. *Journal of Experimental Botany*. 2015;**66**:3945-3958. DOI: 10.1093/jxb/erv194
- [53] Medeiros DB, da Silva EC, Mansur Custodio Nogueira RJ, Teixeira MM, Buckeridge MS. Physiological limitations in two sugarcane varieties under water suppression and after recovering. *Theoretical and Experimental Plant Physiology*. 2013;**25**:213-222. DOI: 10.1590/S2197-00252013000300006
- [54] McCormick AJ, Cramer MD, Watt DA. Regulation of photosynthesis by sugars in sugarcane leaves. *Journal of Plant Physiology*. 2008;**165**:1817-1829. DOI: 10.1016/j.jplph.2008.01.008
- [55] Goldschmidt EE, Huber SC. Regulation of photosynthesis by endproduct accumulation in leaves of plants storing starch, sucrose, and hexose sugars. *Plant Physiology*. 1992;**99**:1443-1448. DOI: 10.1104/pp.99.4.1443
- [56] Sales CRG, Ribeiro RV, Machado DFSP, Machado RS, Dovic VL, Lagôa AMMA. Gas exchange and carbohydrate balance in sugarcane plants under root stressful conditions. *Bragantia*. 2012;**71**:319-327. DOI: 10.1590/S0006-87052012000300001
- [57] Held IM, Delworth TL, Lu J, Findell KL, Knutson TR. Simulation of Sahel drought in the 20th and 21st centuries. *Proceedings of the National Academy of Sciences of the United States of America*. 2005;**102**(50):17891-17896
- [58] Huntingford C, Hugo LF, Gash JHC, Taylor CM, Challinor AJ. Aspects of climate change prediction relevant to crop productivity. *Philosophical Transactions of the Royal Society of London B*. 2005;**360**(1463):1999-2010
- [59] Wheeler TR, Craufurd PQ, Ellis RH, Porter JR, Prasad PVV. Temperature variability and the annual yield of crops. *Agriculture, Ecosystems & Environment*. 2000;**82**:159-167
- [60] Matthieson L. Climate change and the Australian Sugarcane Industry: Impacts, adaptation and R&D opportunities. In: SRDC Technical Report, Sugar Research and Development; Brisbane, Australia. 2007
- [61] Wiedenfeld B, Enciso J. Sugarcane responses to irrigation and nitrogen in semiarid South Texas. *Agronomy Journal*. 2008;**100**(3):665-671
- [62] Glover J, Johnson H, Lizzio J, Wesley V, Hattersley P, Knight C. *Australia's Crops and Pastures in a Changing Climate—Can Biotechnology Help?* Canberra: Australian Government Bureau of Rural Sciences; 2008
- [63] Li Y-R, Wei Y-A. Sugar industry in China: R & D and policy initiatives

to meet sugar and biofuel demand of future. *Sugar Tech.* 2006;**8**(4):203-216

[64] Patterson DT. Weeds in a changing climate. *Weed Science.* 1995;**43**:685-701

[65] Bailey SW. Climate change and decreasing herbicide persistence. *Pest Management Science.* 2004;**60**:158-162. DOI: 10.1002/ps.785

[66] Rodenburg J, Meinke H, Johnson DE. Challenges for weed management in African rice systems in a changing climate. *The Journal of Agricultural Science.* 2011;**149**:427-435

[67] Pereira MRR, Souza GSF, Martins D, Melhorança Filho AL, Klar AE. Respostas de plantas de Eleusine indica sob diferentes condições hídricas a herbicidas inibidores da ACCase. *Planta Daninha.* 2011;**29**:397-404

[68] Pereira MRR. Efeito de herbicidas sobre plantas de Brachiaria plantaginea submetidas a estresse hídrico. *Planta Daninha.* 2010;**28**:1047-1058

[69] Zanatta JF et al. Teores de água no solo e eficácia do herbicida fomesafen no controle de *Amaranthus hybridus*. *Planta Daninha.* 2008;**26**:143-155

[70] Strange RN, Scott PR. Plant disease: A threat to global food security. *Annual Review of Phytopathology.* 2005;**43**:83-116

[71] Showler AT, Reagan TE. Ecology and tactics for control of three sugarcane stalk-boring species in the Western Hemisphere and Africa. In: Goncalves JF, Correia KD, editors. *Sugarcane: Production and Uses.* Hauppauge, NY, USA: Nova; 2012. pp. 1-15

[72] Sanguino A. Impacto potencial das mudanças climáticas sobre as principais doenças da cana-de-açúcar no Brasil. In: Ghini R, Hamada E, editors. *Mudanças Climáticas: Impactos sobre Doenças*

de Plantas no Brasil. Brasília, Brazil: Embrapa; 2008. pp. 207-213

[73] Kriticos DJ, Sutherst RW, Brown JR, Adkins SW, Maywald GF. Climate change and the potential distribution of an invasive alien plant: *Acacia nilotica* ssp. *Indica* in Australia. *Journal of Applied Ecology.* 2003;**40**:111-124

[74] Morrill AW. Commercial entomology on the west coast of Mexico. *Journal of Economic Entomology.* 1925;**18**:707-716

[75] Showler AT, Castro BA. Influence of drought stress on Mexican rice borer (Lepidoptera: Crambidae) oviposition preference and development to adulthood in sugarcane. *Crop Protection.* 2010;**29**:722-727

[76] Showler AT. Drought and arthropod pests of crops. In: Neves DF, Sanz JD, editors. *Droughts: New Research.* Hauppauge, NY, USA: Nova; 2012. pp. 131-156

[77] Mattson WL, Haack RA. Role of drought in outbreaks of plant-eating insects. *Bioscience.* 1987;**37**:110-118

[78] Neumeister L. Crop protection: Anything can happen. In: PAN Asia and the Pacific; Penang, Malaysia. 2010

[79] Kadam NN, Xiao G, Melgar RJ, Bahuguna RN, Quinones C, Tamilselvan A, et al. Agronomic and physiological response to high temperature, drought, and elevated CO₂ interaction in cereals. *Advances in Agronomy.* 2014;**127**:111-156

[80] Sharma SD, Singh M. Environmental factors affecting absorption and bio-efficacy of glyphosate in Florida beggarweed (*Desmodium tortuosum*). *Crop Protection.* 2001;**20**:511-516

[81] Schneider SH. The climatic response to greenhouse gases. *Advances in Ecological Research.* 1992;**22**:1-32

[82] Kumar A, Kumar M. Climate change's impacts on weeds and herbicide efficacy: A review. *International Journal of Current Microbiology and Applied Sciences*. 2017;6(9):2846-2853

[83] Reagan TE, Way MO, Beuzelin JM, Akbar W. Assessment of varietal resistance to the sugarcane borer and Mexican Rice borer. In: *Sugarcane Research: Annual Progress Report*. Baton Rouge, LA, USA: Louisiana State University AgCenter, Louisiana State University; 2008

[84] Showler AT, Reagan TE. Effects of sugarcane borer, weed, and nematode control strategies in Louisiana sugarcane. *Environmental Entomology*. 1991;20:358-370

[85] Singh MC, Dubey SC, Yaduraju NT. Climate change and its possible impacts on weeds. *International Journal of Science, Environment and Technology*. 2016;5(3):1530-1539

[86] Alberto AM, Ziska LH, Cervancia CR, Manalo PA. The influence of increasing carbon dioxide and temperature on competitive interactions between a C4 crop, rice (*Oryza sativa*), and a C3 weed (*Echinochloa glabrescens*). *Australian Journal of Plant Physiology*. 1996;23:793-802

[87] Hasanuzzaman M, Nahar K, Fujita M. Plant response to salt stress and role of exogenous protectants to mitigate salt-induced damages. In: *Ecophysiology and Responses of Plants under Salt Stress*. New York, NY: Springer; 2013. pp. 25-87

[88] Hasanuzzaman M, Hossain MA, Fujita M. Nitric oxide modulates antioxidant defense and the methylglyoxal detoxification system and reduces salinity-induced damage of wheat seedlings. *Plant Biotechnology Reports*. 2011;5(4):353