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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 CO_2 concentration has increased by 30% since mid of eighteenth century [2] and projection indicates that CO_2 concentration would be double in high emission scenario by the end of this century. Increases in concentration of CO_2 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 CO_2 levels, will affect pathogen, insects and weeds distribution and their competitiveness with wheat crop. C3 cultivars are performing well under high CO_2 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 CO_2 are the key factor for sugarcane production in the world [10].

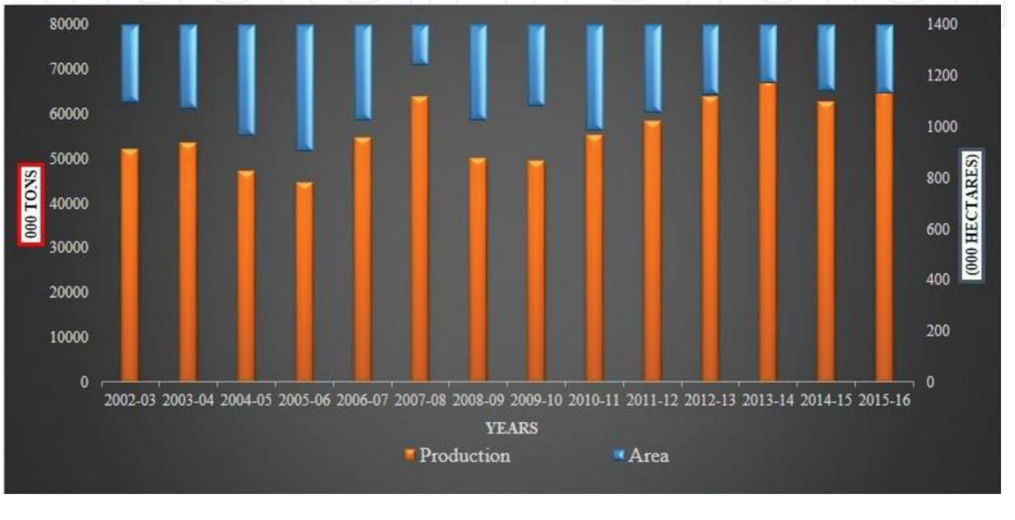

Figure 1.
Total area and production of sugarcane in Pakistan 2002–2016 (Pakistan Bureau of Statistics, 2016).

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

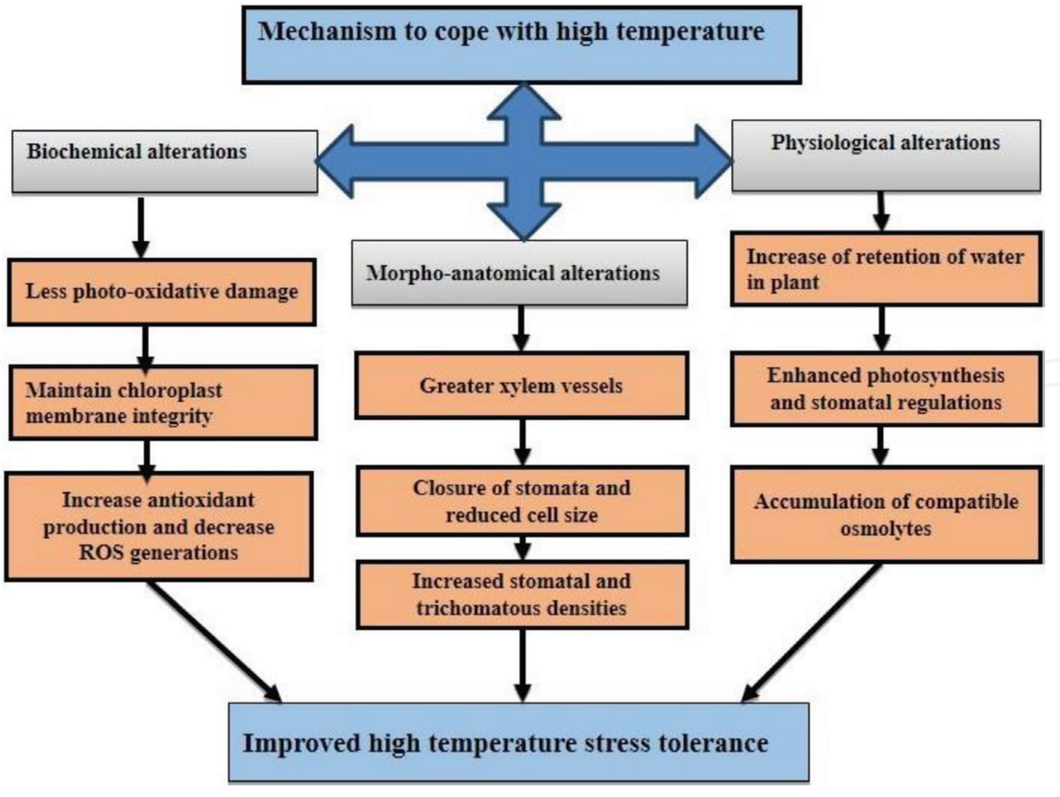

Figure 2.
Mechanism to cope with high temperature.

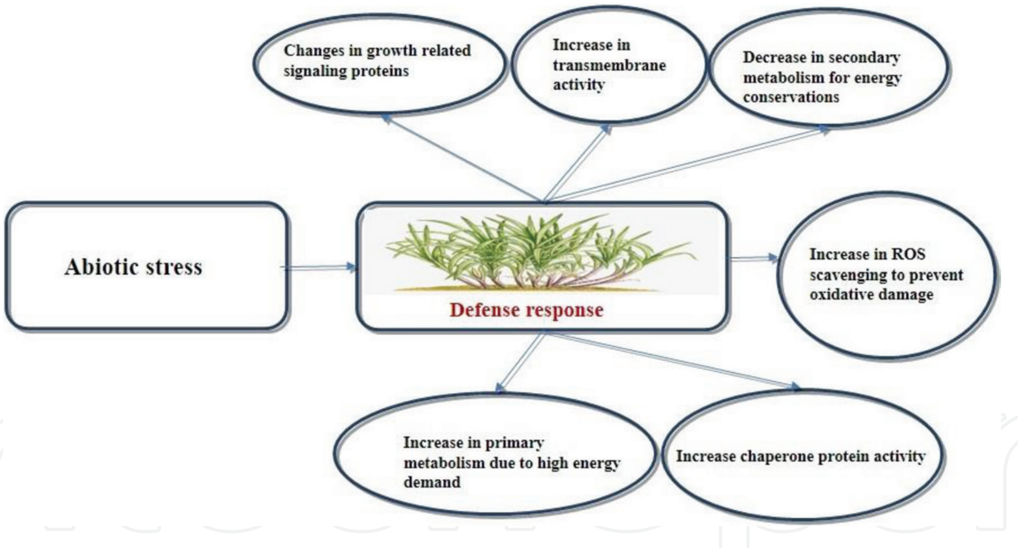

Figure 3.
Plant responses to abiotic stresses.

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

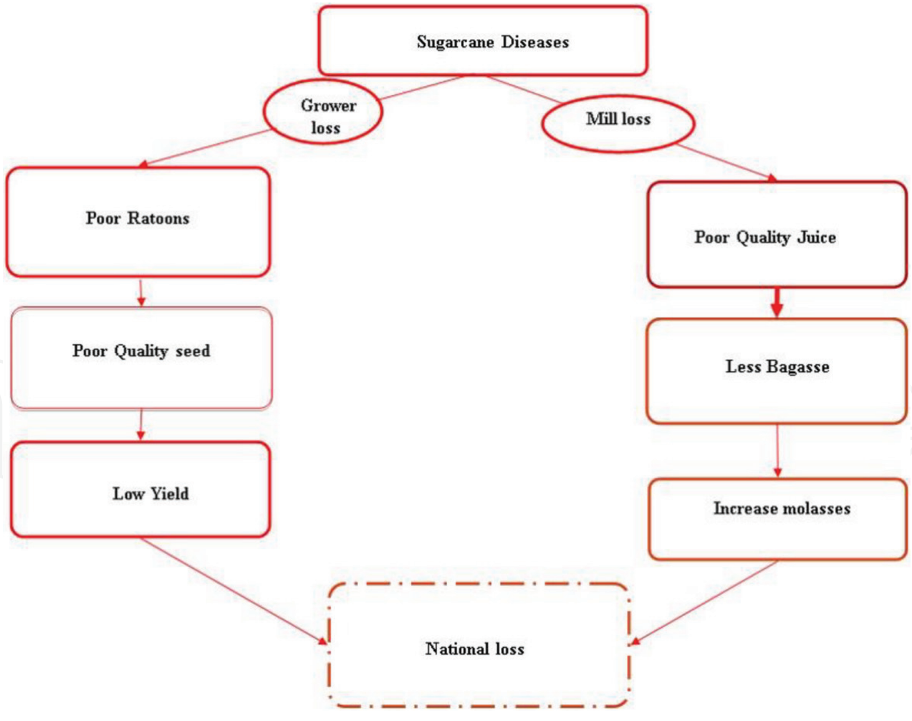

Figure 4.
National loss due to diseases of sugarcane.

(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 verities of sugarcane. Some other cold related miRNAs such as miR156K and miR394 has been reported [4, 35] (**Figures 2**–**4**).

4. Increase in CO_2 concentration and sugarcane production

Increases in CO_2 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 plats, internal mesophyll cell arrangement is different as compare to C3 plant; help in efficient transfer of CO_2 and increase photosynthesis and reduce the photorespiration [33]. In future under increasing CO_2 condition, C4 crop may become more vulnerable to increased competition from C3 weeds. Double concentration of CO_2 may decrease 30–40% in stomatal aperture and 25–40% transpiration loss in both C3 and C4 plant. Double concentration of CO_2 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 CO_2 conditions [33]. Bowes [38] discus that under increasing cons. of CO_2, starch cons. Also increases in tissue reduce protein content. Elevated CO_2 cons. increase the growth and root-shoot ratio [39] and alter the photosynthesis activity in plants. Plants available nitrogen also reduces under elevated CO_2 [40]. Leaves carbon-nitrogen ratio increased under increasing CO_2.

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 CO_2 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 CO_2 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 it efficiency. For weed seeds germination, moisture is require, 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] discus 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 the how environmental conditions affect the herbicides performance.

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

Climate change effect the agriculture sector in different direction, 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 main threat to the food security and the responsible for 10% reduction in globally food production [70], **Figure 4**. Many abiotic and biotic stresses such as weed competition, soil nitrogen and water deficit can exert the stress on sugarcane and increase the herbivores attack. Among herbivores 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] discus the different diseases of sugarcane, such as *Ustilago scitaminea* (Smut), *Sugarcane mosaic virus* (SCMV) and *Xanthomonas albilineans* (leaf scaled disease) and told that all these diseases are systemic and only changed by direct human interference. However Chakraborty [30] told that leaf scaled may spread by severe storms.

Extreme weather events have caused more disease pathogen and overwintering pest and also increased the input cost for control them. Sugarcane leaf and orange rust are bid challenges for sugarcane production in Florida [32]. Reduced rainfall will also reduce the growth of crops and pasture and decrease canopy covers which favor the 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* egg have been positively associated with number of dry leaves [75]. Under well water conditions sugarcane plant had 82.8–90.2% less *E. loftini* eggs than water deficit conditions [75]. In wet tropics, cyclones will disperse weeds seed through flood and wind. Moderate drought can increase the population of many herbivorous arthropods and cause the injury in crop [76] drought also enhanced host plant suitability for herbivores 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] discus 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 CO_2 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 CO_2 has risen to 387 μmol mol^{-1} till 2007 and expected to reach 600 μmol 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 CO_2 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 CO_2 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 CO_2. 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]. CO_2 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 CO_2 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 CO_2 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 CO_2, invasive species may become a threat in changing climate [85]. AT elevated CO_2, C3 plant have higher photosynthesis rate and response more favorable than C4 weeds. Alberto [86] discus the interaction between temperature and CO_2 and reported that elevated CO_2 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 H_2O_2 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.

Author details

Sadam Hussain[1], Abdul Khaliq[1], Umer Mehmood[1], Tauqeer Qadir[1], Muhammad Saqib[1], Muhammad Amjed Iqbal[2] and Saddam Hussain[1]*

1 Department of Agronomy, University of Agriculture, Faisalabad, Punjab, Pakistan

2 Institute of Agricultural and Resource Economics, University of Agriculture, Faisalabad, Punjab, Pakistan

*Address all correspondence to: sadamhussainuaf@gmail.com

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