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REVIEW

Climate Change and Its Adverse Impacts on Plant Growth in South Asia: Current Status and Upcoming Challenges

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ABSTRACT

Socioeconomic development, adaptive capacity of the population, and demographic conditions across the states of South Asia make it more vulnerable to climate change. South Asia is daily going to be more vulnerable to climate change and climatic variability. This region is facing multiple challenges in terms of climate change, dilapidation of ecosystems, and food insecurity. Climate is the primary determining factor for agricultural output, which unswervingly influences food production across the globe. South Asia is mainly an agricultural foundation based region and thus the economy of these regions directly depends on agriculture and agricultural production. Due to the extensive dependence on natural assets for thriving, it makes the people of this region more vulnerable to climate change. This region is now under serious risk from sea-level rising and growing incidences of extreme events such as flash floods, enhanced temperature, drought, salinity, cyclones, storms, landslides, and irregularity of precipitation. These abiotic stresses continuously disturb plant growth and productivity. It is now the time to take urgent action on these issues towards a sustainable, inclusive and resource efficient way to overcome this. In this review, we summarize the overall situation of climate change in the South Asian countries and their adverse consequences on plants, and upcoming challenges towards a sustainable production.

KEYWORDS

Climate change; South Asia; plant growth; abiotic stress; food security

1 Introduction

Weather pattern changes, raising of sea levels, intense weather events, and emissions of greenhouse gases, are now at their maximum phases in history. Climate change is now becoming the most serious concern for every country. It is interrupting every aspect of a daily national development today and it will do it even more tomorrow. Importantly, the poorest and vulnerable people are being affected brutally. The South Asian countries are especially the most exposed territories to climate change due to their geographical locations [1,2]. South Asia embraces 8 countries: Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka [3]. South Asia is the most densely populated region in the world [3]. This area encompasses nearly 51 lacs km^2 which is 11.51 per cent of the Asian continent. Almost 1.749 billion people are living here that covers nearby one-fourth of the world's inhabitants [4].

In this region around 70 per cent of the people live in rural areas and primarily depend on agriculture. This region is severely affected due to the climate change, although it contributes little to the greenhouse gases (GHGs) emission [5,6]. The United Nations Climate Change Organization reports that by the end of this century, climate change could deduct up to 9 per cent of the gross economic development every year in South Asia [7]. Moreover, according to the Asian Development Bank (ADB), by 2050, the South Asian countries will lose collectively an average of 1.80 per cent of their annual gross domestic product (GDP), and by 2100, that loss will be 8.80 per cent [8]. Furthermore, the demand of food will increase nearly 300 per cent by 2080 due to the higher population, and this increase will initiate a discrepancy between the supply and demand of food even with no influence of climate change. By this time climate change will certainly reduce food production and it is likely that there will be a more intensified food crisis and threatening of food security [5]. These problems will be more exaggerated in South Asian countries due to their huge population.

Climate change is initiated by the gathering of GHGs in the atmosphere due to the wide-range use of fossil fuels and the enormous devastation of carbon-storing areas [9]. It causes several environmental problems, such as global temperature rising, sea level rising, salt intrusion in agricultural lands, changes in precipitation patterns, increases of flooding and drought events, changes on seasons, and extreme weather events. These problems are becoming common in recent years. The economy of the South Asian countries predominantly relies on agriculture; this is the most sensitive sector to the changing climate as growing plants are weather-dependent and plants are sessile [10]. In the next 30 years, the average surface temperature will increase at a speed of 0.2°C per decade. Moreover, several studies reported that the global temperature will rise from 2.5 to 4.5°C at the end of 2100 [7].

This global warming will increase plant transpiration losses and reduce net carbon assimilation which ultimately will decrease crop yields. It also can increase the invasion of weed, insects, and pathogens [11,12]. For instance, an increase of 1°C during wheat, rice, and maize cultivation could reduce yields by 8%, 2.6% and 8.3%, respectively [13,14]. It has been reported that extreme precipitation may cause over-flooding whereas the lack or total absence of rainfall for an extended time period leads to drought stress [15]. It is well-known that drought and flooding stresses decline plant growth and productivity of different crops by regulating their morphology, physiology, and reproduction [16]. Salinity adversely affects plant water uptake and causes specific ion toxicities [17,18]. Although an increased atmospheric CO_2 concentration enhances plant growth by increasing photosynthesis rates, it indirectly rises the earth temperature. That enhanced growth might not be effective under drought or salinity stress conditions because higher rates of photosynthesis need a higher amount of available water [19]. Furthermore, the occurrence of different extreme events has increased, which causes severe reductions of plant growth and productivity in the affected areas [16,20,21]. Cumulatively, all those climate changes related issues hamper agricultural productivity, which is more severe in South Asian countries.

Considering the complexity of the subject, we cannot address all aspects of climate change and its impact on plant growth and development in a single synopsis. In this current appraisal, we reviewed the overall situation of climate change in South Asian countries, and summarize its possible impacts on agricultural crop plants.

2 Causes of Climate Change

Accumulation of GHGs in the atmosphere is one of main reason for climate change worldwide, including South Asia. Due to the increasing pollution and urbanization, the gathering of GHGs in atmosphere enhances on a daily basis. According to the IPPC [22], the concentration of atmospheric CO_2 is currently about 388 parts per million. It is predicted that, it will increase nearly 470–570 parts per million by 2050, due to the extensive use of fossil fuels, burning of biomass and deforestation which determines a higher CO_2 generation. The industries on urban areas contribute to the increment on the concentrations of GHGs, atmospheric CO_2, methane, and nitrous oxide [23]. Between 1750 and 2011, the cumulative anthropogenic CO_2 emissions to the atmosphere were around 2040 gigatonne. About 40% of these emissions have remained in the atmosphere (880 gigatonne CO_2); the rest was removed from the atmosphere and stored on the land (in plants and soils) and in the ocean. The ocean has absorbed about 30 per cent of the emitted anthropogenic CO_2, causing ocean acidification. About half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years [7]. The atmospheric GHGs highly affects the radiation absorption, emission and scattering in the atmosphere and shift the energy balance within the climatic system contributing to climate change [22]. Besides, the lifespan and amount of GHGs present in the atmosphere are dependent on the frequency of chemical reactions. For example, methane is mostly eliminated by reducing the hydroxyl radicals to make water and CO_2 within its lifespan of 12 years. With a lifespan of about 20 years, the warming ability of methane is 72 times higher than that of CO_2. However, the concentration of methane in the atmosphere zone is currently far lower than that of CO_2 and the comparative warming effect of CO_2 is much higher [24].

Although the South Asian countries emit low levels of GHGs, the CO_2 has relatively been continually amplified in South Asia because of the prompt mechanization and further anthropogenic actions. Among the eight countries, India and Pakistan contribute the maximum emissions of CO_2 in these territories [6]. The consequences of climate change are displayed in different forms such as uneven rainfall patterns, melting of glaciers, sea level rising, and sudden cyclones or floods. The negative impacts of the climate change are now more visible in water resources, agriculture, forests, and other ecosystems.

3 Climate Change and Its Adverse Impacts on Plant Growth in South Asia

3.1 Devastating Floods and Stagnant Water: Their Consequences on Plants

Climate change increases the frequency of flooding globally, which becomes a major environmental threat to plant growth and development. South Asia is one of the most important climate hotspot regions that are prone to frequent and severe floods [25]. Among the natural disasters in South Asia, floods are the most common in this region which are approximately 40 per cent of all natural disasters [26]. The frequency and severity of flooding in South Asia have increased over the past several decades. It is estimated that around 9.6 million people are currently affected by flooding in South Asia [25]. Widespread monsoon flooding occurs in South Asian countries and the flash flood is also very prominent in this region, which occurs suddenly and progresses just as quickly as it regresses causing severe crop losses [27]. In South Asia, urban flooding is also a common problem in some parts of this region due to improper solid waste management and planning, which also causes damage to urban vegetation. Recently, millions of people across Bangladesh, India, and Nepal have faced a serious flooding, which destroyed their habitants and crops. Unfortunately, 550 people lost their lives and more than 9.6 million people have been overflowed across the South Asia [28]. According to Indian National Emergency Response Centre, about 6.8 million people have been affected by devastating floods in India. In Nepal, many peoples have been evacuated from their homes and around 110 people were killed by flooding and landslides [28].

Flood or excessive moisture in soil negatively influence plant growth and development [29]. Excessive moisture in the soil is responsible for the decrease in plant growth due to a combination of a number of factors. Flooding decreases the oxygen level in the soil, which impedes root respiration and finally leads to the accumulation of carbon dioxide, methane, and nitrogen gases in the root zone. This condition ultimately leads to the death of plants due to suffocation of plant roots. Furthermore, flood or excessive moisture in the soil increases the accumulation of toxic compounds in the soil such as ethanol and hydrogen sulfide (Fig. 1) [30–32], which are also responsible for reduced plant growth and productivity [33]. In the case of severe flooding, plants get totally submerged in water. If leaves and stems are completely submerged, plants experience a decrease in their photosynthetic capacity which ultimately inhibits plant growth, turning it slow or it completely stop [34]. If the plants are exposed to long-term flooding, they become more prone to infection by different disease-causing organisms. For example, excessive moisture in soil tends to favor growth of different microbes (*Fusarium spp*., *Phytophora spp*.), which are responsible for root diseases such as the crown rot disease [35]. Therefore, flood or excessive moisture in soil decreases plant growth by decreasing root respiration and photosynthetic capacity, increasing the accumulation of toxic compounds in soil and disease infestation [36]. In addition, soil erosion is one of the major problems due to flooding; deposition of soil on small plants also damages plant growth and decreases its productivity. Plant roots become exposed to air due to washout of soil surrounding the roots and make them more likely to be uprooted by windy weather [37]. Young plants get more damaged during flooding due to deposition of soil and rocks on to plants; however, healthy and established plants are generally more tolerant to flood than young or very old plants [38]. Damage to plants due to flooding depends upon the longevity of flooding and plants continue to suffer by excessive moisture in the soil even after drainage of the water until the soil gets dry. Researchers are trying to address this severe problem of flooding in South Asia and recommended some ideas to combat this problem. Community preparedness and awareness build up by both government and non-government organizations could be the best possible way to mitigate crop losses. Development of submergence-tolerant crop species could be another possible way to avoid crop losses. Adoption of modern technologies to grow plants in raised beds to avoid the flooding water and the development of short duration crop genotypes to skip from the flooding water, especially flash flood, are another possibility.

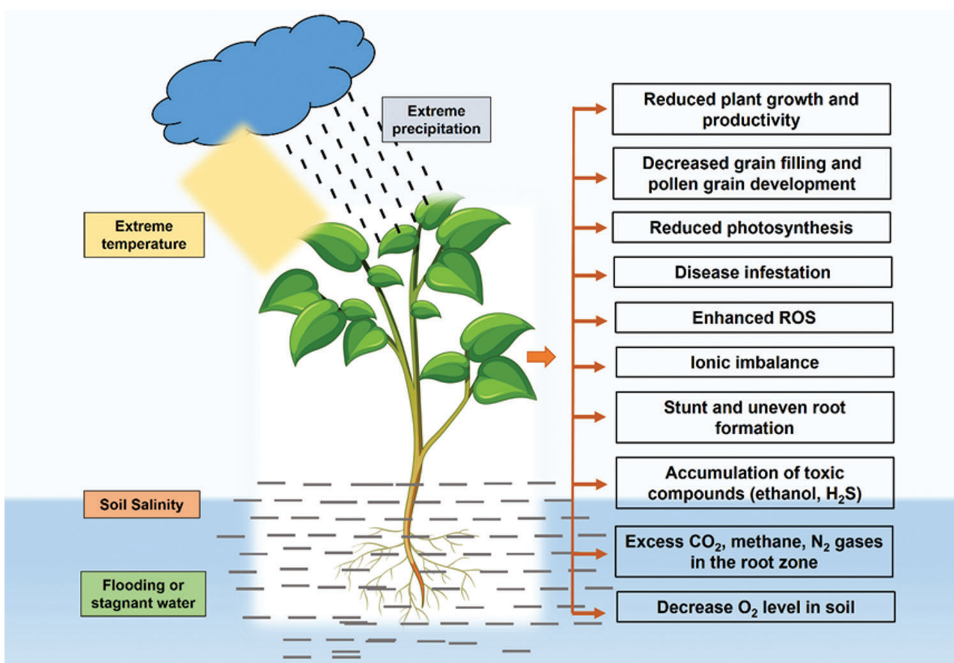

Figure 1: Climatic variability and their possible negative effects on plants. Different climatic factors affect growth and development by decreasing O_2 level, accumulating toxic compounds, increasing reactive oxygen species (ROS), etc., in the rooting zone

3.2 Enhanced Temperature and Its Impacts on Plants

Global oceans excite tremendous heat due to reducing the size in which a huge quantity of collected heat energy is responsible to raise the earth's average surface temperature. In recent centuries, a significant increase in accumulated heat is due to global warming. That extra heat leads to temperature extremes, melting of snow cover and sea ice, intensifying rainfall patterns, and consequently, hampers the ecosystems. Nowadays, the numbers of cold days and nights have decreased and those of warm days and nights have increased across most of Asia. In large parts of Asia, heat wave frequency has increased since the middle of the 20th Century. It is observed that enhanced-temperatures showed positive and negative trends in South Asian countries. For instance, the occurrence of temperature variability has showed a significant decrease in the small regions of India, where a negative trend in the annual number of summer days and annual number of consecutive dry days have been observed [39]. Sheikh et al. [40] reported that different weather stations across India, Nepal, Sri Lanka, and Pakistan showed an increment in the night-time temperatures and warmest day-time temperatures. The several South Asian countries showed an above-normal temperatures in the recent past. In India, temperature increased with an average warming of 0.51°C, which was higher than the 30-year climatological normal [41,42]. In Sri Lanka, annual mean temperature during the period of 1871–1990 showed a 2°C increment of temperature in most regions of the country [43,44]. During 1963–2015, in the Tibet, among 112 weather stations, 87% and 71% of them showed an increment in monthly minimum and maximum temperatures, respectively [45]. Although temperature increases had been reported in all the countries in South Asia, the key temperature in Maldives did not change [46]. In last few decades, in the cold season between November and March, the warming trend determined an increase of 2.4°C in the mid-latitude semiarid areas of Asia [47]. Since the 1960s, the temperature has been increasing at a rate of 0.14°C to 0.20°C per decade across South Asia [47]. Due to the enhanced temperature, the onset of monsoons in South Asia delays up to 15 days [48]. Schewe et al. [49] predicted that in the late 21st century and early 22nd century the enhanced temperature will trigger recurrent fluctuations of the monsoon precipitation up to 70 per cent below normal levels. There are many reasons behind the increasing temperatures. One of the most accepted reasons is GHGs, which trap heat and prevent it from leaving the earth's atmosphere. Agricultural systems are the major sources for the emission of GHGs such as CO_2, methane and nitrous oxide which are contributing to the increase of global temperature [50,51]. Due to industrialization, deforestation, transportation, consumerism, overuse of electricity, and use of aerosols the temperature is increasing daily in South Asia.

Suitable temperatures and enough water are essential for the crops that we grow for food. Climate change has both positive and negative effects on crops. Increasing temperatures have adverse effects on plant growth in many ways. Plant growth and development are dependent on the temperature surrounding the plant species as plants require specific optimum temperatures [52]. Plant physiological processes such as photosynthesis and respiration both rise with increasing temperatures [53]. As a result, crop yield losses have occurred. It is well-known that high-temperature stress induces oxidative damage by the generation of ROS in plants [54] and that ROS affects cell functioning by damaging membranes, lipids, and proteins. Oxidative damage further leads to membrane instability, which further affects the photosynthetic processes such as diminishing chloroplasts and reducing assimilate transportation. The outcome is largely a yield reduction and quality [55]. South Asia has mostly cereal crops like rice, wheat, maize, etc. It has been reported that the enhanced temperature has an adverse impact on rice and wheat yields [56]. Rising temperatures greatly influence not only the growth duration but also the growth pattern and the productivity of rice. Every 1°C increase in temperature determines a rice yield reduction of 10 per cent [57]. Peng et al. [58] reported that each 1°C increase in the growing season mean temperature was associated with a decrease of 15 per cent of the yield of dry-season rice. Wheat is another important cereal crop in South Asia. Kumar et al. [59] reported that 4 to 5 million tons yield losses of wheat in South Asia are due to an increase in every degree Celsius temperature. The effects are more severe if the crop development phases coincide with increases in temperature [60]. Pollen grain development of maize depends on many environmental factors. Temperature is one of the influencing factors for pollen grain development in maize. Maize pollen viability decreases with exposure to temperatures above 35°C [61–63]. Many crops in the hot climate of Pakistan are at the margin of stress, especially cereal crops.

It has been reported that enhanced temperatures seriously affect the grain filling period of crops. For instance, Peng et al. [58] reported that due to fluctuating night temperatures during 2003, the respiration rate was increased and disrupted the photosynthesis causing a reduction in the net gain, and rice grain yield declined 10 per cent for each 1°C increase in the minimum temperature. Due to global warming, agriculture in Bangladesh is already under pressure. In Bangladesh, the temperature shows different patterns during crop production such as low values at the vegetative stages and high values at the reproductive stages. As a result, plant species face severe heat stress in the northern regions of Bangladesh. Reducing climate change is now a hot question for a better crop production. The mitigation should be done by minimizing human interference with the climate as well as adapting innovative approaches such as exogenous application of nutrients and plant growth regulators, and using of seed priming and genetic and breeding techniques for a successful crop production under stress conditions [64,65].

3.3 Severe Drought and Its Impacts on Plants

South Asia is located on the equator and its entire region falls within the warm and humid tropics as influenced by the Asian monsoon. Drought is another major climatic problem for plant growth and sustainable development in this region. The economy of this region greatly depends on agriculture (approximately 40 per cent of GDP), and agriculture highly depends on rainfall. Therefore, water stress causes a significant decrease in plant growth and development, which in turn influences the economy of this region [66]. It has been reported that the successful crop production is drastically reduced due to the inadequate soil moisture content [67]. In the last few decades, South Asian region agricultural lands face serious problems such as moisture content losses due to the uneven rainfall.

Drought is one of the most important abiotic factors responsible for limiting plant growth and productivity. Water stress changes one or more plant physiological processes, which leads to abnormal metabolism and may reduce plant growth (i.e., hydrolysis of starch) [68]. Water stress in soil and plant dehydration also cause a significant change in nitrogen metabolism [69]. Under drought conditions, plants stop protein synthesis and breakdown processes become more active [70]. When plants are exposed to drought stress, they suffer from dehydration of its cells and tissues. Hence, it leads to a considerable increase in the plant body temperature due to a decrease in the transpiration rate [71]. Furthermore, stomatal regulation is an inevitable process for regulating gas exchange and transpirational water loss. Stomata remain closed under drought stress to preserve moisture. As a result, CO_2 cannot enter through the closed stomata which leads to reduced photosynthetic rates [67,72–74]. Less photosynthesis means that less energy is produced by the plant, plant growth ceases and yield is either reduced or not produced (Fig. 2). Drought stress also influences cell wall biosynthesis of plants [75]. It has been reported that cellulose content decreases in the plant cell wall with increasing drought stress [76].

Depending on the intensity of drought, the estimated yield reduction of different crops varies from 10–70 per cent [66]. It has been reported that Aman rice production in Bangladesh was reduced about 25–30 per cent due to the last devastating drought of 2006 [77]. In Afghanistan, during 1990–2009, 12 million farmers were affected by the drought and the cultivation area decayed nearly 70%, where the yields of peas, cotton, wheat, and barley declined by 88%, 17%, and 60–70%, respectively [78]. The combined effect of rainfall, drought, and windstorms caused a crop reduction up to 1–19% in Bhutan [79]. During 2000–2012, consecutive droughts in India caused a severe loss in the agricultural productivity [80]. In Nepal, rice production declined up to 11% due to the drought during 2009–2010 [81].

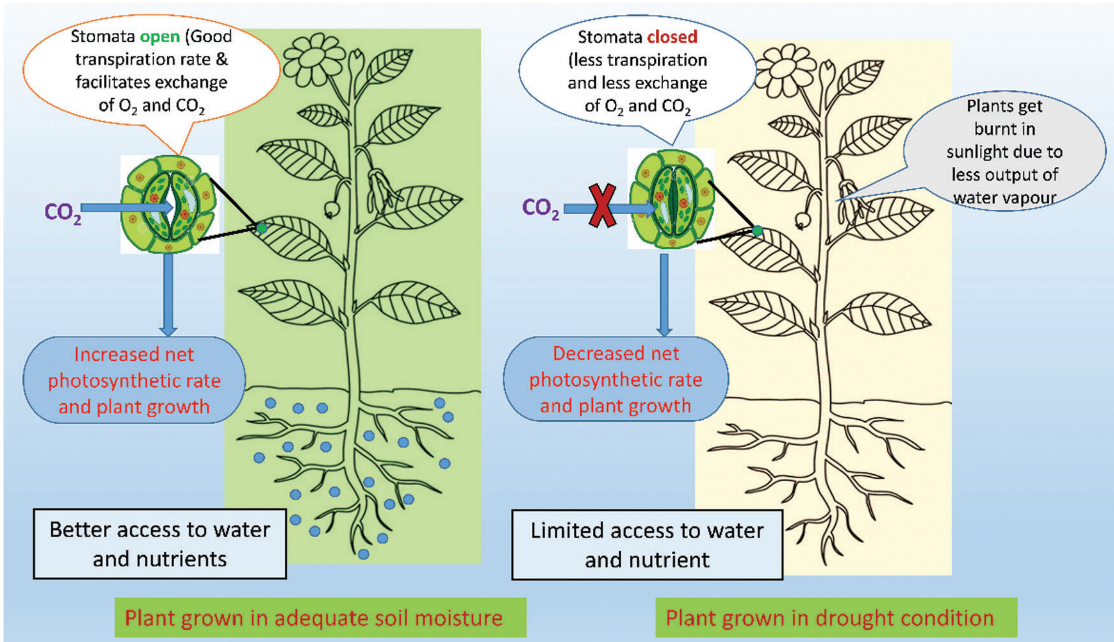

Figure 2: Mechanisms of drought-mediated inhibition of plant growth and yield

3.4 Soil Salinity and Its Adverse Effects on Plants

Climate change causes sea level rising by increasing the temperature of water in the ocean and melting the ice sheets and glaciers continuously. This results in flooding and salt intrusion in coastal areas gradually contaminating the soil [82]. The global sea level is expected to rise at 0.05–0.25 m by 2050 and 0.18–0.80 m by 2100, even with deep reductions in greenhouse gas emissions [8]. This increasing sea level causes a high possibility of saline water flooding in large coastal regions of South Asian countries, leading the people and agriculture to a huge threat [83]. Moreover, the frequency and intensity of tropical cyclones are increasing which results in intrusion of sea water further inland, causing salinity in the river. The effect of salts can be dispelled by precipitation, but drought and heat waves due to climate change led to the more rigorous use of groundwater for irrigation and drinking which further diminishes the water-table and permits even more salt to leach into the soil [84].

It is estimated that around 42 million ha (Mha) of land is affected by salinity, most of which is located in the dry zone. Of this salinized area, approximately 4 Mha is in both India and Pakistan. The irrigated lands are also affected by salinity. Reports showed that 23 per cent of irrigated lands in Pakistan, 10 per cent in India and 9 per cent in Sri Lanka are affected [85]. Bangladesh is the most vulnerable country to salinization among the South Asian countries. Out of 2.88 Mha in the Barisal and Khulna divisions of Bangladesh, a total of 1.05 Mha are distressed by various levels of soil salinization [86]. The intensity and severity of soil salinization are increasing over time, and in the last four decades, the salinity affected region increased from 0.83 Mha to about 1.05 Mha within 1973 to 2009 [86]. There was an increase in the affected area by 0.19 Mha from 1973 to 2000, and a further increase by 0.04 Mha from 2000 to 2009 [86]. It is predicted that if the sea level is rising next to a 1 m level, Bangladesh will face serious problems such as about 15 per cent land will be affected. Moreover, many other climate change-related factors are responsible for the increasing soil salinity in Bangladesh, such as saline river water inundations, irrigation using saline water, storm surge, irregular rainfall, evaporation, and brackish shrimp farming [86,87]. The IPCC foreseen that due to the sea level rising, 17 per cent of land area, 30 per cent of food production, and 20 million people will be affected by 2050 [7].

Soil salinity harshly impedes plant growth and productivity through water stress, nutritional imbalance, and Na^+- and Cl^--induced cytotoxicity (Fig. 1) [88,89]. Salinity usually produces ionic and osmotic stress on plants and reduces plant growth and development [90,91]. Under the saline conditions, the concentration of solutes increase in the root zones, causing a decreased soil water potential. Therefore, under such circumstances, the plant cannot uptake adequate amounts of water from the soil, which unable plants to maintain cell turgor which is known as osmotic stress, and it is the primary effect of salinity on plants [91]. This turgor loss happens within a short time period, and triggers stomatal closure and inhibition of cell expansion mainly in the shoot [92]. However, at low to moderate salinity stress, plants accumulate certain extent of osmolytes to adjust the osmotic balance for the influx of water into the cell [90]. At high salt concentration, specific plant damage symptoms become visible, such as the burning of leaf tips, chlorosis, and necrosis. Also, high ionic concentrations disrupt the plasma membrane function and integrity which lead to internal solute imbalance and malfunction in nutrient uptake causing nutritional deficiency [93,94]. Additionally, salinity usually induces oxidative stress due to the generation of reactive oxygen species (ROS) [95,96]. Moreover, salinity affects photosynthesis by decreasing CO_2 availability and reducing photosynthetic pigment contents [97].

Salinity reduces the yield of crops which have high economic impacts on agriculture. It has been reported that every year soil salinity causes a huge economic loss which is equivalent to around 27 billion US dollars [98]. Moderate soil salinity (8 to 10 dSm^{-1}) causes 55, 28, and 15 per cent yield losses in maize, wheat, and cotton, respectively. A high soil salinity (18 dSm^{-1}) resulted in a 55 per cent yield loss in cotton, and complete death of rice and wheat [99]. Rice covers the majority of the field crop sector in South Asia, such as 71 percent in Bangladesh [100]. Soil salinity limits the rice plant's growth and development, resulting in yield losses of more than 50 per cent [101], yield of rice will be reduced by 12 per cent for every unit of salinity (dSm^{-1}) increment [102]. Thus, climate change-induced sea level rising and soil salinity are a powerful threat to agriculture and the food security of the South Asian countries.

It is well-known that both drought and salinity stresses promote cellular dehydration, which causes osmotic stress, removal of water from the cytoplasm into the apoplast, and consequently excess water loss from the plants [103]. However, plant cells are able to prevent water loss by maintaining the ionic homeostasis and decreasing the osmotic potential in drought- and salt-stressed cells. It has been reported that drought and salinity tolerance mechanisms might be functionally interchangeable in plants due to the similar mechanisms of the stress response [104,105]. Researchers are trying to resolve the problems created by stresses using innovative techniques. Recently, a plant genomic approach is gaining attention to improvement of stress-tolerant crops. Recent scientific advances and the stress-induced challenges in agriculture have accelerated the importance directed to the plant genomics approaches for the improvement of stress-tolerant crops [106]. It has been reported that genomic approaches involve the entire genome, and genic and intergenic positions, to achieve new perceptions into the functional and molecular responses of plants, which will consequently offer specific techniques for crop plant stress-tolerance improvement [107]. Recently, many studies have revealed promising outcomes toward understanding the molecular mechanisms of salt and drought stress tolerance in different crops using progressive genomic approaches [108,109]. Therefore, to overcome the stress-induced damages of crop plants as well as the improvement of stress-tolerant crop plants, plant genomics approaches could be a feasible technology.

3.5 Variability of Precipitation and Its Effects on Plants

The global temperature increase is accompanied by changes in other climatic variables. The most visible increase has been observed in the case of summer rainfall patterns throughout South Asia. In this region, seasonal mean rainfall shows a fluctuating and declining trend with more frequent deficit monsoons under regional inhomogeneities, and light rain events are decreasing on a daily basis while the frequency of heavy precipitation events is increasing [47]. South Asia has many large rivers, which are an important contributor to the regional economy. Himalayan-Hindu Kush is extensively covered by ice masses and it is the source of the nine largest rivers of Asia, including the Ganges, Brahmaputra, and Indus. These ice-mass covered rivers are the source of water for more than half of the world's inhabitants. It has been reported that the wet-day rainfall has enhanced by 22 mm, and rainfall from extreme rainy days has enhanced by 10 mm per decade annually. The climatic variability occurs across this region and between seasons [47]. In recent years, some areas are facing heavy rains which had never seen regular rainfalls in the season; other areas where rainfall was so frequent and heavy are getting almost nothing. Northeast or Southwest monsoons mainly contribute to the rainfall patterns of South Asian countries. Different studies showed that South Asian monsoon rainfall extremes are becoming relatively frequent [110,111]. It has been reported that the monsoon regions of Pakistan showed intense rainfall events [112]. However, during 1976–2005, contrasting trends of decreased rainfall events have also been observed in Pakistan [113]. In Nepal, an increasing trend of annual mean rainfall has been observed during June and July [114]. In Sri Lanka, extreme rainfall events have been observed in the southwestern parts of the country [115].

Due to the uneven precipitation throughout South Asia, it is facing a serious problem in crop production. In these regions, over 60 per cent of all agriculture depends on rain, and therefore remains highly sensitive to changes in rainfall patterns [116,117]. Rice is one of the key staple crops in this region which are going to be hampered by changing rainfall patterns. Bangladesh is a sub-tropical country where the Aman rice depends on the monsoon rain [118]. Currently, the Aman rice production in Bangladesh is hampered due to the variability of the monsoon rain [119]. Pulses are the most important crop after rice and the second most important crop in Myanmar which are widely cultivated in South Asia. During the crop growing seasons, uneven precipitation, especially rain at the flowering stage, can affect flowering by shedding and failure to pollinate them which ultimately affects fruit setting and consequently leads to yield losses [120]. Sardana et al. [121] reported that cloudy weather or rain at the flowering and fruiting stages adversely affect pod setting and seed filling in pulses and may lead to increased damage from pod borers. In arid and semi-arid regions of Asia, the demand of agricultural irrigation water is estimated to increase by at least 10 per cent for an increase in temperature of 1°C [122]. As a result, in the dry lands, farmers are facing a serious problem for cultivating crops. Weather-index based crop insurance programs should be introduced for the farmers to mitigate this climate-related disasters.

3.6 Increased Frequency of Extreme Events and Their Adverse Impacts on Plants

Currently, South Asia has been exposed to a series of extreme weather events such as storms, cyclones, landslides, etc. Several studies showed that uneven precipitation has increased in many parts of South Asia, causing severe flash floods, landslides, and debris and mudflows, while the total amount of annual precipitation has decreased [123,124]. In the recent past, some South Asian countries like India and Bangladesh faced cyclones every year. In 2019, cyclone FANI hit India and Bangladesh and as a result 15 people were killed in India and around 30 people were injured in Bangladesh. South and south-western districts of Bangladesh have faced a notorious cyclone named SIDR in the recent past in 2007. It killed over three thousand human-beings, and thousands of animals and livestock, and caused severe damages to coastal ecosystems. In Myanmar, a cyclone Nargis killed over 100,000 people and destroyed the lives and livelihoods of millions of people in 2008. In August 2018, the southern Indian state of Kerala experienced its worst flooding in a century, leaving more than 1,200 people dead and 1.3 million displaced.

These natural extreme events not only destroyed the human community but also had an adverse effect on the plant community as well as the whole ecosystem. Due to flash floods, South Asia faced a serious problem in crop production and its subsequent effects in recent years. As a result of stagnant water, soil moisture increases led to the accumulation of toxic compounds in the soil such as ethanol and hydrogen sulfide [32], which are known to reduce plant growth and productivity [33]. Land degradation processes such as mass movements, landslides, and soil corrosion are occurring day after day due to changes in the frequency of extreme events. Field crops in coastal areas are severely affected by cyclones through their high-speed winds, torrential rains, and extensive flooding. Due to high tides, sand masses and salinity make the soil inadequate for agricultural crops.

4 Upcoming Climatic Challenges and Food Security in South Asian Countries

Climate and agriculture are closely related to each other as the climate is a primary responsible factor in crop production. More climate-related warnings are knocking the door in the near century. Higher northern latitudes and land surfaces are expected to be extremely warm in the twenty-first century. Due to a future warmer climate, it is expected that heat waves will be more extreme and recurrent. Hijioka et al. [47] projected that the future annual precipitations are going to be extreme in higher latitudes by the mid-21st century, and over eastern and southern latitudes by the late 21st Century. It has been reported that future increases in precipitation are very closely related to the monsoons which are very likely in South Asia. At the end of the century, in South Asia, temperatures may increase by several folds and rainfall may increases by 40 per cent. In recent times, South Asia became the most vulnerable zone to cyclones and storms. It is expected that the sea surface temperatures will increase 2–4°C relative to their current temperatures in South Asia due to the increment of storms. The recent storm-surges are increasing due to the stronger winds. As a result, sea-surface temperatures and low pressures associated with tropical cyclones will increase and consequently have adverse impacts on the coastal regions of the South Asian countries.

Because of high-level global warming, models based on existing agricultural arrangements indicate huge negative influences on the agricultural sector regarding worldwide food production and security. It is well-known that climate change and crop production are disproportionately linked with each other [7]. Changes in climatic factors such as temperature, precipitation, and the increased frequency of extreme events like cyclones, droughts, flash floods, landslides, and wind storms negatively affect crop yield and livestock production. Due to changes of climatic patterns, long-term negative effects on agricultural production are expected in Asia [125]. South Asia is expected to be highly vulnerable to this effect [3,124]. Nelson et al. [10] reported that by the end of this century, changing climate will reduce production up to 40 per cent compared to the existing conditions. Carbon dioxide is essential for plant survival and production. Due to global warming, its rising concentrations may have adverse effects on the plant survival mechanisms as well as productivity. The variability of climate change is also responsible for the uneven precipitation water supplies and the harshness of soil corrosion [126].

FAO [85] reported that 2–3rd of the world's hungry population live in just seven countries like Bangladesh, China, Congo, Ethiopia, India, Indonesia, and Pakistan. Most of these countries are located in South Asia and only depend on the agricultural production. Millions of small farmers sustain their livelihood by rain-fed agriculture. But in this era, climate shows a huge variability which results in erratic rainfall and affects cropping patterns in many regions of South Asia. The agricultural sector requires careful management of the natural resources like soil, water, and biodiversity. Conventional growth strategies should be replaced by new developmental strategies to cope with the impact of climate change in this energy-climate era. In this regards, intensive steps should be taken by South Asian governments along with non-governmental organizations and policy-makers to create mass awareness about the impacts of climate change.

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