Chapter 1
Global Prospects of Climate-Resilient Agriculture

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Abstract Climate change is the main reason for the different abiotic and biotic stresses in agriculture, and it adversely affects crop production and yield. Fluctuating climate conditions such as rainfall, drought, and temperature can cause global changes in atmospheric carbon dioxide levels and sea level rise. These alarming global events have attracted the attention of agronomists because of the detrimental impacts of climate change on the agriculture sector and food security under increasing global food demand. Therefore, climate-resilient agriculture is the only possible and most appropriate solution to mitigate the negative impacts of climate change. Therefore, it is imperative to focus on global food production and its security under changing climatic conditions to meet the needs of the fast-growing population. To deal with climatic fluctuations, different global agricultural practices including water, land, crop, and livelihood management strategies are being adopted worldwide to improve climate-resilient agricultural crops. In addition, the modifications in the plant genetic material such as genomics (molecular plant breeding), genetic

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engineering, and other genome editing approaches are practices to develop climate-resilient transgenic crops to enhance crop productivity and yield. Moreover, conservation agriculture can also be effectively converted into sustainable agriculture through different land management practices and resource utilization. Plants also use various adaptive strategies such as physiological, biochemical, and molecular mechanisms to cope with harsh environmental conditions. However, more research is required to design and develop more climate-resilient management strategies and eco-friendly and resistant agricultural crops under changing climatic conditions.

Keywords Climate change · Sustainable agriculture · Conservation agriculture · Food security

1 Introduction

Climate change refers to the persistence of continuous changes of the Earth's climate over a prolonged period. The primary energy source of planet Earth is the sun which is absorbed in various states, and surplus energy is sent back to the space. The proportion of obtained and liberated energy from the atmosphere of the Earth is designated as the Earth's energy budget (Garrett et al. 2015; Fahad et al. 2019). There are several human activities that result in the absorption of extra energy and, hence, a warmer climate. These human activities are mainly accountable for the shifting of the Earth's energy budget towards positively enhancing climatic temperature with adverse impacts on humans, animals, and agriculture (Zhang et al. 2014; Fahad et al. 2018). The demand for agricultural production will be increased to feed the fast-growing human population. However, climate change adversely affects different forms of agriculture and causes disorders in ecosystem functioning. However, some adaptive strategies showed beneficial outcomes for some crops under moderate climatic conditions (Adnan et al. 2017; Zamin et al. 2019). Therefore, developing different crop varieties with climate resilience can provide better food sources to alleviate poverty, especially in Asia and Africa (Varshney et al. 2011). Moreover, the emission of greenhouse gases (GHGs) has significantly increased, and an average rise in annual temperature by 0.8 °C is predicted causing global warming. Surprisingly, these greenhouse gases have been released continuously worldwide for the last 25 years (Sharma and Ravindranath 2019).

In addition, climate change significantly influences all living organisms such as microbes. The rise in the levels of CO_2 in the atmosphere can have unforeseeable effects on agriculture. Increased CO_2 concentrations can enhance the net photosynthetic rate as well as plant growth, but in contrast, it can reduce the quality of crops in terms of nutrition (Irigoyen et al. 2014). Further, the concentration of CO_2 in the atmosphere before the industrial revolution was 28 ppm which has significantly increased up to 397 ppm till now. According to an estimation, this concentration will increase two times at the end of this century. Furthermore, this rise in CO_2 atmospheric level poses severe risks to plants and perturbs plant defense responses against various types of biotic and abiotic stress conditions. For instance, the attack of barley yellow dwarf virus on wheat plants has significantly increased due to the higher levels of CO_2 (Trębicki et al. 2015). Concurrently, the interplay between water deficiency and heat shock conditions also alters CO_2 assimilation, stomatal conductance, and leaf temperature resulting in disturbed photosynthetic rate and plant growth (Feller 2016). The high temperature under water-deficit conditions aggravates plant growth and productivity in many cereal crops (Ihsan et al. 2016; Zandalinas et al. 2018). Additionally, the effect of heat was studied in soybean and maize, and the results showed that the increase in seasonal temperature by 1 °C reduced the crop yield of soybean and maize by 3.1% and 7.4%, respectively (Zhao et al. 2017). In parallel, water scarcity can influence various physiological processes in plants such as pollination, flowering, and grain filling. In contrast, an elevation in humidity level can also increase pest and insect attacks (Munawar et al. 2020).

Moreover, pathogenic attacks of pests, insects, and fungal species are also predicted under changing climatic conditions based on geographical regions. Various *Fusarium* spp. adversely affect important cereal crops, causing yield reduction worldwide (Shabani et al. 2014: Iqbal et al. 2020, 2023). These fungal pathogens cause *Septoria tritici* blotch and *Fusarium* head blight in wheat in China, the UK, and Europe because of changing climate (Fones and Gurr 2015). Climate change has also compelled farmers to deploy climate-resilient agriculture approaches instead of old traditional methods. These practices include growing diverse and stress-tolerant crops, restoring soil fertility, and harvesting rainwater to enhance food security in the agriculture sector (Altieri and Nicholls 2017). Additionally, the use of modern techniques for a climate resilient agriulture can also be improved with the assistance of farm inputs, market risks, and proper checks and controls (Issaka et al. 2016). Therefore, knowledge in plant physiology and molecular mechanisms including genetics will assist scientists in the development of climate-resilient crops. Next-generation breeding is also a possible option using plant germplasm, data management skills, and biotechnological techniques (Taranto et al. 2018). Parallelly, the utilization of omics approaches, genomic editing, *cis*-genesis, and in vitro regeneration could lead to the establishment of second-generation biotechnological products required for sustainable agriculture (Cardi and Neal Stewart 2016). In addition, genome editing facilitates the development of resilient crops against changing climatic conditions through accurate and precise changes in the genome (Courtier-Orgogozo et al. 2017). It is estimated that the world population would be around nine billion by 2030. At the same time, it would be difficult to deal with changing climate for the provision of food resources. Therefore, it is necessary to develop crops that are resilient against environmental conditions. In addition, the integration of molecular plant breeding and genetic editing, as well as engineering approaches, could assist in developing climate-resilient crops.

2 Climate Change-Induced Effects on Agriculture and Food Security

The drastic effects of climate change over time have been reported in the agriculture sector. Crop productivity has been adversely affected as a result of various environmental factors including high temperature, floods, salinity, and drought. On the other side, adaptive measures can be a suitable option by reducing the susceptibility of the natural ecosystem (Klein et al. 2014). Climate change is considered the main driving force influencing agriculture production because of the industrial and urbanization developments (Wheeler and Von Braun 2013). Moreover, developing countries in Africa and Asia are facing this climate challenge seriously due to a lack of technical and financial aid. Some countries in Africa have food shortages due to water scarcity. In addition, wheat production in South Asia will be reduced by up to 50% by 2050 according to the International Water Management Institute (IWMI). It is estimated that this amount accounts for 7% of food production, resulting in food insecurity (de Fraiture et al. 2007; Munawar et al. 2020). Some studies reported that South Asia and sub-Saharan Africa are facing food shortages and are the most vulnerable regions to changing climate (Vermeulen et al. 2012; Bandara and Cai 2014). Pakistan is enlisted in those countries which have a 65% population and are facing food security problems. According to the Food and Agriculture Organization (FAO), some Asian and African countries cannot afford preventive measures to stop climate change and are unable to meet the Millennium Development Goals (MDGs) and zero hunger (FAO 2015).

The world population is rapidly increasing in an uncontrolled manner which consequently shows a fast and high demand for food supply. In addition, the high food prices and food insecurity will further worsen this scenario and cause the failure of the global food supply (Fischer et al. 2014). Therefore, 1.1–1.3% annual production of main crops is unavoidable to deal with the current challenge (Buchanan et al. 2015). The population in India will be around 1.6 billion by 2050 and will require 400 million tonnes of food. Therefore, the sustainable production of food is very crucial, utilizing the same resources and land. At the same time, the drastic effects of climate change could also affect environmental conditions for future food production. Highly water-scarce areas in Europe will face 19–35% water scarcity by 2070 along with reduced water quality and availability (Husaini and Tuteja 2013). Further, climate changes can cause increased temperature, flooding, higher CO_2 levels, more concentrations of O_3 in the troposphere, saline and sodic soils, heavy precipitations, land degradation, and waterlogged conditions, which will eventually affect agricultural crops and their productivity. Furthermore, the diversity and abundance of agricultural pests and pathogens will also be affected because of changing climatic conditions (Abberton et al. 2016).

Greenhouse gases including methane (CH_4), CO_2, nitrous oxide, hydrofluorocarbons, and sulfur hexaoxide reflect solar radiation and increase global warming. Different agricultural practices such as deforestation, grazing, and use of synthetic fertilizers have significantly increased (25%) the production of greenhouse gases.

Further, the cultivation of beneficial crops and the reduction of greenhouse gases should be practiced to mitigate climate change for food security (Wakjira 2018). The production of drought-resistant traits in the agriculture sector can reduce the effects of climate change in drought-prone areas, avoiding desertification. Another study documented that 45% of irrigation requirements will increase by 2080, and 20% of water withdrawals will increase due to the upgradation of the irrigation system (Ali et al. 2017). Parallelly, the Sustainable Development Goals (SDGs) have been introduced worldwide to eradicate poverty, malnutrition, and hunger by 2030. Interestingly, biotechnology offers a possible solution to reduce climate change by implementing various strategies such as carbon sequestration, reduction in the use of synthetic fertilizers, and energy-efficient farming (Wakjira 2018; Munawar et al. 2020). Therefore, transgenic crops can play a critical role in food production under changing climate to alleviate poverty, eradicate hunger by reducing global warming, and maintain agricultural sustainability.

3 Effect of Climate Change on Crop Yield

Climate change has adversely influenced plant physiology through various means. Environmental stresses increased the possibilities of plant stresses due to variations in climatic conditions (Thornton et al. 2014). Climate change can have negative impacts on plants through different types of exposure such as direct, indirect, and socioeconomic. Climate change such as extreme temperature, floods, storms, drought, etc. has drastically enhanced according to the FAO (Raza et al. 2019). According to a study, climate change has significantly reduced crop yield by around 70% since 1982 (Boyer 1982). It is reported that abiotic stress conditions have an adverse impact on crop productivity. This predicts that in the future, many countries will face shortages or drops in major crops because of global warming, water scarcity, and other severe environmental consequences (Tebaldi and Lobell 2018; Bonan and Doney 2018). Various differences in crop vulnerability to climate change were found in Europe depending on the national crop yields survey. Similarly, Northern Europe is facing problems such as the short duration of crop production and low temperatures. However, in Southern Europe, temperature extreme and less rainfall are limiting crop productivity. Further, adverse and severe negative impacts were reported in Hungary, Serbia, Romania, and Bulgaria (Olesen et al. 2011). It is anticipated that the Mediterranean area will have reduced crop yield while North-Western Europe could produce a high crop yield (Olesen and Bindi 2002).

Likewise, in several countries, wheat production is largely influenced by extreme temperatures that decrease crop yield by up to 6% per 1 °C rise in temperature (Asseng et al. 2015). Therefore, the high temperatures and water-deficit conditions are the main reasons for reduced crop yield (Barnabás et al. 2008). Moreover, the activity of the *Rubisco* enzyme is disrupted above 35 °C, and the photosynthesis process is negatively affected (Griffin et al. 2004).

It was reported that both extreme heat and drought could badly affect the crop yield of barley, maize, and sorghum as compared to individual stresses (Wang and Huang 2004). This effect was also confirmed when both stresses (heat and drought) were given to *Leymus chinensis* and resulted in the reduction of photosystem II (Xu and Zhou 2006). The plant reproductive processes such as flowering and inflorescence were also significantly influenced due to extreme temperature and drought events. For instance, a temperature around 30 °C can result in sterility during floral development (Raza et al. 2019). Another research studied the effects of climate change on crop yield and reported significant reductions of about 3.1%, 3.2%, 6%, and 7% in soybean, rice, wheat, and maize, respectively (Zhao et al. 2017). However, the development of climate-smart agriculture through genomic approaches has offered new possibilities to deal with changing climatic conditions (Scheben et al. 2016). Drought stress also has a bad impact on the developmental stages of the wheat crop, especially during grain formation and reproductive levels (Pradhan et al. 2012). Further, wheat crop yield was decreased to 30% during mild drought conditions and 92% during prolonged drought, affecting grain formation as well as flowering (De Oliveira et al. 2013). Furthermore, water-deficit conditions have greatly decreased legume yields. For instance, mashbean yield decreased from 57% to 31% at the time of flowering and 26% during the reproductive phase under drought conditions (Baroowa and Gogoi 2014). Similarly, a 42% reduction in soybean yield was noticed due to drought stress during the grain filling stage (Maleki et al. 2013). Hence, food security is badly affected by climate change, causing disturbance to the agrochemical environment. Climate change can directly influence crop yield, reduce income circulation, and enhance the demand for agricultural products.

4 Conservation Agriculture Under Climate Change

Previously, seeds were sown in the fields by farmers by making furrows using conventional methods like plowing with oxen. Later, the green revolution globally focused on more food production for the growing population by utilizing chemical fertilizers (Timsina 2018). Chemical fertilizers enhanced food production but on the other hand significantly affected environmental quality, e.g., soil degradation (Bhan and Behera 2014). Undoubtedly, the green revolution provided sustainable agriculture production for 50 years to eradicate poverty (Meena and Lal 2018). Climatic changes pose a global problem due to the industrial revolution, environmental pollution, deforestation, and the release of greenhouse gases (Mbow et al. 2017). The higher emissions of greenhouse gases have caused altered rainfall patterns, increased temperature, and raised sea levels resulting in the melting of glaciers (Mbow et al. 2017).

The conservation of agriculture and its management system is a complex process and includes management practices to enhance sustainable agriculture production using agronomic practices based on targeted crops and environmental conditions of the specific region. The main objective of conservation agriculture is to conserve natural resources, reduce soil erosion or degradation, and improve soil fertility without any harmful effects on crop production (Hossain et al. 2021). The environmental problems due to the cultivation of monoculture can be alleviated by crop diversification. Efficient management of different factors such as soil, landscape, crop, water, and nutrient can promote sustainable agriculture production (Bahri et al. 2019). The use of conservation agriculture has been found more effective in increasing crop productivity by 20–120%. In addition, this strategy can reduce the application of fertilizers by preventing runoff, increasing the efficacy of resource use, reducing irrigated water, producing resilient crops against pests and other diseases, and enhancing crop production (Alam et al. 2017a, b). Similarly, reduced tillage can also improve soil health by up to 30% by decreasing soil erosion and water loss in the soil (Gupta and Seth 2007; Alam et al. 2017a, b). In addition to reduced tillage, other tillage forms such as strip tillage, ridge tillage, mulch tillage, and zero tillage have been used in agricultural practices for the conservation of agriculture (Farooq and Siddique 2015). Moreover, the global prospects of agricultural crops regarding the sustainable use of land, less labor work for crop management, and provision of ecosystem services are not uniform (Hossain et al. 2021). Therefore, geographical and socioeconomic factors have a huge impact on sustainable agriculture production. In addition, government support and effective planning can increase the chances of implementation of agricultural practices to reduce the harmful impacts of climate change.

5 Global Climate-Resilient Agricultural Practices

Several agricultural practices or strategies are employed by farmers to mitigate the negative effects of climate change. These practices include modern as well as conventional approaches. The conventional strategies used in Bangladesh, India, and China require more labor (Viswanathan et al. 2012; Altieri and Nicholls 2017). In parallel, smart farming practices such as aerial vehicles (drones) for weed detection and Microsoft's Cortana Intelligence for the selection of planting dates are popular globally (López and Corrales 2017; Lottes et al. 2017). The farmers adopted these climate-resilient agricultural practices regarding water management, crop management, land management, and livelihood management (Fig. 1.1).

5.1 Water Management Practices

Water management is critically important for sustainable agriculture worldwide even under contaminated freshwater resources. Further, the management of irrigation practices such as deficit irrigation, combined use of groundwater and surface water, water reuse, desalination, and use of water harvesting techniques has played a significant role under changing climatic conditions (Viswanathan et al.

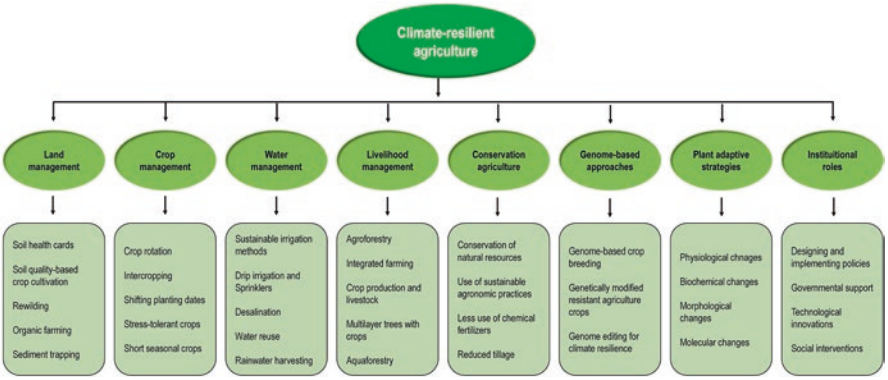

Fig. 1.1 A schematic diagram of various agricultural management strategies used for sustaining climate-resilient agriculture

2020). Therefore, irrigation is considered the most adopted strategy to enhance crops, and the selection of irrigation methods is vital to sustaining water resources (Finger et al. 2011). For instance, micro-irrigation system including sprinkler as well as drip irrigation has become popular in drought-prone areas in India (Viswanathan et al. 2016). In addition, drip irrigation proved to be of utmost significance in Israel, especially in drylands (Tal 2016). Simultaneously, the use of both drip irrigation systems and sprinklers has been adopted across all states in India to mitigate stress conditions caused by climate change (Kumar and Palanisami 2014; Bahinipati and Viswanathan 2019). Another report documented that the adoption of a micro-irrigation system saved 38% water and 58% energy (Kumar and Palanisami 2019).

Desalination is also an efficient approach to deal with water shortage in the agriculture sector (McEvoy and Wilder 2012). For example, wastewater in Vietnam was reutilized to grow rice crops and helped to reduce problems related to water scarcity (Trinh et al. 2013). However, the use of the desalination process for irrigation purposes is more expensive than traditional water bodies. In contrast, desalinated water could be beneficial for economic crops with certain subsidies. Similarly, brackish water can also be a good option in the agriculture sector as compared to marine water (Beltrán and Koo-Oshima 2006). In addition, the use of laser land leveling has also become popular as a water management strategy. Laser leveling is used to level or smoothen the soil surface which can greatly reduce irrigation time and enhance crop yield by up to 7% more than conventional methods (Aryal et al. 2015).

However, another strategy is the intensification of rice which proved to be an effective approach to manage water scarcity and increase rice yield by 25–50%. This approach along with wheat intensification is used for water management in drought-prone areas in Asia (Satyanarayana and Thiyagarajan 2007). Other studies also confirmed that these two intensification methods offer possibilities to enhance crop production with efficient outcomes (Varma

2018; Nayar et al. 2020). Additionally, the harvesting of rainwater is another old method to save water in arid areas. Some studies reported that the collected water from rain can also be used for drinking purposes under extreme water-deficit conditions (Jones and Hunt 2010; Viswanathan et al. 2020). A current report showed that rainwater harvesting and its effective use by constructing ponds or tanks can remarkably increase crop intensity. The existing watersheds can be revived to lessen climatic effects on water sources, especially in drought-affected regions, and can be used by local farmers to increase resilience under worse climate conditions (Patnaik and Das 2017; Patnaik et al. 2019).

5.2 Crop Management Practices

The management practices used for climate-resilient crops include crop rotation, short seasonal crops, different seed varieties resistant to drought conditions, intercropping with legumes, diversification of crops, shifting planting dates, and changing to new crops (Viswanathan et al. 2020). Crop rotation is the cultivation of different crops in the same land in sequence and has been found helpful in reducing different agroecological issues such as a decline in soil quality (Dury et al. 2012). Similarly, another study confirmed the efficiency of crop rotation intensification with an 84% reduction of soil losses without tillage (Deuschle et al. 2019). Moreover, the use of crop rotation of durum wheat as well as sunflower in Spain has significantly increased soil fertility (Pedraza et al. 2015). Therefore, it is essential to use suitable crops to enhance nitrogen levels and increase phytomass production, improving organic matter in the soil (Raphael et al. 2016). In addition to enhanced soil organic matter, this method has also increased carbon sequestration for the maintenance of the carbon cycle. The plantation of new crops with different planting dates also exhibited the adoptive measures in different zones excluding arid regions in Kenya (Bryan et al. 2013). Interestingly, selecting different dates for crop plantation did not affect crop yield and emerged as a practical strategy, especially in the case of wheat and rice in India (Jalota et al. 2012).

Moreover, drought- and herbicide-tolerant crops have also shown the potential to reduce climatic effects and assisted in obtaining climate-resilient crops in Africa (Neate 2013). Similarly in India, one third of rice-growing fields is susceptible to water-deficit stress, and research advancements succeeded in achieving drought-tolerant rice crops (Birthal et al. 2015). In addition, the cultivation of water deficit-tolerant varieties mitigated the stress on existing water sources. Likewise, China also abandoned the cultivation of rice crops because of severe drought and altered crop diversification with cole rice, seedlings, and cotton, as well as cereals (Lei et al. 2016). Nevertheless, a huge shift from staple food rice to other crops because of drought could threaten regional food security. Another adoptive strategy is the use and promotion of genetically engineered crops that are highly resistant to changing climatic conditions. Seeds obtained through genetic modification (GM) have several benefits in agriculture, but their food is greatly challenged (Pray et al. 2011; Saab 2016). Although no such incidents were observed in the consumption of GM food products, many policymakers, researchers, and other civil organizations are suspicious of their use (Key et al. 2008). Further, Bt cotton in India was highly opposed, which resulted in discomfort and suicide among farmers (Thomas and De Tavernier 2017).

5.3 Land Management Practices

According to the United Nations, land management is the utilization of different resources of land such as soil, animals, water, and plants to produce goods for the need of the growing population and concurrently for the maintenance of these resources for the long term to protect environmental health (Sanz et al. 2017). Issuing soil health cards, explaining the detailed description of fertilizer use, and following appropriate crop cultivation on the basis of soil quality are remarkable initiatives taken by the Indian government. In addition, rewilding, organic farming, and sediment trapping have also been identified as natural land management practices (Keesstra et al. 2018). Similarly, organic farming is also another suitable option for sustainable land management practices as compared to traditional farming methods (Andersen et al. 2015). Organic farming can improve soil quality and enhance 22% of net profits (Ramesh et al. 2010). Nonetheless, organic agriculture needs a large land area for the same food produced by other conventional methods. Moreover, this strategy provides fewer environmental benefits as well (Muller et al. 2017).

Kerala (India) has adopted the use of organic vegetables to overcome the climate change problems, which has reduced the transportation costs from other states and the use of chemical fertilizers (Department of Environment and Climate Change 2014). Conservation agriculture is beneficial and environmentally friendly and provides climate-resilient crops. The benefits of using conservation agriculture are the protection of soil cover, reduced tillage, and diversity of crop rotation (Williams et al. 2018). Similarly, another study conducted in Africa showed that the practices used for conservation agriculture including crop growing with parkland trees, green manure, intercropping, soil and water conservation through traditional methods, crop rotation, mulching, and coppicing trees exhibited higher grain yields (Bayala et al. 2012).

Rewilding is also another form of land management commonly found in Europe. This approach includes natural grazing as well as fire regimes in boreal forests and changing flood patterns. Moreover, it is passive management, assisted migration, reprovision of species in a particular area from where species were missing, and recolonization (Sandom et al. 2018). Rewilding is also involved in improving the functions of an ecosystem and supports the ecosystem for its revival. This approach is being practiced in the Netherlands, the

USA, Russia, and Mauritius Island (Lorimer et al. 2015). Besides, sediment trapping has also shown effective outcomes in reducing the adverse impacts of soil erosion and has protected soil cover (Mekonnen et al. 2014). China has also started a new program (grain for green) to lessen soil erosion near river catchments (Neate 2013).

5.4 Livelihood Management Practices

Designing agriculture management strategies against climate change is of utmost significance, especially for developing countries due to their main dependence on agriculture sector. In addition, many farm households, due to climate change, are migrating to big cities for better employment (Alam et al. 2017a, b). Similarly to the case of India, migration because of climate change is considered a survival strategy, and its purpose is to earn money for livelihood (Jha et al. 2018). Agroforestry and integrated farming also offer opportunities for livelihood management practice and are mostly found in Asia, Africa, and America (Singh and Singh 2017). It was documented that approximately 1.2 billion people earn money from agroforestry for their livelihood (FAO 2011). Further, the agroforestry discipline consists of diverse practices such as plantations, improved fallows, gardens, multilayer trees with crops, plants cultivated for soil reclamation and conservation, windbreaks, aqua forestry, and shelterbelts (Nair 1993). Therefore, these integrated approaches are adopted based on their crop production and food security because these activities have a huge potential for climate adoption (Mbow et al. 2014). A study in Vietnam showed that agroforestry has a crucial role in the provision of money, feed, food, and other eco-friendly benefits (Nguyen et al. 2013). At the same time, cocoa agroforestry is practiced in Asia in the form of a multilayer system providing fruits and timber of high quality (Simons and Leakey 2004). The integration of crop production with livelihood practices is a sustainable approach in which livestock can also be managed. It is reported that an integrated approach can support biodiversity and management of food resources using land practices, strengthening the agro-ecosystem under changing climatic conditions (Singh and Singh 2017).

Animal husbandry and its practice in the future will increase in urban areas for more meat and its other products (Herrero et al. 2010). Farmers are forced by climatic changes to select particular varieties of livestock and their breeds that are suitable to local climates. For example, farmers grow buffaloes, goats, sheep, and chickens for commercial use according to climatic conditions in West Africa, South Africa, and Egypt, respectively (Seo 2010). Similarly, the integration of livestock and crop farming is considered a well-constructed strategy among farmers in Asia (Singh and Singh 2017). For instance, rice-fish farming is a highly recommended practice and far better than monocropping due to resource utilization, productivity, and diversification (Ahmed and Garnett 2011). Further, this integrated farming can improve soil fertility, increase nitrogen and phosphorus levels, and decrease chemical use (fertilizers) resulting in the reduction of greenhouse gases (Giap et al. 2005).

Similarly, rice-duck farming is practiced in China, and a better rice harvest is achieved as ducks can protect the rice plants from harmful insects (Juanwen et al. 2012). Likewise, millet-buffalo integrated farming was promoted and practiced in different states of India, and many farmers obtained benefits from both livestock and crop production (Nagaraj et al. 2013).

The above literature illustrates that various management practices have been used against climate-changing conditions based on water, land, crop, and livestock; however, their success in scalability and applicability varies from region to region. Further, the development of technological interventions such as laser land leveling and salt removal from water has also assisted in achieving climate-resilient crops. However, the success of these adoptive strategies also depends upon the formulated policies, financial and institutional support from the ongoing government, and skillful assistance from the private sector.

6 The Important Part of Policymaking, Innovative Ideas, and Institutional Participation for Sustaining Climate-Resilient Agriculture

Numerous national and international organizations including the FAO are continuously addressing the problems arising from climate change worldwide by designing suitable and functional policies. Asian and African countries are badly influenced by climate change due to their whole dependency on agriculture for livelihood. In addition, the emergence of new climatic events is required to be adjusted through the decision-making process to mitigate environmental problems (Lybbert and McPeak 2012). Nevertheless, farmers are incapable to make decisions because of the lack of sufficient knowledge about farm inputs, remedial steps, and crops. Therefore, the climate change-induced global problems must be addressed by technological innovations and institutional support systems and by designing policies.

Technological interventions can promote climate-resilient agriculture without affecting the farmers and their livelihoods. Further, the development of real-time predictions about the weather can provide irrigation schedules and an exact time for fertilizers and for the selection of appropriate crops (Sidhu et al. 2011). Furthermore, different technological interventions like tensiometer, direct seedling, and laser leveling of land could be useful to improve water efficiency and other inputs at the field level. Moreover, the use of remote-sensing technology will also predict risks and assist in making decisions on investments and on the selection of proper technology (Patt et al. 2010; Trærup 2012). Additionally, social interventions have also been found beneficial in providing facilities for adaptation to changing climatic conditions. Local adaption practices are facilitated in Africa and Tanzania, and social innovations are becoming popular in small-scale communities (Rodima-Taylor 2012). In parallel, the social innovations can promote links via collective actions by the local community and add new horizons for the institutional dynamics to deal with climate change and find out sustainable solutions. Researchers have also recommended some adoption options such as climate-smart villages focusing on agricultural problems by combining institutions and technology. The aim of this approach is to find out and resolve the climate change problems locally which would assist policymakers, farmers, and investors to make prospective strategies for agriculture (Aggarwal et al. 2018). Subsequently, designing and implementing policies regarding the use of sustainable agricultural practices with institutional support and social interventions can significantly promote climate-resilient agriculture.

7 The Role of Biotechnology in Climate-Resilient Agriculture

Climate-resilient agriculture is the main focus of all researchers and other socioeconomic interventions to provide sustainable life under changing climatic conditions. Climate change adversely affects all living organisms, especially plants because we are dependent on them for food and energy. In addition, plants also play a key role in matter fixation to sustain life on Earth. Therefore, climate-resilient crops are essential and need time to prepare, and biotechnology has played a key part in the development of climate-resilient agriculture. Biotechnology provided resilience to agriculture against climate change through genomics, genetic engineering, and genome editing (Fig. 1.1; Munawar et al. 2020).

7.1 Genomics-Based Crop Breeding

Crop breeding is not a new method for the production of climate-resilient crops and has been used by farmers to grow specific and suitable crops according to environmental conditions. However, different crops including wheat, rice, soybean, and maize have been investigated under extreme temperatures (Rejeb et al. 2014). Crop breeding is a time-consuming and complex process against stressors to produce numerous crop varieties. A rise of 1 °C in temperature can reduce the crop production of maize and soybean by 7.4% and 3.1%, respectively (Zhao et al. 2017). On the other hand, weather fluctuations in the UK, China, and Europe are causing diseases in wheat crops such as *Fusarium* head blight. Interestingly, many plants showed enhanced tolerance or resistance to these diseases through plant breeding (Wang et al. 2014). The use of crop breeding helped to produce higher food production and lessen the adverse effects of climate change. In order to adapt to climatic changes, full knowledge of genetic and molecular mechanisms is required to identify climate-resilient traits in plants. Further, next-generation breeding also provides plant populations, germplasm, technological advancement, short-time breeding requirements, and superior alleles for plant breeding (Taranto et al. 2018).

Moreover, population mapping is designed to analyze the variations in traits as well as DNA polymorphisms. Appropriate and sustainable selection of genetic material is done in crops to obtain various germplasm resources for plant breeding which shows resilience to climate change. However, the precision of quantitative trait loci (QTL) as well as mapping might be affected due to the rate and frequency of recombination, size of the population, and inheritance of the specific traits (Cockram and Mackay 2018). QTL mapping is a well-known method used for plant breeding to identify variations in the hereditary material that affect the degree of countable traits (Dhingani et al. 2015). Similarly, a genome-wide association study is investigated to find marker genes based on variations in large DNA nucleotides via population mapping. In addition, the data on the phenotype of each individual is obtained from population genomics to find out the essential phenotype-genotype associations (Hayes 2013). In addition, mutation breeding has also become popular to develop novel alleles, mutant varieties, and genetic diversity in different crops. It is the mutation in the hereditary material that is very crucial from an evolutionary perspective (Munawar et al. 2020).

7.2 Genetic Modifications of Crops Against Climate Change

The field of plant biotechnology has diverse and reliable applications in living systems such as tissue culture, molecular breeding, traditional breeding, and genetic engineering. This technique provides genetic variability to select improved genes for plant development under changing climatic conditions. Plant traits such as tolerance to drought, heat stress, salinity, waterlogging, frost, and disease are of significant importance. In addition, early vigor, efficient water use, and other nutrients such as nitrogen are also promoted to lessen the adverse repercussions of climate change. These genetically modified techniques are beneficial to remove the negative effects of greenhouse gases, carbon sequestration, fertilizer use, and biofuel use (Barrows et al. 2014). Climate-resilient agronomic crops are genetically modified for adoption under changing climates to maintain crop production. For instance, golden rice was achieved through genetic engineering in the last decade through the transformation of carotenoid-related genes in the endosperm of rice (Raney and Pingali 2007). The Environmental Protection Agency in the USA recently approved maize (SmartStax) through genetic engineering containing eight-stacked cry genes. It is estimated to provide pest- and herbicide-tolerant transgenic crop Bt maize (ISAAA 2017).

7.3 Genome Editing of Agricultural Crops

The acquired knowledge from genomic-based breeding, and in vitro tissue culture, has allowed utilizing the second generation of biotechnology dependent on genome editing and *cis*-genesis. The technological advancements led to the development of novel crop products to mitigate the adverse effects of climate change for sustainable agriculture. Genome editing is performed in agricultural crops to protect them from pests, diseases, and biotic/abiotic stresses and to achieve the maximum crop production with minimum costs (Appiano et al. 2015; Courtier-Orgogozo et al. 2017). Genome editing is subcategorized as oligonucleotide-directed mutagenesis (ODM) and site-directed nucleases (SDNs). The former category is a DNA fragment (20–100 nucleotides) which is synthesized chemically and then transferred to targeted sites of plant genome through the bombardment of particles or polyethylene glycol-mediated gene transfer, but the mutation efficacy is very low (Aubert and Kesteloot 1986), while the latter are specific enzymes binding at particular places of DNA segments of 9–40 nucleotides. Further, SDNs function in situ to perform various enzymatic reactions including methylation, acetylation, deamination, and demethylation resulting in the modifications of biological activities via genome editing or specific gene silencing (Puchta 2017). Therefore, different genome-based approaches such as genomic-based plant breeding, genetic engineering, and genome editing could have a crucial part in the improvement of climate-resistant agricultural crops.

8 Recent Advancement in Climate-Resilient Agriculture

The integrated approach of plant molecular breeding, genome editing, and genetic engineering provided new ways to design and improve climate-resilient agricultural crops by utilizing whole-plant genome sequences with the help of functional genomics tools for different crops such as rice, soybean, maize, sorghum, wheat, tomatoes, oranges, and potatoes (Manavalan et al. 2009). A drought-tolerant maize crop (MON 87460) was effectively used to deal with drought conditions in the USA. Moreover, this maize variety was found adaptive and effective under water-deficit conditions and enhanced crop productivity as well. In this perspective, various projects were developed by the maize community to assist the population in Africa (Varshney et al. 2011). Interestingly, this maize crop showed a 20–50% higher yield than other varieties under drought conditions. In addition to this, salt stress tolerance was also achieved in *Arabidopsis thaliana* by overexpressing 40 transcription factors. In parallel, the maize variety showed more stomatal conductance, higher photosynthesis, enhanced chlorophyll content, and increased grain production (Nelson et al. 2009).

Rice plants also achieved drought tolerance through the identification of DEEPER ROOTING 1 (*DRO1*) locus and exhibited higher crop production and nitrogen levels because of the vertical and deeper root system (Arai-Sanoh et al. 2014). Further, Monsanto research workers have designed some bacterial proteins against cold shock (*Csps*) that can be beneficial for various plants as an adaptive strategy. Furthermore, other transgenic plants such as rice and maize with *CspB* introduction have also displayed significant crop production and development under drought conditions (Castiglioni et al. 2008). Currently, an aquaporin encoding gene (*NtAQP1*) in tobacco plants was identified which showed the potential to withstand salt stress in transgenic plants. The same gene was also found responsible for salt tolerance in GM tomato plants and improved water use efficiency (Sinclair et al. 2004). Concurrently, nitrogen fixation dependent on rhizobium was also improved via genetically modified canola. In addition, these plants revealed a higher nitrogen uptake and a lower nitrogen loss in the air resultantly leaching into the soil and through water removal. Intriguingly, biotechnology has also reduced greenhouse gas production. It was achieved through less consumption of fossil fuels, maintenance of soil carbon, and less tillage. It was estimated in 2012 that for the removal of 27 billion kg of CO_2 from the atmosphere, 11.9 million cars might have been removed from roads for 1 year (Wakjira 2018).

Carbon sequestration is the absorption of carbon-bound compounds mainly CO_2 from the atmosphere. Transgenic plants assist in carbon sequestration from the atmosphere. For instance, soybean crops resistant to herbicides in the USA as well as Argentina showed carbon sequestration of about 63.859 million tonnes of CO_2 from the atmosphere (Brimner et al. 2005). In addition, salinity is also another problem that has converted 30% of arable land to barren lands in the last 25 years and will be 50% by 2050 (Valliyodan and Nguyen 2006). In order to deal with this salination issue, GM plants have been formed to tolerate salt stress conditions, low or high temperatures, hyperosmosis, hypoxia, and other environmental pollutants (Liu et al. 2007). The recent breakthrough in technology allows scientists to study OMICS data such as transcriptomics, metabolomics, and proteomics at a subcellular level for developing climate-resilient agricultural crops. For instance, the *SNAC1* gene (NAC transcription factor) has been identified in rice against stress conditions which finally improved rice tolerance against saline and water-deficit conditions. Further, knowledge of the entire plant genome provides new opportunities to find out complex traits for grain quality, yield, disease resistance, and other stresses (Hu et al. 2006; Munawar et al. 2020). Therefore, with the advancement in technology, it is of utmost need to utilize next-generation breeding patterns to improve understanding of bioinformatics, genomics, phenomics, and transcriptomics.

9 Adaptive Strategies in Crops to Extreme Climate Changes

Global warming and extreme temperatures due to climate change are possible threats to all life forms, especially crop species (Espeland and Kettenring 2018). Both drought and heat stresses have significantly influenced the physiochemical processes in plants under field conditions (Pereira 2016). However, plants need an optimum temperature for metabolic functions and normal growth, and temperature fluctuations can adversely affect plant physiology

(Hatfield and Prueger 2015). On the other side, extreme heat events can influence grain production and yield losses, cold conditions can result in sterility, and water-deficit conditions can affect plant morphology (Barlow et al. 2015; Salehi-Lisar and Bakhshayeshan-Agdam 2016). These severe climatic changes can affect plant growth and development and induce various responses such as physiological, biochemical, morphological, and molecular changes (Zandalinas et al. 2018). However, climate change has dual effects (negative and positive) on the agriculture sector and humans as well. Moreover, plant scientists have developed stress-tolerant plants against various stresses (Singh et al. 2018). The main cereal crops such as rice, wheat, and maize are very important due to their daily need for food. Wheat is the most demanding and leading crop that is grown in large areas (Tack et al. 2015). Wheat is obtained around 38.8% of total land used for agriculture providing high protein concentrations such as 15% per gram than rice and maize which together provide 2–3% only (FAO 2017). Despite growing worldwide, its productivity is less compared to rice and maize. A significant reduction (6%) occurs in wheat yield with only a 2 °C rise in temperature (Abhinandan et al. 2018). The filling phase of grains is reduced due to the rise in temperature, and this phase is the major reason for its reduced crop productivity under changing climate (Challinor et al. 2007; Abhinandan et al. 2018). Hence, sustainable agriculture is very important in the current scenario to develop stress-tolerant crops.

10 Conclusions and Future Perspectives

Climate change is a global threat to all life forms, especially agriculture due to the dependency of all living organisms on it. Climate change has severely influenced plant growth and crop yield resulting in economic losses worldwide. Therefore, understanding plant physiology and other biochemical processes under stress conditions is of utmost significance to know about the hidden molecular mechanisms under abiotic stresses. Climatic fluctuations have adverse impacts on agriculture, and it is hard to overcome this global issue. To deal with changing climate conditions, different climate-resilient agricultural practices such as land, livelihood, water, and crop management practices must be followed and implemented to lessen the deleterious repercussions of climate change. Conservation agriculture should be promoted and adopted to sustain climate-resilient agricultural crops. In addition, institutional role and government support play a vital role in designing policies and in implementing them. Further, different biotechnology-based advancements such as genomics, genetic engineering, and genome editing approaches have also shown a huge potential to improve climate-resilient agriculture. Furthermore, a recent breakthrough in climate-resilient agriculture has provided us with better and more reliable means for sustainable crop productivity and food security under different environmental stress conditions. Moreover, different adaptive strategies in crops such as physiological, biochemical, morphological, and molecular changes enable plants to withstand changing climatic conditions. However, more scientific research work is still required to increase implementation efficiencies of different agricultural practices for climate resilience, and novel eco-friendly genetic engineering could offer appropriate and suitable solutions for climate-resilient agriculture.

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