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REVIEW ARTICLE

Nexus on climate change: agriculture and possible solution to cope future climate change stresses

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Abstract

The changing climate scenarios harshen the biotic stresses including boosting up the population of insect/pest and disease, uplifting weed growth, declining soil beneficial microbes, threaten pollinator, and boosting up abiotic stresses including harsh drought/waterlogging, extremisms in temperature, salinity/alkalinity, abrupt rainfall pattern)) and ulitamtely affect the plant in multiple ways. This nexus review paper will cover four significant points viz (1) the possible impacts of climate change; as the world already facing the problem of food security, in such crucial period, climatic change severely affects all four dimensions of food security (from production to consumption) and will lead to malnutrition/malnourishment faced by low-income peoples. (2) How some major crops (wheat, cotton, rice, maize, and sugarcane) are affected by stress and their consequent loss. (3) How to develop a strategic work to limit crucial factors, like their significant role in climate-smart breeding, developing resilience to stresses, and idiotypic breeding. Additionally, there is an essence of improving food security, as much of our food is wasted before consumption for instance post-harvest losses. (4) Role of biotechnology and genetic engineering in adaptive introgression of the gene or developing plant transgenic against pests. As millions of dollars are invested in innovation and research to cope with future climate change stresses on a plant, hence community base adaptation of innovation is also considered an important factor in crop improvements. Because of such crucial predictions about the future impacts of climate change on agriculture, we must adopt measures to evolve crop.

Keywords Biotic/abiotic stresses on agriculture · Climate change · Threat and impact of climate change on agriculture · Food security · Use of biotechnology and genetic engineering in crop improvement · Resilience in agriculture · Ideotype breeding · Climate-smart breeding · CFF

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Introduction

Global warming is the proceeding with the elevation of the average hotness of the globe's atmosphere framework. Environmental change, along with rising worldwide mean temperature with associated consequences, sets an extreme risk to familiar frameworks and socio-economic prosperity (Smith et al. 2009). The Intergovernmental Panel on Climate Change (IPCC) inferred that "human influence on the environment has remained the main source of noticed Warming up, since the mid-twentieth century." Increments in temperatures because of environmental change could predominantly adjust bio-physical connections for crops/domesticated animals/fisheries/timberlands, for example, shortening of the growing time frames, altering the species design, extending warm and dampness stresses, fluctuating water necessities, shifting soil features, and growing the risk of aggravations and diseases (Ullah 2017). Variations in the reappearance and seriousness of drought and floods could pose difficulties for ranchers or farmers and imperil food security (Ziska et al. 2016). Shortage of water can be dangerous without a doubt (Dar et al. 2020). Extreme water inadequacy although has a negative effect on crop, animals, and ranchers in various area of the nation, most importantly California, the Great Plains, and the Midwest, over the previous decade and science, states that rising temperatures will probably make such dry seasons significantly eviler, decreasing water supplies, and, in certain situations, damaging rapidly spreading wildfires (Dar et al. 2019).

Climate change affects every single feature of the natural environment. The variation in the natural environment is due to excess in alteration of climatic factors, essentially making change within the earth (Haigh and Griffiths 2009; Huo et al. 2020a); for example, ecological alteration makes temperatures increase on multiple bits of the planet. This results in a gentler cold season in various areas. These milder winters infrequently allow insect pests to survive in more significant numbers and show up earlier, appearing in the springtime. This results in further pressure on plants and other crops, and, in fact, leads to die-offs in certain regions. Plants' and animals' products are straightforwardly influenced through fluctuation in climatic aspects such as temperature and precipitation and the regularity and brutality of severe events as a shortage of water, floods, and storms. Plant systems, and consequently crop yields, are affected by numerous ecological elements, and these factors, such as moisture and temperature, may act either synergistically or destructively with other factors in deciding yields (Pan et al. 2020; Waggoner 1983). So this is crucial to address the threat and impact of climate change that severely affects crop production and yield. In the coming section of the article, we analyze the risk and implications of climate change on agriculture and what the possible solution is (either it will be on a molecular level or plant character/trait) to cope with future climate change stresses.

The main objective of this study basically relies on the identification of the problems caused by climate change in agriculture, recently and in the near future, and this will include a possible solution to solve these critical problems. This study tells how climate change is influencing the biotic (like beneficial soil microbes, insect pests, weeds) as well as abiotic factors (including drought, heat stress) which are ultimately causing decreased annual agricultural production, and we will discuss strategies required to cope with these problems using traditional and modern methods of breeding.

Climate change effects/impacts on biotic factors relating to plants

Climate change threatens pollinators

Pollination is one of the vital steps in sexually reproducing flowering plants. Most flowering plant species depend on insects or other organisms, instead of wind, to spread pollen among different plants. The pollinators also give an advantage by acquiring floral assets such as nectar or pollen (Giannini et al. 2017).

Crop pollinators fail because of the challenge of climate change in agriculture, pollination being an essential ecosystem service to sustain the output of the bulk of crops (Giannini et al. 2017).

Ever-shifting plant and pollinator range, causing deviations in pollinator populaces that inhabit the edges of their species' climatic range so that they become even more susceptible to population failures and even annihilation, is a consequence of climate change. Differential relocation paces of co-occurring plants and insects as a result of different climatic conditions may incite a spatial dislocation of process cycles like pollination (Potts et al. 2010). As well as upsetting the distributions, there is alteration synchrony between plant blossoming and pollinator flight period as a result of climate change. Phenological differences possibly contribute to pollinator failures that subsequently upset the pollination of plants, and delay flowerings in the season (Vanbergen and Initiative 2013).

We analyze the interactive impacts of three climate change drivers, viz CO_2 fortification, N sedimentation, and growing temperature on a mutualism of pollinator-plant, by applying a series of research. Single driver results suggest that the pollination process will be affected by altering crop morphology, phenology, and nectar production as CO_2 will be uplifted. Gene suppression at exalted CO_2 may delay flowering. In addition to higher carbohydrate levels from CO_2 increment, nectar volume and concentration may be disturbed by elevating temperature. Also, improved plant development through N enhancement can elevate flower numbers, lifetime, and size, and N enrichment can influence the amount and composition of amino acids in nectar, probably altering pollinator preferences. Nitrogen deposition, uplifting temperature, and CO_2 increment could act altogether to unsettle this critical mutualism by changing plant chemistry in ways that change flower attraction or nutritional composition for pollinators (Huo et al. 2020b) (Vanbergen and Initiative 2013).

Simulations indicate that shifts in phenology stimulated by climate change can disrupt the temporal overlap between pollinators and their floral food resources, believing no compensating mechanisms. There is a possibility of species extension by hindering individual reproduction and survival due to anthropogenic climate change, distracting the number and accessibility of suitable habitat, or eradicating other beings that are crucial to the species in question (Memmott et al. 2007).

Climate change effects on soil beneficial plant microbes

It is seen that many types of microbes in the soil are useful for plants; some of them stimulate plant growth, and help in nitrogen fixation, while some others are involved in increasing disease resistance and resistance against other abiotic aspects as heat stress, and drought stress (Rai et al. 2020). It has been concluded that climate change affects plant–microorganism and crop quality by the anthropogenic introduction of xenobiotics (polycyclic aromatic hydrocarbons, pesticides, etc.) presenting dangers to soil well-being by upsetting soil microbial enzyme activities and system structures (Singh et al. 2019).

Most of the studies demonstrated that raised carbon dioxide positively impacted the arbuscular and ectomycorrhizal fungi, though the consequences for plant growth–stimulating microbes and endophytic parasites were more variable. In most situations, plant-associated microorganisms reflect a beneficial effect on plants under elevated carbon dioxide (Compant et al. 2010). Soil microbial processes, such as soil respiration, microbial biomass, microbial community composition, and soil carbon dynamics, may alter the variations in the concentrations of carbon dioxide (i.e., elevated CO_2). Change in the organic carbon content of the soil is the leading cause of these effects (Singh et al. 2019).

According to available data, it is seen that the colonization activity of AMF (arbuscular mycorrhiza) is increased with the elevated carbon dioxide level. Researchers have shown increased plant growth under increased temperature due to climate change. The impacts of increased temperature on useful plant-related microorganisms were more flexible, positive, and neutral, and negative impacts were similarly normal and differed extensively with the examination framework and the temperature range explored. Furthermore, various studies suggested that plant growth–stimulating microorganisms (both bacteria and fungi) positively influenced plants exposed to drought stress. It is verified that endophytic fungi present a competitive benefit to their host plant by developing resistance to environmental stresses. Some endophytes, moreover, can enhance plant growth during drought stress disclosure (Compant et al. 2010).

Climate change effects on insect pests and disease outbreak

Climate change belongs to the boosted carbon dioxide and other greenhouse gases, which raise the overall temperature; in this way, fluctuation in the temperature also causes alterations in the precipitation pattern; this changed precipitation pattern.

Generally, the impact of climate change on insect pest populace comprises shifts in phenology, spreading, population composition, and ecological dynamics that eventually resulted in eliminating species. The consequence of ecological variation will be immediate, through the impact that climate may have on the pests' physiology and behavior. Furthermore, the indirect impacts can emerge through the effect of the atmosphere on the pest's host plants, natural enemies, and interspecific interaction with different other insect pests (Sharma and S.V.a.K.S.M. 2012).

Fluctuation in precipitation, humidity level, temperature, and carbon dioxide level may affect agricultural pests by:

- Early on, the emergence of pests in fields
- Boosting up the reproduction rate
- Shifting life cycle
- It may also cause the movement of insects from one area to another

According to research, an increase in temperature causes the increased metabolic and reproductive rate in insect pests, which causes the increased population growth rate of insect pests. If the temperature is extremely cold or extremely hot, the population will grow more slowly (Stange and Ayres 2010). That is the reason the losses will be most noteworthy in temperate areas, however less extreme in the tropics. "Gentle regions are not at that optimal temperature, so if the temperature ascends there, populaces will become faster," said Merrill, a scientist who studies plant-crop interactions. "Yet, insects in the tropics are now near their optimal temperature so that the populaces will develop more slowly. It's simply excessively hot for them" (Vermont 2018).

As indicated by the Food and Agriculture Organization (FAO), unusual climate and atmosphere conditions have added to the scatter of locust outbreaks, including hefty and widespread downpours since October 2019 in Pakistan, which caused misfortune in yield (Baldos and Hertel 2014).

The fall armyworm, also known as *Spodoptera frugiperda* (fruit destroyer), likes to eat corn but also causes troubles in many other crops, for instance, sorghum and rice, which are significant to human food security. Fall armyworm is indigenous to America, but it also spread across Africa, posing a threat to livelihood by damaging the crop. In Sri Lanka, 20% maize infested contribute to 40,000-ha area with an economic loss of 1–3 billion in Asia since infestation and USD 2400–4000 million per year loss (Chhetri and Acharya 2019a). Armyworms rapidly spread across south Asia and all over the globe as an impact of alteration in climate patterns (Chhetri and Acharya 2019b).

It is seen that under elevated CO_2 level, the stem and leaf growth will be boosted up. Analysts have demonstrated that higher development paces of leaves and stems observed for plants developed under high CO_2 rate may bring about denser canopies with higher dampness that favor pathogen. Due to raised CO_2 concentration, lower plant part deteriorates on which disease organism can overwinter, bringing about higher levels of inoculum at the starting of the growing season, and prior and quicker malady pandemics. The development of pathogens may be influenced by raised CO_2 concentration bringing about more prominent contagious spore creation. In any case, physiological change in the plant can bring about by exceeding the CO_2 level, which can build protection from microorganisms (Petzoldt and Seaman 2006).

Effects of climate change on weed

Weeds have more genetic diversity as compared to crops. Subsequently, weeds will show a more prominent growth and reproductive comeback certainly if a resource like light, water, nutrients, or carbon dioxide fluctuates within the environment. It is seen that several weed species will indicate a smaller response towards the increased concentration of atmospheric carbon dioxide as compared to the C_3 crops as they have C_4 photosynthetic pathway (Ziska 2007).

However, C_3 and C_4 plants are differently affected by climatic change, notably increased CO_2, and lead to some combinations of crop-weed interactions. They are (1) C_3 crops with C_4 weeds, (2) C_3 crops with C_3 weeds, (3) C_4 crops with C_3 weeds, and (4) C_4 crops with C_4 weeds. Growth of C_4 plants is usually more tremendous than C_3 plants under optimal temperatures, but under this optimum temperature, the growth of many C_3 plants is increased with an increase in CO_2 (Ramesh et al. 2017). Recently demonstrated that barnyard grass in sequence with a mycorrhiza likewise gets benefited from higher CO_2 concentration. In drought conditions, C_4 weeds possibly also have benefits over C_3 crops under elevated CO_2. Under the high CO_2 concentration, the C_3 weed *Abutilon theophrasti* [Medicus] increased the biomass, and reduced the yield and biomass of C_4 crop, e.g., Sorghum (Malarkodi et al. 2017).

In many situations, there might be competition between weeds and plants. Temperature defines the type and distribution as well as life cycle duration of plants in a specific area. Changing and rise of temperature is one of the most important attributes of climate change which may alter existing plants (weeds shift) and permit some other plants (weeds) to replace native and to expand into different regions which are not affected before. An increase in temperature indirectly means an increase in weeds. With a global warming trend of 3 °C, several studies have shown that a weed called itch grass, vigorous and a plentifully tillering weed, can invade California and the central Midwest (Amare 2016).

Climate change is also the cause of change in rainfall patterns, which also reflects many effects on weeds. The way of weed spread and their influence on the production of crops could be altered by variation in the pattern of rainfall and increased aridity consistent with a warm environment. In many agronomically essential areas, in the near future, an increase in temperature about 1–5 °C with respective doubling in the carbon dioxide concentration and aridity is expected. The rise in temperature similarly triggers a high evaporation rate, and monsoon regions will become drier according to a prediction because of flexibility in rainfall trends across the world, leading to an increase in 5–8% in drought-vulnerable areas. Beneath these consequences, the management and distribution of weeds in crop ecosystems will be changed, and in particular, weed management of crops sown in spring will be affected due to summer droughts. Rodenburg and Johnson, 2009 hypothesized that surplus water environment conditions would favor some weeds like *Rhamphicarpa fistulosa* (Hochst.). On the other hand, extended drought spells will favor parasitic weeds as *S. hermonthica* and some other C_4 weeds in some areas. Here persistent drought spells would encourage C_4 over C_3 weeds, while the change in the rainfall patterns will support hydromorphic weeds. As a consequence of limited access to water for flooding, little or no rainfall will make it difficult to perform appropriate land preparation practices for wet season crops like rice, especially when rice is more vulnerable to the weed. As a result, it will restrict the conventional system of weed management in rice (Ramesh et al. 2017).

Climate change effects on abiotic factors relating to plants

Climate change and drought: a perspective on drought indices

Drought is an outrageous climatic occasion that is insidious since it grows gradually and frequently sneaks up on one. As it progressively increases in strength and time, this issue can have significant effects, which makes that event attentive to natural hazards.

Droughts can also occur in the natural condition, but environmental change has largely speeded up the hydrological processes to render them set faster and become more severe, with large effects; one of the major hazards is wildfire. Many kinds of drought have been analyzed, for example, meteorological, agriculture, hydrological, and socioeconomic dry spells (Mukherjee et al. 2018). Due to climate change, the average temperature is boosted up, and the earth's water cycle speeds up through an increased evaporation rate. As an enhanced evaporation rate makes more water accessibly noticeable in the air for precipitation, it additionally adds to drier land zones and abandons less dampness in the soil. Consequently, as environmental change proceeds, numerous regions are expected to experience a rise in precipitation, and this will increase the flood hazard, even though territories situated a long way from storm tracks are expected to experience less precipitation and increased threat of a dry spell (Pathak et al. 2018).

Environmental change is significantly affecting the accessibility of water assets for agriculture productions. Where the stability and sustainability of crop production are being upset by the deficiency of water concerning the drying propensity ever since the 1950s, global climate model (GCM) outfit plans forecast that intensified ET and expanded crop water demand by 2050 because of a worldwide temperature boost, which will diminish water resource surplus (precipitation–ET) around 4–24% and raise the irrigation water demand fundamentally in plant development stages (Mo et al. 2017).

Heat stress in plants due to climate change

Carbon dioxide is one of the important heat-trapping greenhouse gas, which is mainly emitted during human activities, including the burning of fossil fuels, due to deforestation, also because of natural processes like volcanic eruptions and respiration (NASA 2020). Its current concentration is 414 ppm, which is continuously increasing; this increase is the primary cause of global warming, indirectly increasing temperature, which in turn causes heat stress in plants. In the development of the plant, temperature plays a critical role, whereas severe consequences may be observed because of an unexpected rise in temperature. Heat stress worsens plant growth, photosynthesis, and development of pollens along reproduction. The plant photosynthetic activity is primarily reduced because of denaturation of heat shock proteins, and excessive production of reactive oxygen species followed by the alteration in many enzyme activities (Ihsan et al. 2019).

In this way, this whole phenomenon causes a loss of yield. Usually, the heat stress of a plant will reveal itself by wilting, which is a sure indication that water loss has taken place. If this is overlooked, the condition will get worse, as the plants will ultimately dry up, transforming into a crunchy brown before dying. Various plants will essentially shed some of their foliage in a struggle to preserve water (leaf drop) (Thussadmin 2020).

Plant growth and development is likewise significantly influenced by many physiological, morphological, and biochemical alterations followed by high temperature. At present, heat shocks are becoming one of the foremost limiting aspects to crop productivity throughout the earth due to the increasing atmospheric temperatures. This rising temperature can trigger a change in the distribution of agricultural crops and the growing periods of various crops. High-temperature stress interrupts major enzyme activities and damages membranes, and also causes severe harm to the proteins, and interrupts their synthesis. On the other hand, heat stress could have significant outcomes on the cell division cycle, hence improving yield as well.

Effects of flooding and salinity as a result of climate change on agriculture

Waterlogging, as well as salinity, put significant constraints on crop production. There are three common adverse environment factors viz waterlogging, moisture stress, and salinity which are believed to influence the crop production and also one of the principal factors from which the geographical distribution of the food crop, as well as limitation of crop yield in agriculture, can be determined (Singh et al. 2018). Millions of acres of farmland in Pakistan turn barren because when field sodden with excess, stagnant water that gradually turns saline, there are triggering experts to alert that the Indus basin could change into lakes of saline water.

A special report on extremes can be noticed by the Intergovernmental Panel on climate change IPPC; it is even more clear that there is “evident influence” of the climate change. These certain water-related variables eventually lead to floods, such as snowmelt and rainfall. Annual run-off in regions is because of seasonal snow-melting in those areas, triggering more rain-on-snow occasions due to hotter temperatures. Because of this, warm rains fell, inducing faster and often prior to melting. According to the IPCC, this phenomenon is acting in the western USA since 1950, where snowmelt-fed rivers have made the highest flow earlier in springtime. Spring flooding as in winter can exacerbate because of the combination of rain and melting snow, and spring soils are typically high in moisture and often still frozen, and therefore minus clever to soak up rain run-off and snowflake (Denchak 2019).

Climate change pushes soil salinization in various ways. First, ice sheets and icy masses of ice are softening and filling the seas. Warmer water is going to take more space as ocean temperatures are rising. Worldwide mean sea levels will climb up by at least 1/4 to ½ meter by 2100, even with significant declines in heat-trapping gas emissions, estimated by researchers presently (Morris and Brewin 2014). This activity pushes salty water onshore near coastlines. Environmental change likewise triggers heat stress, which will lessen groundwater sources and raise up saline tainting of soils inland. Depending on the season and the level of saline contaminations, the rice ranchers in India can be relied upon to lose anywhere in the range of 7 to 89% of their crop (Morris and Brewin 2014). Rising temperatures will boost up the probability of heavy rainfall, and the severity of that rainfall is also on the rise. The outcomes of climate change in the years to come to include more severe floods and droughts, speeded up the thawing of glaciers, increasing the hazard of glacial lake outburst floods (GLOFs) (Farooqi et al. 2005), due to which many hectares of land of crops are brutally damaged. The young seedling completely fails due to flooding. Combined flooding and salinity declines the growth and existence of plants more than either stress alone.

Salt-stressed land could stifle the development of plants. The effects of saltiness comprise low agricultural yield, low financial profits, and soil disintegrations. Saltiness effects are the consequences of complicated relationships among physiological, morphological, and biochemical cycles, including seed germination, plant development, and water and supplement take-up (Shrivastava and Kumar 2015). Practically all parts of plant improvement involving germination, vegetative development, and regenerative development are influenced by the salty environment. Soil saltiness forces osmotic stress, ion toxicity, supplement viz Zn, K, Ca P, Fe, N lack, and oxidative stress on plants, and consequently limits water take-up from the ground (Shrivastava and Kumar 2015). These saltiness results have triple effects viz it diminishes water potential and causes an ionic imbalance or unsettling in ion homeostasis and toxicity; this changed water status prompts initial growth decrease and limitation of plant yield (Parihar et al. 2015). The destructive effect is noticed at the whole plant level as mortality of plants or decline in yield. Many processes, for instance, germination, development, water relation, nutrient imbalance, photosynthetic pigment, and photosynthesis oxidative pressure, and crop yield, and all the significant cycles are influenced by salt stress (Parihar et al. 2015). Therefore, salinity stress seems to be a major restriction to crop and plant production.

Change in rainfall pattern due to climate change

Since the 1950s, the worldwide average air temperature is elevating steadily, principally credited to the increment in the discharge of substances that causes the depletion of ozone. This dangerous effect of global warming is not only restricted to worldwide and local changes in temperature, but it also has adverse impacts on the change in rainfall pattern, which may not only alter rainfall amount but alter rainfall distributions and patterns (Adefisan 2018).

Present atmosphere models show that this increasing global temperature will escalate the water cycle of the earth, intensifying evaporation. Increased evaporation will cause further successive and exceptional storms; however, it will similarly add to drying across some areas/regions. Subsequently, areas affected by storms are more likely to experience an increase in the danger of flooding and precipitation, while zones situated far away from storm tracks are probably going to confront less threat of flooding, drought stress, and rainfall. The water holding capacity of air is usually increased with the increase in its temperature (the greater the air temperature, the greater its water holding capacity), significantly above the oceans. According to the Clausius Clapeyron equation, for each 1 °C of temperature, air can hold almost 7% of more moisture. In this way, currently, the climate would have around 28% more moisture/water vapors in the air than a premodern period as there is an increase of 4 °C temperature than the premodern era. However, this elevated moisture will not fall uniformly over the planet. But this increase in moisture will not fall equally all over the world. Some areas are expected to face increased precipitation; on the other hand, some other regions are expected to confront less precipitation because of the shift in the weather patterns, including some other factors (Meehl et al. 2000). This uneven rainfall is a big challenge in agriculture.

Changes in the precipitation and rainfall pattern are the essential elements that will decide the expected effect of climate change. Rainfall is considerably more challenging to foresee than temperature. Generally, the difficulty in the prediction of rainfall is due to the change in weather patterns, which makes it hard to predict. It is confirmed to show that zones that are now wet are probably going to get wetter; until now, it is harder to discover what impacts there will be on the neighborhood and how much wetter it will be. The regions of subtropics which are dry are likely to get drier and will shift towards the poles (Guardian 2011, November 10). This changed rainfall pattern affects not only plants but also the soil in case of intense rainfall. But low rainfall also has adverse effects. Whenever a land/area or region for an extended period is exposed to the below the average or normal level of rainfall/precipitation, which is usually required, then we call this land/area/region drought. Drought can have adverse impacts on the environment; therefore, it can badly disturb the life cycle of all the members of an ecosystem. Many plants are unable to withstand the long period of drought, and these plants ultimately die because of water shortage, and the animals that eat those plants are left battling to discover food and water (Cairoli 2017, April 24).

Similarly, low rainfall may also cause plants to be susceptible to disease and fire because when rainfall or precipitation is beneath the normal/average level, soil exposed to this situation begins to dry out; therefore, plants battle to acquire enough water/moisture and start to dry out also. It is seen that plants exposed to drought stress are more susceptible to diseases and also to fire. As plants exposed to drought stress are dry due to water shortage, hence when they come in contact with lightning or spark, they catch fire more rapidly (Cairoli 2017, April 24).

Impact of climate change on agriculture and food security

According to IPCC, later, “Earth atmosphere will be heat up with continuing effectS, this process will continue, and this statement is unequivocal.” Hence, it is presently clear from observations of rises in global average air and sea temperatures, climbing worldwide normal ocean level, and broad melting of snow and ice. The climate change impact is unequivocally clear that there is a change in the precipitation pattern and rise in average global temperature; climate change has already affected biodiversity, ecosystem, and human system all over the globe. Future challenges are worse because of unpredictable precipitation pattern change and temperature persists in rising. The threat of climate change on agriculture is most significant, along with numerous other unfavorable impacts (Kotir 2011).

Agriculture is one of the main sensitives to climate sectors. Temperature intensification and related climate events cause impacts. Climate change endangers Food Security and will deeply affect the productivity of crops and livestock, forests and fish, health, and dependent relative rural capital (Selvaraju Ramasamy 2009).

Agriculture, ranger service, and fisheries are generally vulnerable to climate alteration. The influences of mean temperature increment will be experienced in an unexpected way, contingent upon the area. For instance, modest warming (rise in temperature 1–3 degree) is likely to promote pasture and crop yield in moderate climate regions, and it is expected to have a harmful impact, especially on cereal crop in the seasonally dry areas and tropical areas. Thawing of greater than 3 °C is likely to have adverse effects on production in all regions. When there is an effect on the feed crops, which account for roughly 25% of global cropland, the supply of meat and other livestock product will be affected (Al et al. 2008).

As indicated by a gauge, plant-parasitic nematodes are affecting considerably more harm contrasted with insect pests. The yield of crop misfortune because of these little hidden pests in different nations is colossal. They affected an extended loss of yield of 12.3% ($157 billion dollars) around the world (Singh et al. 2015).

Climate change threatens food security

Food security is a measure of the availability of food and individuals' ability to access it. At the same time, affordability is one of their parts. The term "food security" was specified at the 1974 world food conference, which focuses on food supply. The definition of food security is "accessibility at all the times of sufficient, nutritious, stable, judicious and diverse global food resources of essential food items to maintain a constant growth of foodstuff use and to compensate instabilities in rates, as well as production." The food system consists of main four forms of functions: (1) producing food; (2) processing food; (3) packing and delivering food; and (4) selling and consuming food (Ericksen et al. 2009).

The effect of climate change is on food security at the regional and local level and as well as on the global level. Climate change can disrupt food security; for instance, change in precipitation, rise in temperature and reduction in water availability, and change in extreme weather events all will result in a reduction in agriculture production, reduce access to food, and affect food quality, as the frequency and intensity of severe climate occasions can interrupt the food supply chain and cause inflation in the price of foodstuffs. These outrageous events are likely to become more frequent in the future. Temperature increment can also cause contamination and spoilage (Agency). The impact of climate change on food utilization has two dimensions, viz health impact from climate change that mediates nutritional income and food safety through the supply chain. Typically, the higher rate of microbial activities with rising temperature because of climate change will reduce food security, mainly in vegetables and moist fruit. Environmental change influences well-being through diverse pathways, including heat stress, natural disaster, and vector-borne ailments, which thus affect individuals' nourishment, alongside their capacity to give care to youngsters and dependents' nutrition security (Campbell et al. 2016).

According to the FAO of the USA, the semi-arid region of the world (e.g., the Sahel region of Africa) can face unpredictable yield for cereals, at least 80% the result of climate variability. It is one of the reasons that if climate change affects food production, it will also affect food access. Thus, supply and demand has broad influences: weather disasters (as drought or floods) due to climate change can lead to extravagant prices of available food. Hence, the lowest household is more vulnerable to these price spikes and thus 75% of the total budget spending by the poor on food alone. Currently, the food system releases 21–37% of GHGs, which means that the climate crisis will contribute to food losses, but still, there will be no clear-cut strategy for malnutrition levels or food security (Concernusa 2019, October 23).

Change in climate will already reduce the global yield of wheat and maize by 5.5% and 3.8%, respectively (Lipper et al. 2014). Without CO_2 fertilization, genetic improvement, and effective adaptation, there is a reduction in global yield of rice by 3.2%, wheat by 6.0%, soybean by 3.1%, and maize by 7.4% as on average, each degree-Celsius increase in global mean temperature (Zhao et al. 2017). Increased climate alteration exacerbates production risks and challenges farmers' coping ability. And several researchers will warn that when the temperature exceeds the critical physiological threshold, there will be a steep decrease in crop production, and by increasing risk and disrupting the market, reducing agricultural production and income, climate alteration will pose a serious threat to food accessibility for both urban and rural population. The marginalized ethnic groups, poor producers, and the landless are predominantly susceptible (Lipper et al. 2014).

Climate change effects on some major crops

The increase in global warming is due to the rise in the CO_2 concentration; the increase in CO_2 is positively related to the yield. Still, on the other hand, there is also the severity in the environment like increase in the hurricanes and change in the pattern of the precipitation; these all factors are very closely related to agriculture. This change affects different crops in different ways.

Climate change effects on wheat

Climate change has adverse impacts on agricultural production and quality. Due to global warming, the intensity and frequency of occurrence of severe events like drought, which affects the rain-fed crops, including wheat, which is one of the important rain-fed crops, is expected to increase. Global wheat production is strongly influenced by the availability of water during and before the typically unirrigated growing and crop-specific season (Wise 2019, September 27). Commonly, agriculture is vulnerable to several factors like water temperature and air; all these factors determine the yield of a crop along with genetic makeup. Wheat plant is about 3–5 ft in length, and the most economical part of the wheat plant is spike; every plant bears a number of spikes having an average length of about 7–17 in.; these spikes further contain spikelet.

The spike is the part of the wheat plant which carries grains about 40–150 grains per spike depending upon the genetic material of the concerned variety and provided environmental conditions. Germination of seed, production of central stem leaf, production of the tiller, elongation of the stem, booting, heading, anthesis of flower, grain milk stage, grain dough, and ripening stage are ten most essential growth stages of wheat according to Zadoks. To come out of dormancy, winter plants generally require a low temperature of about 5–10 °C as higher temperature delays the process of vernalization and wheat is a winter crop, so it requires low temperature for a long period before flowering occurrence to hasten plant development (Pervez Zamurrad Janjua et al. 2010, December 28).

Increased CO_2 concentration is positively related to the yield in the way that there will be more photosynthesis; as a result, the output will automatically be increased. Aggarwal and Sinha (1993) reported that wheat grain yield at all levels of production is increased significantly at 425 ppm CO_2 concentration and no rise in temperature (Singh 2014, March 15). But the increased temperature has negative effects on crops in the way that it causes a greater rate of evapotranspiration, which causes loss of water due to stomatal opening at an increased rate and sometimes causes plant death in severe cases; also, it causes disturbance in several growth patterns. In a field experiment, 50% reduction in the wheat kernels and 50% reduction in the grain yield of wheat were observed after exposure to the heat stress of up to nearly 40 °C before and after anthesis of flower for 12 days (Biology 2018, November 22).

Maximum increased temperature of 25 °C as compared to the 31 °C and a constant temperature of 10 °C compared with a constant temperature of 25 °C reflected no effects on the time of filling of grains during grain filling stage, but it affected the days of maturation of wheat plan. Kernel weight was reduced about 15–30% due to the increase of grain filling rate because of high temperature as a result of short-grain filling duration. Similar results of decrease in kernel weight were concluded due to the heat stress in a review of 21 experiments, and 10–15% decrease in wheat grain yield was observed due to the increase in temperature above the optimum during grain filling stage of wheat and anthesis stage in Australia and the USA (Biology 2018, November 22).

Climate change effects on cotton

Cotton is one of the most important crop mostly grown all over the world and is considered a major crop in countries like Pakistan, India, China, and Turkey, grown as the most important source of fiber. Like other crops, cotton is also vulnerable to climate change in many aspects depending upon the environment in which it is grown. One of the abiotic stresses affecting plant physiological, morphological, molecular, and biochemical processes along with plant growth and yield is a high temperature (Ekinci et al. 2017). Cotton needs nearly high temperature for its growth; increase in temperature has varying effects on the cotton; like temperate regions with a low-temperature increase in climate temperature would affect positively in the early growth of cotton, but it will affect negatively in the tropical area where the temperature is already high; further increase in temperature would cause loss of yield. The high temperature will cause flower bud shedding majorly in the early reproductive stage, but in later stages, the high temperature would cause boll shedding, which is a part of major interest; this loss will ultimately result in the loss of yield (Routh 2017, February 27).

In this way, it is seen that increased carbon dioxide also has positive as well as adverse effects. Production of cotton is also affected by the high concentration of carbon dioxide in the atmosphere (Routh 2017, February 27) (Ton 2011). Elevated moisture level also has adverse effects because cotton plants exposed to the higher moisture level are more vulnerable to certain fungal diseases.

Climate change impact on maize production

Maize is one of the most essential and valuable food crops in the world. Maize originated from Mesoamerica and is currently grown all over the world (Shiferaw et al. 2011). The worldwide area of Maize is about 150 million hectares. Maize is grown in different types of soils and over a broader range of latitude and altitude than some other food crop; the temperature for their growth is ranging from very hot to cool and on wet to semi-arid lands. From 2008 to 2010, the average production of Maize was 750 million metric tons. Hence, by far, such yield will be largest than the other two chief staple cereal crops viz rice and wheat (Shiferaw et al. 2011). Maize also has considerable importance for Pakistan (Shakoor et al. 2017).

As already discussed, climate change will alter rainfalls (both temporally and spatially), and this has a direct impact on the crop water cycle, which will possibly pose water stress on the growth and development of the crop. Because the rise in temperature will uplift the rate of transpiration demand and evaporation, hence, it will pose further stress on the crop. Continuous rise in temperature will reduce yield during the cropping season (Shakoor et al. 2017).

Oseni and Masarirambi (2011) concluded that because of uplifting temperature, maize production would steeply decline in Swaziland. Makadho (1996) evaluated that decrease in rainfall (due to abrupt climate patterns) along with rising in temperature will threaten the production of maize in Zimbabwe. Average rain has a negative impact on maize in the short run while having a positive effect on maize yield in the long run (Shakoor et al. 2017). Although if moderate rises in total summer precipitation for instance, 50 mm, then yields may be improved by 5–10%, countering a portion of the harmful impacts associated with enhanced temperature (Kucharik and Serbin 2008).

Most importantly, future forecasting concludes that extremities in temperature will produce alarming effects on maize yield for the coming 15 years, and also there will be a prediction that maize yield will be reduced about 10% until 2030 due to rising temperature (Shakoor et al. 2017). Besides, change in any component of climate will adversely impact maize production; the rise in atmospheric CO_2 will directly affect maize growth.

Tao and Zhang (2010), based on a larger number of simulations, revealed that on average, yield of maize will decline during the 2050s by 13.2–9.1%, relative to 1961–1990. Meza (2008) informed that by depending upon maize hybrid and environmental alteration scenario, maize production would be reduced between 10 and 30%. The environmental alteration will also disrupt crop life cycle processes, for instance, crop efficiency in finishing its growth cycle in a shorter time and rate of development (Lashkari et al. 2012).

Climate change impact on rice (*Oryza sativa*)

Rice is one of the main agriculture commodity with 741.5 million tonnes production in 2014 and has third-largest production, after maize 1.0 billion tonnes and sugarcane 1.9 billion tonnes, and rice cultivation is well suitable to regions and country with high rainfall and small labor costs; depending upon water availability, rice can be grown on different environments. Mostly, rice does not flourish in a waterlogged area, yet it can grow and survive herein, and it can endure flooding.

As climate will change, there will be an extreme abiotic factor like low and high temperature, salinity, osmotic stress, flood, frost damage, and heavy rainfall which pose a severe threat on rice yield and also affect the livelihood of the farmer (Dabi and Khanna 2018). Temperature fluctuations will affect growth patterns, growth duration, and yield of rice. Extremism in temperature, either low or high, will have a negative consequence on rice yield. High temperature is one of the main restrictions in rice production. The study revealed that there is a vastly negative impact of high temperature that led to pollen sterility as seen in some areas of Pakistan recently; high temperature of just 1 or 2 h at anthesis (about nine days before heading or at heading) will result in a large number of grains sterility, hence in some regions of Pakistan will show small grain size and pollen sterility in maize recently (Nguyen 2002). Therefore, it will also have a severe impact on pollination processes, pollen shedding, pollen germination, and pollen fertilization, and cause sterility (Dabi and Khanna 2018). As peak temperature will cause rice flower sterility, hence, no grain will be produced. The uplifting temperature, along with rising CO_2 level and hinted at alternative sinks, becomes an active recipient with reduced carbon sink capacity of the grains.

The extremely cold temperature is one of the key factors that will limit rice growth and yield, and seedling growth is very sensitive to chilling stress. Both chilling and freezing stress can increase reactive oxygen species (ROS), which can be damaged at the cellular level; it can also trigger a series of functions, viz morphological and physiological processes (Dabi and Khanna 2018).

A research will reveal that moisture stress will affect rice at the molecular level (altering gene expression which encodes transcriptional factor and also a defense-related protein), biochemical level (accumulation of osmoprotectant like sugar, polyamines, antioxidant, and proline), and physiological (reducing transpiration and photosynthesis, stomatal conductance, water use efficiency, relative water content, membrane stability, chlorophyll content, photosystem 11 activity, ABA content, and carbon isotope discrimination) level (Dabi and Khanna 2018). Increasing water stress, abrupt rainfall pattern, and rise in temperature will decline the yield of wheat, rice, and maize in Asia in the past few decades (Wassmann et al. 2009). Particularly in semi-arid tropic and arid regions, because of diversity of rice ecosystems, growing conditions, and its semiaquatic phylogenetic origin, rice production systems will rely upon plenty of water supply and hence are more vulnerable to drought than any other crop (Wassmann et al. 2009).

We can make inspections number of farmers' fields over the last 10 years, and the results will demonstrate that pests and disease of rice will intensify due to climate alterations. Some disorders, e.g., brown spot and blast, tend to increase in strength due to irregular rainfall patterns, water stress, and relative water stresses. Weed infestation and rice-weed competition are expected to rise and will be considered the main challenge for sustainable rice production. Correspondingly, in Asia, the extreme temperature will enhance the Populus of rodents because of asynchronous and unseasonal cropping (rice).

Effects of climate change on sugarcane

Where climate change is creating problems for other crops, it is also affecting sugarcane. Global warming is the cause of an increase in temperature, which is the result of an elevated level of greenhouse gases. In this way, it is affecting climate very badly also by altering rainfall pattern, moisture level, etc. Global warming will change rainfall patterns, solar radiation, and temperature, which have both positive and negative consequences on sugarcane yield. The temperature extended, i.e., daily minimum and maximum temperatures, may be severe, which will be more severe in case of nighttime temperature. The temperature role in the development of cane will start from the very beginning and continues up to the later stage. It will be directly related to photosynthesis, and the growth of the plant, as well as other biochemical processes involving the development of bud. Photosynthesis efficiency of cane grows linearly with temperature in the range of 34 °C maximum to 8 °C. Early morning temperature 20° in summer and 14° in winter along with the cold night will significantly inhibit photosynthesis the next day. The leaf growth is reduced if the temperature will fall less than 14–19 °C. Sunny days and cold nights will slow down growth rates and carbon consumption, whereas photosynthesis may continue (Srivastava and Rai 2012).

Climate change will affect sugarcane by different means, e.g., direct impact via altering precipitation or temperature and indirect impact via changing availability of pollination services and altering pest population. The disease is viewed as one of the principal dangers to food security and the responsibility for a 10% decrease in international food production. Several biotic and abiotic stresses such as soil nitrogen, weed competition, and drought can put severe stress on the cane and also intensify herbivores' attack. Climate change can alter the temperature, which in turn affect insect pest, disease, and weeds of cane. Due to high-temperature conditions, Smut disease (causal agent: *Sporisorium scitamineum*) is expected to rise. Extreme environmental events have triggered more overwintering pests and disease pathogen. Abrupt rainfall patterns and reduced rainfall in the cane-growing season will reduce growth and favor weed infestation (Hussain et al. 2018).

If we look from another perspective, elevating CO_2 will directly affect stomatal physiology and photosynthesis. Similarly, uplifting CO_2 and rising temperature will increase the ability of weed to grow in number and modify the spreading of weed around the world and their competitiveness with main crops in a different habitat. Sugarcane is a C_4 crop, and the future prediction under elevating CO_2 was that the C_4 plant becomes more susceptible to boost competition from C_3 weed. There will be a double in the concentration of CO_2 which can cause loss of transpiration 25–405 and may decrease stomatal aperture by 30–40%; twofold convergence of CO_2 may diminish 30–40% in stomatal aperture and 25–40% transpiration loss in both C_3 and C_4 plants. Under elevated CO_2, available nitrogen for plain also reduces and leaves' carbon-nitrogen ratio enhanced under this scenario (Hussain et al. 2018).

Relative humidity along with wind has a relatively minus influence on the plant, although the extreme case will have a large extent impact on the crop. Warm weather conditions and humidity up to 80–85% will favor the rapid growth of the sugarcane. In the ripening phase, a limited water supply, along with moderate humidity, is favorable (Mali et al. 2014). Similarly, high wind velocity during the initial stage of plant growth will be destructive while wind has no severe impact until its velocity will increase up to the level of breaking and lodging of the sugarcane; also, there will be a loss of moisture due to long-term high wind velocity. In the life cycle of the crop, two different sets of climate parameters are required. (1) In the growing season, optimum rainfall high humidity along with the long duration of the bright sunshine warm season will favor rapid growth of cane along with length with the best yield. (2) Warm days, clear sky without precipitation, and dry weather conditions during the ripening season, which is a phase of sugar storage, are required (Chohan 2019). Thus, alternation in humidity and wind will also affect sugarcane.

C_3 and C_4 plants under elevated carbon dioxide concentration

C_3 are the plants in which CO_2 is first converted or fixed into three-carbon atoms containing compound before entering into another cycle called Calvin cycle of photosynthesis. C_4 is a plant that uses the C_4 carbon fixation pathway in which phosphoenolpyruvate in mesophyll cell is bounded by carbon dioxide bringing about the formation of four-carbon compound called oxaloacetate; in the next step, oxaloacetate is decarboxylated to free the carbon dioxide to be used in C_3 pathway in the bundle sheath cell (Lara and Andreo 2011). Additionally, C_3 photosynthesis is stimulated by rising CO_2 generally. The acceleration of the expansion of C_4 plants will be about 10–20%, while that in C_3 plants will be 40–45% by doubling the present ambient CO_2 concentration. Thus, it is concluded that the activity of C_3 plants is increased under elevated carbon dioxide concentration about three times as compared to the activity of C_4 plants.

Future strategies to cope with these problems

Resilience in agriculture to abiotic stress

Climate-resilient crops, as extreme weather worsens, growing crops that are resistant to drought, flooding, and unexpected changes in weather will be key to protecting world food security. There are many ways to define resilience, as the propensity of a system to retain its organizational structure and productivity following a perturbation or an ability to survive and prosper is driven by profitability. Therefore, a resilient plant will involve providing essential services; e.g., food production is challenged by a considerable reduction in rainfall or severe drought (Lin 2011).

Climate change will significantly alter factors of agricultural production in the coming years. Changes in temperature and precipitation associated with sustained emissions of greenhouse gases conflict with sustainable agriculture and will affect crop and biomass yield. This will constrain agricultural productivity to meet the demand of the steadily increasing population worldwide. For maintaining sustainable, environmentally benign agriculture under the forecasted future climate conditions, it is essential to design effective plant breeding and protection strategies, principally exploiting the available genetic resources.

A multitude of defense strategies is adapted by the plant to survive, adapt, and reproduce if projected to stress condition. With the on-successful functional characterizations of different genes and advancement of *~omics* technologies, now it becomes clear that there is tight control over environmental adaptation, crucial for plant survival. Key elements of the monitoring networks are pathogen recognition, environmental stress adaptation, and defense that comprise ROS signaling, changes in redox status, plant hormones, and inorganic ion fluxes, for example, Ca^{2+} (van Zonneveld et al. 2020).

Breeding targeted traits to cope with drought and heat stress will include early maturation and flowering. If we are screening the plant for drought resistance, significant physiological and morphological traits are viz number of xylem vessels and its diameter, root suberization, low leaf hydraulic conductance, and stomatal leaf conductance, among others. Drought stress can be avoided if we develop a plant with long roots or tubers, but it may involve reducing pod, leaf, or bean productivity. Heat-tolerant trait involves pollen viability, membrane stability, and anther dehiscence, and increase in antioxidant enzymes, drop-in GABA (γ-aminobutyric acid), and among other traits during the period of plant growth. Salinity-tolerant trait will involve leaf K+ and Na+ concentrations, malondialdehyde (MDA) levels, and antioxidant activity of the enzyme, the relative quantum yield of photosystem II, etc. (van Zonneveld et al. 2020) (Ahmad et al. 2014).

Crop for the future to extend our genetic base/resources

As climate will change, e.g., increasing extremity of both water and heat stress, it will result in crop failure and rate of crop failure will rise with uplifting mean temperature, with increments in maximum failure rates being more prominent than those in medium failure rates. Spring wheat crop in northeast China will fail due to the rising extremity of both water and heat stress as a result of climate change (Challinor et al. 2010).

Recently, two analyses about vegetables and corn will alert the intensifying risk of malnutrition and food shocks with an unchecked global climate warm. Scientists will already warn that climate change will be increasing the hazard of simultaneous failure of the crop over the world's prime corn-growing areas, and this will result in less of the nutritionally critical vegetables that health experts say people are not getting enough of already (GUSTIN 2018, Jun 11).

In several parts of the world, mainly in Asia and Africa, crops will fail. Due to changes in climate, the area suitable for the cultivation of the current crop will be shifted. Despite many species, 90% of world food comes from 12 plant and eight animal species, and more than 60% of the human diet comes from only three species viz wheat, rice, and maize (Massawe et al. 2015). Only four crops, viz maize, rice, wheat, and soybean, will involve in 2/3rd of the global food supply. But Malaysian scientists are seeking to change that by reviving crops that have been relegated to the sidelines (Jha). Climate change will intensify genetic diversity loss: diversity in the crop is one of the vital factors to adapt against effects of climate change: crop diversification—a key adaptation strategy, income generation, nutrition, and food security.

We need to extend our genetic base and add other minors' crops for our feed and to enhance the nutritional values of our diet; we need to add desirable features from other crops into our major crops. And in such climate change scenario, we do not rely only on major crops for feed because if it fails to give result, it will cause economic, nutritional, and dietary constraint. Here are some examples of how these crops are useful; e.g., Bambara groundnut are well adapted to poor soils and are reasonably free from pest and disease, also having drought resistance character. Beyond the main crops, diversity of small millets, it is often grown under adverse weather and edaphic condition, drought-prone area, and gives reliable harvest finger millet, foxtail millet, proso millet, and fonio millet. Amaranth is a heat- and drought-tolerant crop; it is an early-maturing crop—20 to 45 days. An amaranth C_4 cycle plant, under high radiation intensity and high temperature, will sustain high photosynthetic activity and ideally tolerate abiotic stresses under climate change. Amaranth seed water requirement is 40–50% less than maize and 53–58% less than wheat (Massawe et al. 2015).

Climate-smart breeding

Plant breeding is the science and arts of manipulating plant genome for the improvement of plants in certain aspects for the welfare of mankind. Here climate-smart breeding refers to the breeding of plants/manipulation of plant genome to cope with the changing climate, including increasing temperature, carbon dioxide, and changing rainfall pattern. Hence, a plant breeder requires knowledge of plant molecular mechanisms, physiology, and morphology, which may allow the plant to respond to the stress conditions which occur due to climate change for its successful survival and adaptation.

Climate-smart breeding also relies on the following major objectives:

1. Productivity
2. Adaptation
3. Mitigation

Conventional plant breeding generally involves the improvement or development of the plants/crops using traditional methods for manipulating plant genome within the natural genetic limits of the species (Acquaah 2016). The conventional plant breeding methods for self-pollinated crops consist of mass selection, bulk method, pedigree method, single seed descent, backcross breeding, and pure line selection method. In contrast, cross-pollinated crops include family selection, mass selection, and recurrent selection of synthetic varieties. And hybrid development is applicable in self- and cross-pollinated crops. However, conventional breeding methods are unable to fulfill the demands of changing climate; hence, modern plant breeding is needed to meet these demands, which includes biotechnology tools and maybe genetic engineering.

Modern plant breeding technologies

1. Molecular markers methods: in conventional plant breeding, the genetic sequences of progenies or populations were not available. But now, with the availability of the genetic sequence of several crops, it is possible to develop molecular markers. These are molecular markers (RFLPs, RAPDs, SSRs, SNPs, etc.) combined with link maps to modify and improve plant characteristics based on genetic testing. It includes several advanced reproduction strategies such as marker-assisted selection (MAS), marker-assisted backcrossing (MABC), and marker-assisted recurrent selection (MARS). QTL, known as quantitative trait locus mapping, is the identification of DNA molecular markers (e.g., SSR, SNP) for quantitative traits that are correlated with a given trait in an isolated (mapping) population, thereby allowing a link map to the QTL state. Genome-wide association study, also known as GWAS, involves rapid scanning of up to 5 million markers (SNP) in a complete DNA set.
2. Participatory plant breeding: also known as PPB, means that farmers participate in the plant breeding program with the opportunity to make decisions at several stages of the concerned crop. Farmer participation in participatory plant breeding may include explaining breeding objectives and priorities, sometimes selection or presenting germplasm, testing their fields, selecting better plants for further reproduction, commercializing selected lines with research design and administration processes.
3. Evolutionary plant breeding (EPB): mainly is the process of creating genetic variation with repetitive sowing and harvesting in one or more agricultural environments without actively selecting individual plants and using the seeds as food or feed or further breeding, using seeds as a basis. EPB combines high-yielding, stress-resistant variation, and evolves with genetic variation.
4. Genome selection (GS) facilitates the selection of improved genotypes, shortens the reproductive cycle, and reduces the cost of reproductive line development. The prediction of global climate change presents a severe threat to the annual agricultural production across the world, thereby challenging nutrient security and food security. Scientific developments, molecular reproduction technologies, and especially transgene-based, have contributed to the advancement of superior genotypes with consistent adaptation to climate change. In the advancement of climate change, and resilient crops, genome-assisted breeding is supposed to play a vital part. Some excellent organisms have been identified as a model to cope with climate change phenomenon, such as foxtile millet and green foxtile (for C_4 photosynthesis). Brachypodium (grass model) have been identified having traits which seem best to fight against climate change situation and needed to be introgressed into other crops by decoding these traits. In addition to advanced genetic tools, developments in DNA sequencing techniques will accelerate the identification of novel genes and key regulatory areas of stress tolerance towards the development of new buds with durable resistance. Although the impacts of climate change on crop resistance may vary depending on the environment and crop and also it is difficult to predict, however, the effects of climate change on future crop scenarios can be significantly reduced by genome-assisted breeding.

Ideotype designing for changing climate

To describe the idealized appearance of a plant, Donald in 1968 introduced the concept of ideotype in plant breeding. It means “a form denoting an idea.” A biological model that is supposed to perform within a defined environment in a particular manner is called an ideotype, according to Donald. A crop ideotype, when developed as a cultivar, is expected to yield a more significant quantity or quality of the grain, oil, or other useful products.

Climate change is a challenge for the future; to cope with future climate problems, we can design an ideotype for the crop. Some essential modifications in crops for ideotype development is as follows.

Temperature tolerance

Temperature is the more common and foremost problem of climate change as two types of crops are Rabi crops (sown in winter season) and Kharif crops (sown in rainy season also called summer or monsoon crops). To the development of crops ideotype with heat tolerance, there may be two strategies. The one is heat escape, which includes early flowering. Early flowering will lead to higher floret and tiller survival, reduced screening, and well-filled grains, which contribute to high yield. The other one is late-flowering, which performs well with increased grain weight and grain number, which will ultimately cause a higher yield.

It is seen that at the high-temperature genotypes with higher chlorophyll content at grain milking stage, early anthesis, higher NDVI (normalized difference vegetation index), higher gain number and grain weight, and taller stature produce high yield and better grain quality. These traits can be used to design ideotypes of wheat in changing climates to cope with heat stress problems.

Water uptake by roots

We assume that the ratio of soil water available from each layer in the root zone can be extracted by the plant on any given day, depending on the water extraction rate (λ) and the root water take (RU). The daily water ratio collected by the plant decreases by 10% from the RU at the top of the soil to the maximum root length. Rapid root water uptake reduces the current water pressure experienced by the plant by absorbing excess water available during seasons such as rain or irrigation. But in contrast to the dry environment, another alternate strategy can be achieved that is slower water uptake by roots, which can conserve water for successful completion of the plant life cycle, which would cause an increase in yield.

Drought tolerance

When an area or region experiences a precipitation rate below regular or average precipitation, this period is called drought. Conditions like reduced groundwater or reduced soil moisture, reduced streamflow occurrence due to the lack of precipitation, either snow or rain, and ultimately water shortage problem along with crop damage may occur. After hurricanes, droughts are the second-costliest weather events.

Changing climate has adverse effects on the rainfall pattern. In this way, the rainfall pattern is sometimes changing rainfall pattern which is modified in such a way that there is excessive rainfall, a condition which may cause waterlogging, but sometimes the alternation in the rainfall pattern is such that there is no or low rainfall, which leads to a condition called drought. To combat with future climate, which is a challenge, while designing ideotype for climate change, the phenomenon of drought stress can be fixed by altering the following trait while looking at its synergistic and antagonistic effects; these traits may be as follows:

- Leaf surface area
- Leaf angle
- Xylem diameter
- Stomatal modification
- Root system

Transpiration rate is one of the major factors which is concerned with drought stress, lower transpiration is beneficial in case of drought stress for successful plant life cycle, and transpiration rate depends on leaf surface area, leaf angle, and the number of stomata and their opening/closing. Plant leaf with lower surface area and less number of stomata has a low transpiration rate. Moreover, transpiration rate can also be decreased by adjusting the angle of sunlight to the leaf surface; that is, it should be less than 90° to the leaf surface area so that the leaf surface may not be much exposed to the sun. But in this way, the photosynthesis rate will also be affected, which will be lower; in this case, we will have to compromise on yield. The modification of all these traits depends on how much compromise we may have for yield.

Canopy

The aboveground portion of a plant crop or community formed by the collection of individual plant crowns is known as canopy. The rate of canopy expansion and development of the final canopy are the factors related to the transpiration and sunlight intercepting plant parts. The maximum flat-leaf area is the trait involved in achieving maximum leaf area index, which is directly proportional to the rate of transpiration and photosynthesis rate, which affects the plant growth and grain yield. In contrast, reduced leaf area leads to a lower leaf area index for drought conditions to conserve water for a successful plant life cycle and low transpiration rate.

Improving food security

Almost 1 billion individuals are suffering from hunger around the world. Therefore, poverty is the most crucial factor in chronic household food insecurity. Despite food available in the market, poor people do not have enough purchasing power to secure access to food. Food is also wasted or lost throughout the supply chain, starting from agriculture production to its final supply to household consumption. Extra losses may occur early in the food supply chain in the industrial areas with inadequate harvest times, equipment downfalls, unavailability of workforce, and mismanagement. In developing countries, due to poor handling and distribution channels, food is lost mainly during the early stages of the food supply chain; much of the food is wasted despite the high price of food. To achieve food security, at all time, all the people have economic, physical, and social access to sufficient good quality food for an active and healthy life. Thus, the definition of food security contains all four basic features of food security: availability, accessibility, consumption, and constancy. It will also include safe drinking water, food quality, and hygiene.

Food securities have three dimensions to achieve. Primarily, it is important to safeguard nutritious food and safe sufficient food should be supplied. Second, it is essential to supply adequate supply and stability in supply either during the year and from 1 year to the next one. Third, and most serious, it is very important to ensure that all individuals will have access to an adequate quantity of food.

To achieve food security, we have to work with collaboration. (1) We have to adopt a development strategy for economic development, and we just have to focus on poverty alleviation, sustainable agriculture development, and food security. (2) To make sure access to food, the countries have to develop such programs that will uplift the level of food production and agriculture trade. (3) The government has to protect natural resources and places of production. (4) The government should encourage the private sector to take their best part in industry, rural area development, business, and handicraft, to uplift opportunity for rural people. (5) Minimize post-harvest losses due to climate change, and improve storage, packaging, preservation from disease, safe food during distribution, and transport to decrease losses at all stages. To cope with climate change problems, we have to introduce a variety of cropping strategies, develop agroforestry approaches, protect our biodiversity and environment, reduce fluctuation in price by making an efficient market system, and promote community and household gardens.

To cope with environmental stresses, we have to develop followed different strategies, including extension and research, input, and irrigation provision. We have to develop the modern crop variety via research which are the basis to improve food security, especially in Asian countries. Free Germplasm exchange that contains important character to adapt plant against climate change and International collaboration is important to achieve production challenges.

Reduce food waste and post-harvest losses in CC scenario

Worldwide, 30–50% of food is wasted due to post-harvest losses as climate change will also reduce food production; in addition to food spoilage, the inadequate storage facility will also contribute to food wastage. It is estimated that 413 million people per year can be fed if we reduce food wastage in India, China, and the USA. Food losses and waste will be different in different countries, and it will depend upon the type of food and variety of crops grown at farm and loss of food during storage, processing, packing, handling, consumption, and distribution. Because of the unavailability of technical inefficiency during the storage stage, as much as 50–60% of cereal grains will be lost. If we use the scientific method of storage, it will reduce grain losses.

As climate change is already posing a serious threat on the crop, which counts for reduction of yield, along with postharvest loss, it will account for direct quality losses and physical losses that add up the extra decrease in economic value. This case will become more severe in the African country, where it is estimated that 20–40% of grains will be reduced. Hence, it will highly contribute to low agriculture production. To address the post-harvest issue, if we use already-existing best practices and cost-effective technologies widely, it will minimize yield losses, e.g., more efficient transport system, improved post-harvest processing techniques, and practices like hermetic storage.

As we already know that population burden and changing climate will contribute to lessening yield, hence, there is a need for worldwide policies and strategy to minimize food losses during post-harvesting, storing, processing, transport, etc. and through value addition and food processing, handling of crop residues and wastes, and by-product recovery. WFP (World Food Programme) is already working on how to resolve the issue of post-harvest handling, training the smallholder farmers, and using an effective hermetic storage facility. The equipment which is subsidized is both air and water-tight, helping to guard against insects, rodents, mold, and moisture.

Government and international partners altogether use a variety of ways to address all dimensions of food security. This activity is ranging from uplifting research to make disease-resistant crop varieties, educating families for good field practices for children, or developing a strong market for farm products.

Food security/safety is one of the main issues as it already becomes worse and expected to become more hazardous in the near future; it can uplift the price of food; there are three strategies that, together, could reduce vulnerability to price shocks: (a) educating the people to not waste the food in the activity like parties, etc., strengthen safety nets, and improve access to family planning services; (2) increasing investment in research to improving rural livelihood, and enhancing domestic productivity; and (3) by developing more efficient food supply, we can reduce fluctuation in market price and suitable usage of economic instruments to hedge risk. All the risks associated with food losses will either be due to climate vulnerability or from post-harvest losses; there will be a need for strong global responses, funding international or at the research institute, civil society, non-government organization, and private departments.

Solving the problem using biotechnology and genetic engineering

Biotechnology is a wide-ranging area of biology concerning the development of useful products using living systems and living organisms. Reliant on the tools and applications, it frequently overlaps with related scientific disciplines. In the late twentieth and mid-twenty first hundreds of years, biotechnology has reached out to incorporate new and various sciences, for example, genomics, recombinant gene techniques, applied immunology, and the advancement of drug treatments and diagnostic tests. Biotechnology is closely associated with genetic engineering. Genetic engineering (GE) involves the direct alteration of an organism's genome through biotechnology. It is a set of techniques applied to modify the genetic makeup of cells, involving the transfer of genes within and across species boundaries to produce improved or novel living beings. Genetic engineering implies that the desired gene is isolated, cloned, and incorporated into the host organism. Initially, the plasmid vector was designed to transfer candidate genes to the crop plant gene. The transition vector often consists of a cassette with transgenic-expression cassettes that allow the selection of transgenic plant cells with a selective marker.

How biotechnology and genetic engineering differ from conventional breeding

Genetic engineering is different in many ways from traditional breeding which is mainly based on choice using sexual natural processes. Genetic engineering uses the process of inserting a gene by material gene gun or some other direct genetic contact methods or specifically created a bacterial truck that cannot be done in conventional breeding while genetic engineering via biotechnology can insert genetic material from one form of life to another. Traditional breeding generally can only work within one species or within a maximum related species when we do wide crosses.

Conventional breeding depends on mixing characteristics from different populations within the same species (sometimes out of species depending on the compatibility); however, genetic engineering is the direct insertion of genetic material, more often from unrelated species, from the unrelated genus, and even between the organisms which are not related by ancestors. A genetic engineer requires to add a specific promoter gene, which is the on switch for genetic material inserted, while in conventional breeding, there is no such need. It should be reminded that genetic engineering always relies on biotechnology.

In access to information and expertise in countries, there is a demand to increase food production very urgently, which will be a key factor in the application of genetic engineering and biotechnology for sustainable food safety.

Development of temperature tolerant transgenics by biotechnology and GE

Temperature-tolerant transgenics can be developed in order to fulfill future needs and cope with increasing temperature due to climate change by following strategies by genetic engineering via biotechnology.

By altering the level of osmolytes Osmolytes are the organic compounds having low molecular weight, and these compounds greatly influence the properties of the biological fluids, fluids within the cell such as quaternary ammonium compounds, amino acids like proline, sugars, polyamines, and sugar alcohols. Their primary responsibility is to sustain the integrity of the cell by changing the viscosity, melting point, and ionic strength of the aqueous solution. When the cells swell up due to external osmotic pressure, the membrane channels open and permit the osmolytes to take water with them which re-establish normal particle size. Glycine betaine by means of stabilizing O_2 evolving photosystem II complex is believed to protect the photosynthesis machinery; the introduction of bacterial codA gene, which encodes choline oxidase protein, achieved increased biosynthesis of glycine betaine in Arabidopsis plants. However, overproducing levels of proline, mannitol, trehalose, etc. are not seen to enhance osmotic stress tolerance. In the same way, it is seen that in tobacco, overexpressed level of betaine aldehyde dehydrogenase protein from spinach showed greater thermotolerance due to the result of increased glycine betaine level.

Modifying fluidity of cell membrane Membrane fluidity implies the lipid bilayer viscosity of a cell membrane. Membrane fluidity depends upon the presence of saturated or unsaturated fatty acids, which is dependent upon temperature further. A decline in temperature leads to a reduction in membrane fluidity; as a result, increased expression of the genes encoding fatty acid desaturases occurs. These enzymes compensate for the increase in membrane fluidity by the introduction of double bonds into the fatty acyl chains of membrane lipids; these unsaturated fatty acids help plant in facing the low-temperature phase and minimize the damage due to low temperature; this strategy can be adopted for the acclimatization of plants which are exposed to low temperature (which may also be due to climate change, i.e., harsh environment).

But at high temperature, there is a decrease in membrane fluidity, therefore, causing an increase in rigidity of membrane because of more production of saturated fatty acids, which is due to the enhanced expression of the genes encoding these fatty acids. The over-expression of Fad8 imposed much greater heat sensitivity than that with other desaturases like Fad3 by overexpressing *Brassica napus* cytosolic Fad8 protein in tobacco. Introgression of such genes in crops exposed to the high temperature and also to develop crops for future climate change, i.e., the elevated temperature will cause the crops to acclimatize in high-temperature regions.

Altering the production of antioxidants for elevated temperature Heat stress generally causes an increased level of reactive oxygen species (ROS) like hydrogen peroxide and hydroxide; these molecules are harmful in terms that these ROS cause damage to the macromolecules and the cellular membranes, but fortunately, plants have developed a mechanism to deal with this problem that is the production of antioxidants also called as reactive oxygen species scavengers. Here ROS scavengers include several compounds like non-enzyme molecules (including glutathione, anthocyanins, ascorbate, anthocyanins) and enzymes (such as ascorbate peroxidase, superoxide dismutase). Twofold increase in the pool of the xanthophyll cycle in Arabidopsis is observed by overexpression of the chyB gene that encodes β-carotene hydroxylase, which is an enzyme active in the zeaxanthin biosynthetic pathway (Mínguez-Alarcón et al. 2019). Greater tolerance to high light and increased temperatures was observed in these transgenic plants. In the same way, the enhanced or overexpression of the genes encoding antioxidants would help the plant to survive in high temperature; this strategy is also helpful in case of low temperature. It is possible to develop plants with multiple stress tolerance traits by targeting detoxification pathways.

Development of drought tolerance transgenics by biotechnology and GE The predicted climate change is also addressing the future drought conditions, which need to be fixed for the future; according to predicted climate change, there is a change in the weather pattern and rainfall pattern in which low or no rainfall is the central issue. Thus, drought is the condition of a plant lacking water due to no or less rain and a low quantity of available water. As reactions of the plants are multigenic towards abiotic stresses, it is not possible to induce the whole cascade of cellular changes by the introduction of a single gene compulsory for rendering the plants stress-tolerant unless regulatory genes are used. Recently, genes encoding for the abiotic stress-induced TFs have been identified, cloned, and utilized in genetic engineering experiments (Zhang et al. 2000).

It is seen that plants combat the drought stress in types of pathways.

1. ABA-dependent pathway

ABA plant hormone is one of the significant metabolites produced in response to the drought stress in plants; recently, a cytochrome P450 CYP707A family has been recognized as ABA 80-hydroxylases, in addition to a key ABA biosynthesis gene, and during seed dehydration stress and imbibition conditions, it plays a central role in the regulation of ABA levels, beneath circumstances of drought stress; it is possible that these findings could enable us to control the level of ABA and may ultimately contribute to development in the engineering of drought tolerance (Taishi Umezawa et al. 2006). Leucine zipper (bZIP) plant TF family comprises of ABA-responsive element binding factors known as AREB/ABF, and these are identified to perform a function during seed maturation and dehydration in ABA signaling. About 75 AREB/ABF homologs have been discovered in the Arabidopsis genome. To regulate gene expression, activated AREB/ABF attaches to the regulatory cis-component having sequence (ACGTGT/GC) called the ABA-responsive element in response to ABA. In Arabidopsis, in the promoters of the genes which are stimulated due to overexpression of AREB1/ABF2, ABF3, or AREB2/ABF4 by ABA, ABRE is observed that resulted in increased response to ABA, decreased transpiration, and more guard cell closing (Kang et al. 2002). In this regard, transgenic plants engineered accordingly seemed to be more tolerant in case of drought (Yang et al. 2010).

2. ABA-independent pathway

Several TFs are responsive to the dehydration/drought in contrast to SNAC and AREB/ABF, but several TFs are not responsive to the ABA, and therefore these TFs are called ABA-independent dehydration-responsive TFs. To trigger the expression of a target gene, these TFs usually bind to a conserved cis-component, generally A/GCCGAC sequence in the promoter site of the target gene. All the TFs are DREB and CBFs; plant-specific AP2/ERF TF superfamily comprises 147 members in addition to the participation in the regulation of cold responses and dehydration, and all CBFs/DREB are the members of this superfamily in the development of the flower, leaf, and seed; these TFs perform a significant role, using yeast one-hybrid screening for proteins which are attached to DRE elements in Arabidopsis; two classes of DREBs were isolated called DREB1 and DREB2, and DREB1 expression is upregulated by means of cold stimulus. However, drought, salt, and heat stresses regulate the function of DREB2 (Yang et al. 2010).

Resistance to insect/pests and diseases

Climate change has severe effects on every aspect of agriculture globally. The quality and quantity of agricultural commodity production is badly influenced by the changing patterns of climatic factors like precipitation, humidity, temperature, and other meteorological components. Climate change is threatening food production via pest worldwide in addition to direct impacts on crop productivity. About 10–25% of yield losses due to insect pests are increased with each additional degree rise of temperature. Climate change is enhancing the survivability of insect pests and allowing these pests to develop adaptability and by expanding diversity, it has increased pest population and their potential for damage. The rise of temperature, altered precipitation patterns, change in atmospheric gaseous composition, etc., are causing the variation in behavior of insect pests and population. Currently, climate change is the cause of (1) increase in abundance and diversity of the insect pests, (2) altered geographical distribution of insect pests, (3) overwintering in insects, (4) rapid population, (5) introduction of alternative host plants, (6) variation in host plant resistance, (7) increased in the risk of invasive pest species, and (8) insect-transmitted diseases emergence (Shrestha 2019).

Large-scale applications of chemical pesticides to reduce the crop losses caused by insect pests and diseases, valued at over US$250 billion annually, have not only led to serious environmental hazards but has also resulted in the development of resistance to pesticides in the pest's population. So, we will have to develop resistance against these insect pests and diseases in crops. Genes from the wild relatives of crops, and novel genes, such as those from *Bacillus thuringiensis* are also being introgressed into different crops to make "plant resistance" a significant weapon in pest management. Development of pest-resistant varieties will not only cause a major reduction in the development of resistance against pesticides in insects and use of pesticides, but this would also cause a reduction of pesticide residues in food, increased activity of beneficial microorganisms in the soil, and a safer environment to live (Dar et al. 2006).

When plant traits referring to insect pest resistance are identified, these traits are introduced into the plant genotype having desirable traits already priority-wise, e.g., growth form, and yield. It is possible to transfer traits by conventional breeding when the following plants are sexually compatible, and the traits of interest are within the same species as in a landrace, and marker-assisted selection reduces timescales for a breeding project. However, the production of cultivars with insect resistance and other desirable traits can be accelerated many folds by using modern genetic technologies, including genome editing and genetic transformation as compared to conventional breeding and especially when crops have limited genetic diversity in desired traits; these techniques are essential (Douglas 2018).

Tobacco was the first transgenic plant and was genetically engineered in 1982, and cotton and maize were genetically modified (GM) to produce Bt toxin, and thus these crops are called Bt cotton, and Bt maize. Bt cotton was approved in 1995 in the USA, while Bt maize was approved in 1996. Different Bt toxin domains have been recombined to enhance the efficiency of GM products; e.g., the fusion of Cry2Aa and Cry2Ac produced Cry2AX1 product, which protects against several lepidopterans.

The arsenal of Bt toxins engineered artificially can be complemented by insecticidal activity with several other proteins, like venoms of some insect predators, plant lectins, and protein toxins produced by some soil bacteria which have the potential to perform this activity. For example, chlororaphis produced by soil bacterium Pseudomonas is a protein that is toxic to coleopteran pests, western corn rootworm, however not to lepidopteran insects. In principle, by appropriate stacking of specific genes, we can design the insect resistance in plants, including genes that are engineered for optimal efficacy. For example, activity against lepidopteran pests can be induced by fusion of a scorpion neurotoxin domain (As1T), and against hemipterans, the GNA lectin domain is active, and in Arabidopsis, tobacco, and rice, it confers resistance against multiple hemipteran and lepidopteran pests. In another example, by fusion with a luteovirus, the coat protein toxicity of an orally delivered spider toxin Hv1a is enhanced for aphid pests (Douglas 2018).

Introgression of the wild gene, to cope with climate change, adaptive introgression

The fundamental component of plant biodiversity includes plant genetic resources, the precious heritage of humankind. Genetic resources of the plant consist of genetic stock, population or genotype of landraces, wild/weedy species, and advanced cultivars. It can be maintained either in situ or ex situ in the form of the plant, tissue, or seed. Many countries are trying to save the genetic stock; hence, these plants have great potential to improve many vital crops. These genetic resources can be used currently or near future for plant improvement for the benefit of mankind. These genetic resources are vital for the breeding program, as it contains required character; they can be used for developing new varieties having character related to abiotic disease resistance (e.g., drought/salinity/alkalinity/heat/cold/chilling stress/wind) and biotic stress resistance (e.g., insect-pest and diseases).

The gene pool will include all the genetic information, their all genes in a particular species of population. Introgression, also known as introgressive hybridization, represents the transfer of genes from one to another species via recurrent backcrossing with one of the parental species of an interspecific hybrid. Now it is possible to flow the gene out of reproductive barriers even between species or genera for this genetic engineering, or bridging species are used which are compatible or cross with both species which otherwise do not cross with one another. In plant breeding, it is common to transfer the gene artificially from a wild relative of a crop into the crop gene pool. Two scientists, J. M. J. de Wet and Jack R. Harlan, expand the definition of the gene pool. They put the wild ancestor and gene pool of crop, together, which usually satisfy the conditions of a biological species, the primary gene pool. They also proposed the grouping of the secondary and tertiary gene pool, depending upon the ease of introgression of genes into a member of primary gene pools. In other words, all the members present in the primary gene pool can easily cross with each other, and the production of sexual hybrids needs no unique technique in this pool rather than synchronized flowering. While the members of the secondary gene pool can be difficult to cross with the member of the primary gene pool, the secondary pool involves some manipulation and occasionally special techniques. In contrast, tertiary gene pools may or may not crossbreed simply with the primary gene pool and produce infertile plants most of the time.

Global climate change will put a severe threat on domesticated as well as wild species biologically and their related ecosystem services. As already discussed, global warming will result in a change in the yield and phenology of crops. In dealing with the climate change challenges of agriculture in this century, there is a vital requirement for harnessing the genetic variability of crops and adapting them to new conditions. We need to adapt the crop to various environments and to extend our genetic diversity either through the transfer of genes from one species to another or through mutation breeding. “Adaptive introgression” represents increasing the fitness of species by incorporating a foreign variant gene. It is stated that naturally, introgression of the gene between domesticated species and their wild relative would contribute to the evolutionary process and genetic variability.

Traits associated with insect pest or disease resistance and adaptive character to soil and climate are much more present in the wild as compared to domesticated plants.

Introgression of the gene from crop wild relatives

Plant breeders will explore the crop wild relatives (CWRs) and discovered that these are having a novel beneficial character variant for stress tolerance. By utilizing sexual or somatic hybridization, CWRs can exchange genes with the cultivated taxa (LU 2013).

Steps introgressions program The steps involved in the introgressions program are as follows: (a) recognition of CWRs containing the character of interest; (b) hybridization and backcrossing of the crop with a large number of CWRs from different gene pools, also use a unique technique of crossing where needed; (c) by utilizing the genomic tools, develop several specific introgressed populations that contain a character from one or many CWRs; (4) build a database containing genomic or phenotypic details, also make repositories of the introgressions populations; (5) use the material in breeding programs.

Some notable examples of introgression of the genes to cope with stresses There will be a significant success in traits introgression into the domesticated plant from CWRs, over the past few decades, typically for overwhelming biotic stresses. A crucial part of the green revolution involves overwhelming rust resistance in wheat, and late blight in potato was responsible for the Irish potato famine. Breeding of crops with their wild relatives will continue to advantage the most from wild genetic diversity (Dempewolf et al. 2017).

A notable example of targeted introgression of a wild relative arises from the common bean, *Phaseolus vulgaris*. Breeders will successfully introgress insect resistance genes (for instance, *Apion* pod weevils, bruchid beetle seed predators) and pathogens (e.g., *Fusarium*), as well as higher iron, calcium, and nitrogen seed content from existing collections of wild *Phaseolus*. These efforts will be highly significant in improving nutritional quality and uplifting yield, and it enables to cope with climate change stresses, reducing environmental pollutions, e.g., reduced herbicide and pesticide use (Warschefsky et al. 2014).

Intergeneric or interspecific hybridization is the basis of traditional hybridization of disease resistance; for instance, the introgression of the gene from *B. fruticulosa* and *Erucastrum cardaminoides* into *B. juncea* makes them resistant against Sclerotinia.

Several plant species are well known where the concept of adaptive genetic variation is applied, such as *Senecio* and *Helianthus*. For instance, *Helianthus annuus* ssp. *texanus* (a hybrid of *Helianthus debilis* and *H. annuus*) gained augmented herbivore resistance from its parent *H. debilis*; it will show that for the adaption of hybrid subspecies, introgression of biotic resistance trait is essential (Suarez-Gonzalez et al. 2018).

In dry-adapted *Iris brevicaulis* and flood-tolerant *Iris fulva*, introgressed adapted traits have been reported. If we artificially backcross these two species, due to the presence of *Iris fulva* alleles throughout the genome, introgression of the gene will make them capable of surviving in extreme flooding conditions. In a serpentine autotetraploid, *Arabidopsis arenosa*, mineral nutrition deficiency, phytotoxic level of metals, and adaptation to drought are driven from accepting alleles from *Arabidopsis lyrata*, and also driven by genetic variants locally arising but also by capturing a diploid that independently colonized serpentine barrens (Suarez-Gonzalez et al. 2018).

The recognition of adaptive introgression will be a better way to target the relevant adaptive diversity to be deployed for the development of climate-resilient and more sustainable varieties.

Identification of loci of interest applying QTL analyses and associated studies Genetic mechanisms involve complicated signaling pathways and the influence of several genes and regulatory regions in a crop responding to biotic and abiotic stresses. QTL (locating all the regions in the genome that are associated with a particular trait) analysis successfully reports regions associated with climate-relevant QTL in various plant species; e.g., in barley, QTL has identified 20C-repeat binding factor (*CBF*), important genes considered main regulators of cold tolerance genes. In bread, wheat QTL has analyzed three noteworthy genomic regions on chromosome 2B, 7B, and 7D, and they are regarded as heat-tolerant genes. In meadow fescue, QTL has analyzed 3F on the chromosome and on chromosome 5F, which are considered a drought-tolerant gene.

Genome editing Genome editing is one of the unique techniques (it can alter the DNA to include desirable character; e.g., CRISPER Cas9 cut the gene for gene repairing or inserting desirable segment). Hence, it helps in crop improvement by inserting traits viz nutrient use efficiency and stress tolerance. This technique will also be used in the improvement of agronomic traits related to a climate like resistance to insect/pest and pathogen in the crop. In maize, CRISPR/Cas9 will be used to target the *OsERF922* gene to develop blast resistance. In wheat, this technique will be used to lose the function of the susceptible gene *TaMLO* to make plant powdery mildew resistant (Scheben et al. 2016).

Wheat-alien introgression lines with main introgressions of rye, but also of *Leymus* spp. and *Thinopyrum junceiforme* into bread-wheat (*Triticum aestivum* L.). From this material, lines carrying 2RL were discovered having many resistance traits (e.g., powdery mildew) and superior agronomic performance traits. A line Sr59 found, which comes from 2RL, will have a novel resistance gene, e.g., rust resistance. Lines with multiple introgressions from 4R, 5R, and 6R were deemed resistant to different races of stripe rust recognized now (Johansson et al. 2020). To make potato resistant to late blight, two genes were introduced from the potato CWRs *S. venturi* and *S. stoloniferum* in numerous potato cultivars (Prohens et al. 2017).

Research/innovation-supportive community-based adaptation strategy

As in Asia, smallholder farmers are already facing many issues related to sustainability in agriculture and related to production and livelihood. This issue is becoming worse as the risks associated with climate change become more hazardous (Bhatta et al. 2017).

The induced innovation hypothesis emphasizes improving agriculture via using improved variety having quality, stress, and disease resistance character, using appropriate agronomics practices, and use of specialized input. Innovation systems involve change in conventional practices and upgrade them to scientific research and development. Innovation is a unique concept defined as the change in practices, knowledge, policy, institution, and technology. We have to understand the relation between innovation and adaptation to draw the attention of supporting institute, stakeholder and farm communities, and research group as well as supporting institute (Bhatta et al. 2017).

Among the known theories, the economic growth theory is distinguished from technologies. One of the theories is known as economic growth theory that distinguishes among technologies. These distinguish among innovations is according to their form, for instance, managerial, institutional, and technological innovations. Managerial innovations will describe the most suitable practices, for instance, improved pruning techniques, crop rotation, and IPM (integrated pest management). Institutional innovations include trade improvement, for instance, contract farming and a future market system, and new organizational forms (e.g., cooperatives). Technological innovations are embodied in new machinery and can be divided into biological (e.g., seeds), chemical (e.g., fertilizers), and mechanical (e.g., tractors) innovations (Bhatta et al. 2017).

There will be wide research on the agriculture system, but still, there will be a need to understand what innovation in agriculture is included overtime to cope with future climate change stresses.

Conclusion

It is confirmed that climate change and their severe impact will threaten the food security, insect pollinator, crop survivability, and production. The most severe issue that will cause significant yield loss is an insect outbreak due to abrupt climate change. The abiotic factor viz water stress, heat stress, salinity/alkalinity, and abrupt rainfall pattern will become harsh due to CC, which continuously threatens crop production. Furthermore, the major crop like wheat, cotton, rice, maize, and sugarcane production will impair due to the recent climate change scenario, and this issue becomes inordinate worse with time.

Therefore, it is meaningful to make the future strategy to cope with upcoming climate change stresses on plants. CFF (crop for the future) has already launched the program to extend our genetic base and also to add significant characteristics from the minor crop into our major crop via breeding. Climate-smart agriculture, climate-smart breeding, and adapting smart agriculture practices have considerable importance in the recent era and upcoming harsh times to improve yield, quality, and essential characteristics of the plant.

In such a worse situation, we must develop resilience in crops to protect them from abiotic/biotic stresses that already become eviler. Therefore, looking forward and designing an ideotype is vital to make crop fit in a crucial situation.

An advanced technology that upgrades many significant plant characteristics quickly but with more capital is biotechnology and genetic engineering. An efficient way to transfer desirable character beyond the crossing barrier, transfer of a vital gene from the wild plant, is another way to develop plant immune against harmful stresses.

We must turn to adaptive introgression of the crop. Otherwise, this situation will become hard to handle, and we may face the failure of the crop as in Africa. So, we just have to launch research/innovation-supportive community-based adaptation strategy to fit crops in the upcoming worse days.

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