Chapter 1
Advances in Research Trends in Vegetables Under a Changing Climate: A Way Forward

Shashank Shekhar Solankey, Meenakshi Kumari, Hemant Kumar Singh, Pankaj Kumar Ray, Shirin Akhtar, and Bholanath Saha

Abstract Change of climate is a never ending process but from last few decades the swiftness of alteration causes vulnerability in atmospheric temperature (heat, cold), rainfall (flood, drought), greenhouse gasses (CO_2, CH_4, N_2O, O_3) and intensity of extreme events, that is basically due to direct and indirect human interferences. Due to change in climate, agriculture food products are significantly impacted particularly succulent crops like vegetables, which are extremely vulnerable to change of climate. Vegetables has vast production capacity to fulfill the daily requirements of growing global population, but the present climate change severely affect the vegetable productivity. Hence, the scientists are thinking to reduce the speed of climate change and to work on the adaptation and mitigation strategies. Studying how climate change affects the growth, development, production and

S. S. Solankey (✉)
Department of Vegetables & Floriculture, Agricultural Research Institute, Patna, Bihar, India

M. Kumari
Department of Vegetable Science, Shree Guru Gobind Singh Tricentenary University, Gurugram, Haryana, India

H. K. Singh
Krishi Vigyan Kendra (Bihar Agricultural University, Sabour, Bhagalpur), Kishanganj, Bihar, India

P. K. Ray
Krishi Vigyan Kendra (Bihar Agricultural University, Sabour, Bhagalpur), Saharsa, Bihar, India

S. Akhtar
Department of Horticulture (Vegetable and Floriculture), Bihar Agricultural College, Sabour (Bihar Agricultural University, Sabour), Bhagalpur, Bihar, India

B. Saha
Department of Soil Science, Dr. Kalam Agricultural College (Bihar Agricultural University, Sabour, Bhagalpur), Kishanganj, Bihar, India

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quality of agricultural products is therefore urgently needed. At present a number of climate tolerant varieties have been evolved in various vegetable crops and with the help of recent molecular techniques the task of gene identification, genetic modification and varietal evolution is little bit easier for the olericulturists. Agronomic practices that preserve water and vegetable crops from harsh environmental conditions must be constantly developed and made broadly accessible to farmers in impoverished countries. A successful expansion plan that considers technological, social, and political aspects must be in place.

Keywords Climate change · Heat · Drought · Salinity · Greenhouse gasses · Adaptation · Mitigation

1.1 Introduction

Farmer struggle to cultivate crops as a result of the changing environment, which eventually puts tremendous strain on the ability to supply food for the world's expanding population. Unpredictable weather patterns and unstable atmospheric temperatures are results of climate change. Numerous international researchers have issued warnings in this direction, stating that if we do not implement eco-friendly agricultural practices, climate change could cause the world's food supply to decrease, making it impossible for us to produce high-quality food. However, affluent countries contribute significantly more to greenhouse gas emissions than under developed nations do. The Food and Agriculture Organization of the United Nations (FAO) estimates that global food production will need to increase by 70% by 2050 in order to feed an extra 2.3 billion people.

This issue is brought on by the atmosphere's buildup of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3), which are produced by humans as a result of long-term, intensive industrial expansion and high-consumption lifestyles in industrialized nations. India requires a national strategy to first adapt to climate change and then improve the ecological sustainability of India's growth path while working with the international community to collectively and jointly address this challenge.

Vegetables are thought of as a wholesome food and an essential component of the human diet. In addition to being rich in vitamins and minerals, vegetables also bring in more money than traditional food crops (Solankey et al. 2021a). Despite the fact that vegetable production has increased much more than the 15 million tonnes of 1950 to 191.77 million tonnes in 2021, moreover in fiscal year 2022, the total production of vegetables was estimated to be at approximately 200 million metric tons (Anonymous 2022).

More vegetables must still be grown to provide at least 300 g of vegetables per person everyday. Indian is the biggest producer of okra and ginger, while it comes in second place for potato, onion, cauliflower, brinjal, cabbage production. Cultivation of varieties which are both high yielding and have increased nutritional content with resistance to a variety of biotic and abiotic stresses can help to achieve our goal. Vegetable breeding combined with molecular techniques has a bright future in developing vegetable varieties with high amounts of nutraceuticals and bioactive chemicals appropriate for different markets. However, it is crucial that nutrient-rich foods are consumed to promote health security and bio fortified vegetable varieties be bred to meet the food needs of an ever-growing population.

Additionally, the distribution and quality of natural resources are impacted by climate change, which has a negative impact on people's ability to support themselves. The globe may be in serious danger due to the anticipated changes in climate because of an economy that is heavily reliant on its natural resource base and sectors that are vulnerable to them, including forestry, agriculture, and water. Food production has increased dramatically as a result of the green revolution, which also improve global food security. The natural resource basis for agriculture has been destroyed worldwide as a result of intensive agricultural production practices, endangering future output. Revolutionary discoveries made in the 1970s and 1980s fuelled expectations of significant improvements in agriculture and sparked interest and investment from entrepreneurs. These predictions are already coming true in the market because ongoing improvements in knowledge, technology, and business experience. Due to the effects of climate change and the rising competition for land, water, energy as well as farmers in developing countries will need to triple food production in order to fulfil demand over the next 40 years. Plant biotechnology and the application of molecular markers in conventional plant breeding techniques have established the foundation for molecular plant breeding, an interdisciplinary approach to crop improvement in the twenty-first century, much like recent advances in genetic engineering. Although molecular plant breeding techniques are constantly changing and are of great interest to agricultural specialists worldwide (Nelson et al. 2007; Lörz and Wenzel 2005; Varshney et al. 2006; Eathing ton et al. 2007; Mumm 2007). In 1994, the first wave of products in biotechnological application in vegetables was made available in pilot test markets. By using biotechnology tools some traits like postharvest life, quality of processing (deep red colour) was increased in vine ripe tomatoes, novel virus resistance in squash and insect killing protein in potato were increased. The Flavr Savr® tomato, which is reported as a superior vine-ripened flavour, was one of the first products to receive both popular attention and regulatory scrutiny. Alarming impact of change in climate are predicted. By 2030, due to change in climate 22 million people, the bulk of whom are farmers could be surviving in the extreme poverty. Variability in production is projected to rise when droughts and floods occur more frequently. Consider the possibility that, by 2100, grain productivity may drop by 10–40% while prices could rise by 29%. Every degree Celsius increase in temperature results in a 4–5 million tons decline in wheat production (Mohanty 2021).

Productivity of crop could be dropped by 10–40%. The rising temperatures would raise the amount of fertilizer which is needed by crop to achieve the same production goals thus increasing the emissions of greenhouse gas. The spawning, migration, and harvest of fish are anticipated to be affected by rising sea and river water temperatures. By 2030, coral reefs will begin to deteriorate. Increased animal needs for food, shelter, and energy would have an impact on milk output. There is a glimmer of optimism among these alarming figures. The soil holds the key role as a carbon sink, the soil of the earth absorbs and holds onto greenhouse gases. Carbon is released when soil is disturbed. Agriculture and the food value chain are responsible for 25% of all greenhouse gas emissions. Climate-smart farming techniques assist minimize soil disturbance, reduce greenhouse gas emissions, and maintain the soil's fertility (Mohanty 2021).

Lower intake of unprocessed meals but higher consumption of ultra-processed foods, particularly in tropical areas, were linked to decreases in rainfall and rise in temperature. Change in climate affects a wide range of health outcomes.

1.2 Effect of Climate Change on Vegetable Production and Its Management Techniques

Vegetables are usually succulent and sensitive plants therefore, severely affected by minor changes in the climate pose several challenges and negative impacts upon both quality as well as yield (Solankey et al. 2021b). The impact of various climatic threats and their mitigations are as follows:

1.2.1 Temperature

The main consequence of climate change that harms vegetable output is fluctuations in daily mean maximum & minimum temperatures since many physiological, biochemical, and metabolic processes in plants are temperature dependent (Abewoy 2018). In tropical and desert regions, the prevalence of high temperatures affects the production of vegetables (Abdelmageed et al. 2004). The plant‘s morphological, physiological, biochemical, and molecular responses are significantly altered by high temperatures, which has an impact on the plant‘s growth, development, and yield. Hazra et al. (2007) outlined the signs that high temperatures in tomato plants cause failure in fruit set, which include development of abnormal flower, poor dehiscence, viability and production of pollen grains, dropping of buds, abortion of ovules, minimum availability of carbohydrate & abnormalities in reproduction. In a similar manner, temperatures exceeding 25 °C have an impact on pollination and fruit setting in tomato (Abdelmageed et al. 2004; Solankey et al. 2017). In addition, high temperatures can significantly diminish tomato yield since they result in smaller, lower-quality fruits and reduced fruit set percentage (Bhardwaj 2012). Increased temperature after pollination in pepper decreased setting of fruits, demonstrating that fertilisation is vulnerable to extreme heat stress. However, pre-anthesis temperature exposure had no effect on pistil or stamen viability (Erickson and Markhart 2012). High temperatures results in flower and fruit dropping, abortion of ovule in green chilli (*Capsicum annuum*) while affect the red colour development in mature fruits of chilli (Arora et al. 2010). Additionally, seeds of *Citrullus lanatus, Cucurbita pepo, Cucurbita maxima* & *Cucurbita moschata* will not germinate above 42 degree Celsius. Seeds germination of *Cucumis sativus* and and *Cucumis melo* var. *cantalupensis* is significantly inhibited at 42 and 45 °C, respectively (Kurtar 2010). In melons, fluctuations of temperature results in delay ripening and also decrease the sweetness of fruit. Low yield of warm season crops such as *Benincasa hispida*, *Lagenaria siceraria* & *Cucurbita moschata* is a result of poor production of female flowers and also due to vegetative growth increased under warm humid climate (Ayyogari et al. 2014). The author also reported that high temperatures have resulted in increased abscission of floral buds, blooms, and immature pods, as well as decreased pod size and number of seeds per pod. When cole crops are produced for vegetables, high temperatures results in bolting, which is undesirable (Abdelmageed et al. 2004).

1.2.1.1 Plant Response to Heat Stress

Even slight temperature fluctuations can be detected by plants (Steven 2008). This process involves a large number of molecules, including transcription factors, chaperones, and osmoprotectants (Jacob et al. 2017). ER-UPR, Cyt-UPR, and membrane cyclic nucleotide gated calcium channels (CNGCs) appear to be heat stress sensors (Hasanuzzaman et al. 2013; Singh et al. 2020). Decreased rate of photosynthesis is caused by heat stress because it lowers internal CO_2 concentration, stomatal conductance, and leaf water potential (Hasanuzzaman et al. 2013). Heat stress, however, also has an impact on photosynthesis by altering stromatic reactions, grana and thylakoidal membrane architecture, as well as the grana and stromatic responses. Photosynthetic pigments are diminished by the lipid peroxidation of membranes, and PSII activity (Fv/Fm) is similarly decreased. Additionally, a decrease in Rubisco subunit proteins was observed under heat stress (Sage et al. 2008) and of the creation of starch and sucrose (Hasanuzzaman et al., 2013). Additionally, the ROS singlet oxygen ($1O_2$), superoxide radical (O_2), hydrogen peroxide (H_2O_2), and hydroxyl radical (OH^-) are produced during heat stress (Hasanuzzaman et al. 2013). Oxidative stress harms cell membranes by resulting in lipid peroxidation, protein breakdown, and the inhibition of root development after heat stress.

This happens as a result of the root cells' increased O_2 levels (Hasanuzzaman et al. 2013). Heat stress can have an impact on a plant at different phenological phases. However, the high temperature during blooming can entirely stop all grain production, while it can cause blossoms to drop off, give birth, or generate sterile flowers during the reproduction stage.

At different phenological stages, heat stress can have an impact on a plant. While it can cause flowers to droop, abort, or produce sterile blooms during the reproduction stage, the high temperature during blooming can completely cease all grain production (Maheswari et al. 2012). A shift in meiosis in both the male and female organs, which decreases pollen fertility and results in aberrant ovule and stigma development, is what causes heat-induced sterility in flowers (Cao et al. 2008). The rise in ethylene under high temperature provides an explanation for how heat affects pollen sterility. The metabolism of starch appears to be inhibited by ethylene, which results in less grain filling and sterile grain. The effect of high temperatures that is most concerning overall is yield decline. It has been demonstrated that tolerance species are less impacted by cereal pests than sensitive ones, with a 1000 grain weight reduction of up to 8% in sensitive rice species and up to 4% in tolerant species (Bashandy and El-Shaieny 2021).

1.2.1.2 Plant Heat Stress Defence Mechanisms

Living things have been classified as either psychrophiles, which prefer growth temperatures between 0 and 10 °C, mesophyles, which prefer growth temperatures between 10 and 30 °C, or thermophyles, which prefer growth temperatures between 30 and 65 °C. (Zróbek-Sokolnik 2012; Giordano et al. 2021). However, based on how they respond to high temperatures, the different species have been grouped into sensitive, tolerant, and resistant species, and their adaptation to high temperatures has been split into avoidance and tolerance (Hasanuzzaman et al. 2013). Stress brought by the heat that has similar effects as drought. The morphological and physiological avoidance methods that plants use when they are under heat stress include changing the direction of their leaves, closing their stomata, increasing their density, and changing the lipids in their membranes (Hasanuzzaman et al. 2013). To shield their leaves from heat, plants can also produce tomentose hairs, which grow thickly on their surfaces and cuticles. To prevent too much light from being reflected, leaves are either oriented parallel to the sun's rays or they roll up to limit water loss (Zróbek-Sokolnik 2012). Smaller leaves can handle heat better than larger ones because they experience less resistance on their surface as heat is expelled from the inside to the exterior. Additionally, in order to survive periods of high temperatures, plants attempt to complete their reproductive cycle when the weather is favourable. Many plants adapt their photosynthesis to high temperatures via the C_4 and CAM processes, which helps them survive in arid situations (Zróbek-Sokolnik 2012).

Other pathways that might lead to tolerance include those involving ion transporters, proteins from the late embryogenesis abundant (LEA) family, osmoprotectants, antioxidants, and transcriptional regulators (Hasanuzzaman et al. 2013; Singh et al. 2020). Tolerance though, can differ between tissues, organs, and species within a single plant. Other method of avoiding the damaging effects of heat stress is by the creation of heat shock proteins (HSP) (Xu et al. 2013). Five of these proteins work with other chaperones to repair damaged proteins while also being involved in systems for avoiding stress. Their elimination from the plant determines developmental changes (Raza et al. 2020). Under conditions of heat stress, salicylic acid supports the regulation of other stress hormones (Raza et al. 2019). The quantity of ascorbate, glutathione, tocopherols, and carotenes is increased by the plant as well as a number of antioxidant enzymes in response to the oxidative stress brought on by heat stress (Raza et al. 2019). Beyond a certain temperature, antioxidant enzymes lose their ability to function. For instance, it was shown that tolerant genotypes, as opposed to sensitive ones, showed an increase in the activities of catalase, ascorbate peroxidase, and superoxide dismutase under circumstances of heat stress. But at temperatures above 500 °C, these enzymes are inactive (Zeng et al. 2021).

1.2.1.3 Heat Responsive Genes

With a high degree of conservation and fairly predictable patterns, the heat-shock reflex is a biological response that almost all species display. At the transcriptional level, the heat shock response is characterised by a complicated alteration in mRNA and protein production as well as a significant accumulation of a collection of typically conserved proteins.

Genes are activated as a result of heat stress, especially if it losts for a long period, although the Heat Shock Proteins (HSPs) and related transcriptional activators are the main sources of an increased accumulation of transcripts (Guo et al. 2016). The term "HSPs" refers to a diverse class of proteins that was first studied in model organisms. HSPs are divided into five classes based on their molecular weight, though there are other classifications as well. The tiny HSPs are particularly prevalent in terrestrial plants (Waters and Vierling 2020). However, more recent studies in the fields of transcriptomics and functional biology have shown that the relevance of HSPs is far broader than previously thought. It essentially entails having a major impact on the stability and folding of proteins. It includes an essential part of cellular homeostasis under normal circumstances as well as defence against biotic and environmental stress. The fact that HSPs have been used successfully in the vegetable industry to increase post-harvest freezing tolerance is only superficially conflicting (Aghdam et al. 2015). A very extensive multigene superfamily, whose members are categorised based on their intracellular localization and function, encodes HSPs in plants. In plants, HSPs are encoded by a very large multigene super family, whose members are classified according to their intracellular location and function (Wang et al. 2004). The molecular response to heat stress in plants involves genes involved in a variety of processes, such as perception of stress, inhibition of "normal" protein and mRNA synthesis, preservation of cellular functions, development of thermo tolerance, long-distance signalling, and the beginning of morpho-physiological adaptation to long-term stress (Qu et al. 2013). The association of heat inducible genes with primary and secondary metabolism in plants, as well as with basic biological functions including transcription and translation, phytohormome signalling, and post-translational modifications, is not surprising. For heat responsive genes, post-transcriptional regulation, changing inducibility, and transcriptional control are all conceivable (Janni et al. 2020). Additionally, the modulation of the transcriptional regulation in plants under heat stress is governed by the small RNAs (Sunkar and Zhu 2004). Different genes are overexpressed in different crops when they are exposed to heat stress (Plantenga et al. 2019; Aleem et al. 2020; Singh et al. 2020).

1.2.2 Drought

Climate change is anticipated to have a considerable influence on water availability, and high levels of water stress will lower agricultural output in general and vegetable productivity in particular. Drought is the main reason for crop loss in dry and semi-arid areas & significantly lowers down the average yields by more than 50% for the majority of agricultural crops (Sivakumar et al. 2016). Lack of rainfall or inadequate soil moisture can produce drought stress can result in a number of biochemical, plant physiological, and genetic processes that drastically restrict crop growth (Vadez et al. 2012). The seeds germination in vegetable viz. onions and okra as well as the sprouting of potato tubers are negatively impacted by the presence of drought conditions (Arora et al. 2010). The drought environment causes embryo abortion in tomato flowers (Bhatt et al. 2009). Water stress during the reproductive stage was reported to have reduced tomato output by more than 50% (Srinivasa Rao and Bhatt 2012). Water stress during the flowering stage is thought to decrease the amount of nutrients given to the floral organs during assimilation and photosynthesis, which may enhance the pace of abscission. Increased soil solute concentration brought on by drought stress causes water to osmotically drain out of plant cells. Moisture stresses lowers the production of most vegetables by increasing the loss of water in the cells of plants and a variety of biochemical and physiological processes, including respiration and photosynthesis (Abewoy 2018). In addition to slowing down photosynthetic rate by lowering stomatal conductance, drought stress causes metabolic disfunction (Yordanov et al. 2013). When there is not enough water available, photosynthesis & the ability of photosynthesis are diminished. Reduced invertase activity may alter the body's capacity to metabolise sucrose, which could impact ovary growth and hexose concentration (Abewoy 2018).

1.2.2.1 Plant Response to Drought

In response to drought, plants have developed defences that differ depending on the species, the severity, and the length of the drought (Zhu et al. 2020). Numerous physiological traits are linked to water availability and can be employed as indicators of drought stress, such as leaf water potential, osmotic adjustment (OA), maximal quantum yield of PSII (Fv/Fm), water consumption efficiency (WUE), cell membrane integrity, and relative water content (RWC) (Hasanuzzaman et al. 2014; Goto et al. 2021). The decrease in cell turgor pressure and associated processes (such stomatal closure) during drought stress suggest decreased water losses and decreased plant nutrient absorption from the soil (Escalante-Magaña et al. 2019; Taiz and Zeiger 2017). For instance, the tomato stomata close at a water potential between −0.7 and −0.9 MPa, whereas the pepper (*Capsicum annuum* L.) stomata close at a somewhat greater range between −0.58 and −0.88 MPa (Chatterjee and Solankey 2015). Stomata closure decreases transpiration on the one hand while decreasing gas exchange and photosynthetic rate on the other. Other metabolic activities, such as the effectiveness of carboxylation, the quantity and regeneration of Rubisco, and the suppression of PSII activity are also impacted by prolonged drought stress. Since, drought-tolerant species have high WUE and can open their stomata quickly when the water deficit is alleviated, which enable them to fix carbon under stress (Chatterjee and Solankey 2015). Plants can modify OA by accumulating organic solutes in their tissues in order to combat the physiological harm brought on by drought (Taiz and Zeiger 2017). The cellular osmotic potential is decreased by an increase in solute concentration, allowing water to enter the cells and stabilising their turgor. It has been demonstrated that in Brassica species, a high value of OA enables the extraction of water from 90 to 180 cm deep soil layers (Chatterjee and Solankey 2015). Additionally, genotypes with high OA allow for the maintenance of a high turgor pressure even when the leaf potential is below 2.4 MPa (Chatterjee and Solankey 2015). Proline, glycine betaine, sugars (trehalose and sucrose), polyols (sorbitol, mannitol, arabitol, and glycerol), and other low-molecular-weight molecules, such as dimethylsulfonium propionate (DMSP), are among the most often found solutes in water shortage conditions (Escalante-Magaña et al. 2019; Sun et al. 2015). All of these substances serve as osmolytes, allowing the body to absorb water, as well as stabilisers and stress-resistance agents for proteins, cell membranes, chloroplasts, and liposomes (Razi and Muneer 2021). Proline has received a great deal of attention in particular because of its multifunctional role in plants'reactions to stress as a source of nitrogen and energy for cells as well as a radical scavenger (Sun et al. 2015). On the other side, it was discovered that proline contributes to the creation of cell wall proteins, such as extensin, that provide mechanical support under stress. In response to diverse abiotic pressures, glycine betaine builds up in a variety of species (plants, mammals, bacteria, cyanobacteria, and algae) (Escalante-Magaña et al. 2019). Because the light that is caught cannot completely be converted into chemically bound energy under drought stress, the pace of photosynthetic growth is delayed, and the energy surplus causes photo inhibition, which results in a decrease in the maximum quantum yield of PSII reaction centres (F_v/F_m). Several methods, include non-photochemical quenching, photorespiration through the Mehler reaction, and dissipation of non-radiant energy, and chlorophyll content management, can counteract the harmful effects of photo inhibition. Fv/Fm can be used to both identify water stress circumstances and identify genotypes that are resistant to and susceptible to water stress. As an illustration, tomato genotypes tolerant against moisture stress and maintained good PSII activity, leading to better photosynthetic activity than susceptible genotypes (Chatterjee and Solankey 2015). The ratio of photosynthesis (ACO_2) to transpiration (E) over time can be used to define water usage efficiency. Additionally, it shows the proportion of dry matter accumulation to water use throughout the growing season. WUE stands for a genotype's ability to efficiently absorb water from the soil in water-stressed situations. The genotypic differences in WUE, which are based on the ability to use soil water for absorption rather than transpiration, can help distinguish between tolerable and sensitive genotypes (Chatterjee and Solankey 2015).

Stress from the environment can disturb the cell membrane because it changes how permeable it is and causes ions to leak out. The loss of electrolytes from the cell can be used to measure this loss. The electrical conductivity of cytoplasm can be used as a gauge of drought tolerance since tolerant genotypes keep their membranes intact and display less electrolyte leakage than sensitive genotypes do (electrolyte leakage) (Chatterjee and Solankey 2015). Another drought indicator is the RWC, which shows the hydration status of plant tissues under water stress. Although this decline is genotype-specific, it reduces as the water shortage grows (Zhu et al. 2020). Abiotic stressors like drought often result in an increase in the amount of ROS in plant tissues (Sun et al. 2015). When oxygen is reduced by reducing molecules, ROS are created. When a plant is under stress from its environment, its stomata close to prevent water loss and the amount of CO_2 in its leaf's decreases. This causes oxygen to be reduced in its radical forms, including superoxide (O_2), hydrogen peroxide (H_2O_2), and hydroxyl radical (HO), through the action of NADPH, or reduced ferredoxin. It's conceivable for macromolecules like proteins, lipids, and nucleic acids to react with the recently created ROS (Sgherri et al 2018).

1.2.2.2 Defence Mechanisms Against Drought Stress

According to the research, resistance to drought stress is produced by combining three separate defence mechanisms, namely escape, avoidance, and tolerance (Kumar et al. 2012; Giordano et al. 2021). Plants‘ability to complete their life cycle before the start of drought conditions allows for the escapement process. Plants mature more quickly as a result of this response, which is caused by the shorter maturation durations for the distinct phenological phases (Kumar et al. 2012). On the other hand, the avoidance approach results in high water potential in plant tissues by increasing water absorption and reducing water losses from cells during the dry periods. This is achieved via a variety of methods, such as decreasing the canopy and leaf area, which decreases transpiration by diminishing the perception of solar radiation. Stomata closure, the production of cuticular wax, and adjustments to root density and length are also a part of this system (Kumar et al. 2012; Giordano et al. 2021). Finally, plants may endure drought stress if they maintain cellular turgor and water loss in circumstances of moisture deprivation and low water potential. This can be accomplished by increasing the cytoplasmic concentration of solutes (such as OA), increasing the flexibility of cell membranes, and shrinking the size of the cells (Kumar et al. 2012). Despite the fact that plants‘ability to endure in water-stressed conditions has overall advantages, the adaptation processes may result in undesirable features that have a detrimental effect on crop yield and output. For example, stomatal closure or a reduction in leaf area significantly affect CO_2 absorption, which affects biomass output and total yield (Kumar et al. 2012). While osmolytes accumulation may have a negative impact on the quality of the finished product, osmotic regulation by osmotic adjustment typically entails a significant energy expenditure, reducing the amount of photons available for biosynthetic processes. Therefore, it is imperative to establish the ideal balance between crop performance and drought survival, especially in commercial farming settings.

1.2.2.3 Drought Responsive Genes

Numerous species have been shown to include genes that alter physiological and morphological features in response to drought stress. For instance, the expression of numerous genes' recessive alleles dictates root thickness whereas the activity of several genes and the expression of their dominant alleles defines the length and number of roots (Kumar et al. 2012). The genes involved in the accumulation of solutes (such as the mannitol-accumulating mtlD gene or the proline-accumulating P_5CS gene) useful for reversing the decline in water potential in plants, encode various enzymes required for the production of these molecules.

Several species have previously discovered several of these genes, and their overexpression results in particular responses to drought tolerance (Kumar et al. 2012). DREBs/CBFs and ABF_3 genes that produce transcription factors that provide resistance to cold, salt, and drought stress; The production of transcription factors by the $SNAC_1$ gene increases stomata's sensitivity to ABA, which reduces water loss. When there is dryness, the ERA1 gene decreases stomatal conductance; Mn-superoxide dismutase is produced by the Mn-SOD gene, which confers resistance to several forms of stress; Root development is influenced by the AVP_1 gene; Osmo-tolerance is mediated by the build-up of proline and mannitol via the P_5CS and mtlD genes. Increased photosynthetic rate and tolerance to water deprivation during drought stress are mediated by the $GF_{14}l$ gene; WUE and stomatal conductance are affected by the NADP-Me gene. Under drought stress, the wilty gene contributes to the withering of tomato leaves. (Kumar et al. 2012; Giordano et al. 2021).

1.2.3 Salinity

Salinity is a serious problem that inhibits the growth and production of vegetable crops in many salt-affected areas. Throughout the course of a plant's development, many agricultural crops, including the majority of vegetables, are highly sensitive, suffer from excessive soil salt, which lowers output (Abewoy 2018). Because of the comparatively large solute concentrations in the soil, salinity physiologically imposes an initial water deficit, results in ion-specific stressors from changing K^+/Na^+ ratios, and creates a build-up of Na^+ and Cl^- concentrations that are harmful to plants. Salt stress causes the plant to lose its turgor, grow more slowly, wilt, shed its leaves, produce less respiration and photosynthesis, lose its cellular integrity, develop tissue necrosis, and eventually die (Cheeseman 2008). Onions are extremely vulnerable to saline soils, but cucumbers, eggplant, peppers, and tomatoes are just marginally sensitive to them.

In cabbage, salinity significantly lowers the germination rate, germination percentage, length of the fresh shoot and root weight (Jamil and Rha 2014). Because the mechanism in early, growing potato leaves that prevents salt build up from occurring has been disrupted, the combined stress of saline and heat causes vegetative development recovery to fail. The leaf area index and canopy function are adversely affected by this (Bustan et al. 2004). As stated by Lopez et al. (2011), In chillies, salinity lowers down the net absorption rate, relative growth rate, leaf area, and dry matter production.

The author also mentioned that salinity has a greater impact on fruit production per plant than it does on fruit weight. All cucurbits lose fresh and dry weight due to high salt content. Relative water content and total chlorophyll content changes are related to these changes. Salt stress in bean plants inhibits growth and photosynthetic activity, as well as changing the conductivity, number, and size of stomata. Salinity reduces transpiration and cell water potential in bean plants (Kaymakanova et al. 2008). It is well recognised that the excessive saline levels of soil and irrigation water influence many metabolic & physiological processes, which inhibits cell development.

1.2.3.1 Plant Response to Salinity Stress

Dissolved salts in the soil solutions come into direct contact with roots due to the osmotic effect and may hinder plant growth by reducing water potential in leaves and tissues. Plant development and production will be hampered by an excessive concentration of salts since these substances might interfere with key processes including among other things, germination, photosynthesis, nutrition balance, and redox balance (Petretto et al. 2019; Parihar et al. 2015). For instance, salinity may hinder germination because it lowers the osmotic potential of the germination media and inhibits seed imbibition (Parihar et al. 2015) & it also modifies the activity of enzymes necessary for the metabolism of proteins and nucleic acids (Parihar et al. 2015). Species and cultivars utilised, as well as salt levels, all affect salinity's impact on germination differently (Lauchli and Grattan 2007). Salinity and germination rate typically have a negative association, as evidenced by studies on rice, wheat, maize, *Brassica* spp., and tomato (Giordano et al. 2021). Two distinct phases of the salinity influence on plant development can be seen (Parihar et al. 2015). The initial stage of salinity has no detrimental effects on plant growth because Na^+ and Cl^- that enter the xylem are collected in the vacuoles and the meristems continue to grow by feeding through the phloem. Only the decrease in the growth of the leaves and roots is seen during this period (Parihar et al. 2015). During the second phase, salts accumulate in plant tissues, but cells are unable to store them in vacuoles. As a result, the cytoplasmic salt content increases and various enzymes' activities are significantly reduced. Salinity also affects photosynthesis because it lowers plant water potential and produces more chlorophyll. Cl was found to particularly inhibit chlorophyll synthesis, and 490 mg kg^{-1} of Cl in the soil may result in a 10% decrease in crop yield (Parihar et al. 2015). However, there are species-specific differences, and the levels of Cl required for plant growth can vary from 4–7 mg g^{-1} for species that are Cl sensitive to 15–50 mg g^{-1} for species that are Cl tolerant (Parihar et al. 2015). Salt can also lessen the number of carotenoids and xanthophylls as well as the intensity of chlorophyll's fluorescence, as shown in mung beans. However, it was shown that chlorophyll b is more susceptible to a rise in salt than chlorophyll a (Saha et al. 2010). Salinity can jeopardise the nutritional balance of plants because of its adverse impact on nutrient uptake and delivery within the plant (Parihar et al. 2015). Salinity significantly affects pH and redox. Potential of soil solution, which decreases the solubility of micronutrients. However, the species and salinity levels affect the micronutrients status (Parihar et al. 2015). Salinity may reduce the absorption of nitrogen due to interactions between sodium and NH_4^+ or chlorine and nitrate (Parihar et al. 2015). Atriplex griffithii's shoots and leaves showed decreased Ca absorption as a result of excessive salinity, although K levels were steady in the roots and decreased in the leaves. Due to the high salinity, the shoots and leaves of *Atriplex griffithii* exhibited decreased Ca absorption, but the K levels in the roots and leaves were stable (Parihar et al. 2015). Additionally, it was demonstrated that soluble ions (Na^+, Cl^-, SO_4^{--}) in the soil reduced phosphate absorption (Parihar et al. 2015). As the stomata close, an excessive amount of energy is transferred to oxygen, resulting in the creation of superoxide (O_2), hydrogen peroxide (H_2O_2), hydroxyl radical (OH-), and singlet oxygen, high salinity may cause oxidative stress comparable to drought and heat stress ($^1O_2$) (Raza et al. 2020; Petretto et al. 2019).

1.2.3.2 Plant Salinity Defence Mechanisms

Halophytes are referred to as plants that can survive in salty environments. The ability of plants to tolerate salt is influenced by a variety of traits at the genomic, proteome, and metabolomic levels. The plant uses a variety of strategies to deal with high salt concentrations, including reducing, absorbing and moving of salt or compartmentalising and extruding salts from plant tissues. The transcription level of proteins is altered during salt stress, but post-transcriptional alterations are also an issue. The answers provided by genomic and transcriptomic analysis can therefore be completed by proteomic analysis. A proteomic investigation of a protein's function, post-transcriptional alterations, subsequent interactions with other proteins, and distribution in the cell and tissues may all be used to learn more about a protein's function in salt stress tolerance. Different protein types undergo functional group changes during salt stress. Among these are ion transporters, energy-metabolizing proteins, and signal proteins. Saline stress activates some of these proteins, such as the calcium-binding calmodulin and annexin. They are involved in the transmission of abscisic acid signals. The transmission of saline stress signalling is mediated by additional guanosine triphosphate-binding proteins from the Rab family (GTPase). Under saline stress, $OsRPK_1$ protein kinase controls plasma membrane H^{+-}ATPases and restores ion homeostasis. Additionally discovered to accumulate during salt stress, the glutamate ammonia ligase protein aids with plant tolerance. It contributes to the synthesis of amino acids and the uptake of nitrogen.

Additionally, it was shown that salt stress causes the protein glutamate ammonia ligase, which is essential for assimilating nitrogen and producing amino acids, to build up (Kumar Swami et al. 2011) as well as glutamine synthetase. Several of these proteins are down-regulated in salt-sensitive plants, such as potatoes, emphasising their significance for salt tolerance. Protein breakdown is another feature of the changes observed at the protein level during salt stress.

An illustration of this is the rise in the ATP-dependent metalloprotease FtsH-like protein, which breaks down PSII's D1 core component. Under saline conditions, osmotic stress causes stomata closure, which lowers CO_2 absorption. This decrease affects the proteins that make up the Oxygen evolving enhancer (OEE) complex proteins, Rubisco subunits, and Rubisco activase. NADPH reductase and CP_{47} protein in ferredoxin, which protects D1 cells from salt stress, are additional proteins whose concentrations fluctuate (Parihar et al. 2015). Salinity causes the enzymes necessary for the manufacture of numerous hormones to increase, including the amounts of ethylene, abscisic acid, jasmonic acid, and giberellins (Raza et al. 2020). Lipid metabolism also has a role in salinity. For instance, the decrease of monogalactosyl diacylglycerol synthase, an enzyme of the galactosylglycero lipids of the membranes of chloroplasts and thylakoids, jeopardised the integrity of cell membranes (monogalactosyl diacylglycerol, digalactosyl diacylglycerol) (Parihar et al. 2015).

1.2.3.3 Salinity Responsive Genes

Plants that are tolerant seem to have particular genes that sensitive plants lack. The literature has identified three gene families as being crucial for salt tolerance: (i) genes that control how ions are transported and absorbed; (ii) genes that modulate osmotic pressure (iii) the genes that influence plant development (Munns 2005). Analysis of Arabidopsis mutants prone to high external Na^+ concentrations allowed for the discovery of three SOS genes implicated in salt tolerance (Parihar et al. 2015) (i): SOS_1 encodes a protein kinase that activates SOS_1, SOS_2, and SOS_3. SOS_3 also produces a calcium-binding protein that activates SOS_2, as well as a plasma membrane Na^+/H^+ transporter that transports sodium in the apoplast. Additionally, SOS_4 (a fourth gene) appears to control SOS_1, SOS_2, and the $SCaBP_8$ protein, which is controlled by SOS_2 (Parihar et al. 2015). Not only was salinity tolerance seen in Arabidopsis plants with overexpressed SOS genes, but also a decrease in Na^+ accumulation and an increase in K^+ accumulation. (Yang et al. 2009). SOS_1, SOS_2, and SOS_3 genes have been linked to tolerance to salt stress and a high Na^+/K^+ ratio in Brassica and rice (*O. sativa* L.) plants (Giordano et al. 2021). Other genes produce suitable solutes, osmolytes, or osmo protectors. Four classes of these osmolytes are distinguished: N-containing solutes include sugars like sucrose and raffinose, straight-chain polyhydric alcohols (polyols), such as mannitol and sorbitol, and cyclic polyhydric alcohols (cyclic polyols) (Parihar et al. 2015). The genes involved in plant development are all influenced by hormones, transcription factors, signal molecules, and environmental stressors. Examples of stress sensor molecules that can vary their concentration or proteins that can change their structure in response to drought, salt, and cold include the molecules that move from roots to shoots to create tolerance to salinity stress (Parihar et al. 2015).

1.2.4 Flood

Another important abiotic stress is flood by which the development and productivity of vegetables are negatively affected, which are typically thought of as crops prone to flooding (Parent et al. 2008). O_2 deficit is typically brought on by flooding situations because of the sluggish gas diffusion in water and the O_2 consumption of microbial life and plant roots. The majority of crops are extremely vulnerable to flooding, and tomato in particular exhibits minimal genetic diversity in this regard. Vegetables damaged by flooding are typically harmed because there is less oxidation in zone of root, which hampered aerobic functions. *Solanum lycopersicum* plant that have been flooded build up endogenous ethylene, which harms the plants (Drew 2009). In tomatoes distinctive responses to wet conditions is the quick development of epinasty growth of the leaves, and the significance of ethylene build-up has been suggested. Rising temperature make flooding symptoms more severe, and tomato plants typically wilt and die quickly after a brief flooded interval during a hot season (Kuo et al. 2014). Flooding during bulb development in onion also causes yield lose up to 30–40%. The growth stage, duration, and intensity of the shocks, which collectively account for more than 50% of yield losses globally, determine how plants react to environmental pressures (Kumar 2017).

Vegetable plants' physiology is impacted by flooding. Reduced stomatal conductance is one of plants'earliest physiological responses to soil flooding (Folzer et al. 2006). It increases the amount of CO_2 inside the plant, slows down carbon exchange significantly, increases CO_2 concentration, and ultimately raises leaf water potential. It also causes a decrease in stomata conductance (Liao and Lin 2014). Flooding has a detrimental impact on plant development, both vegetative and reproductive as a result of its deleterious effects on physiological function. Flooding harms sensitive crop plants by causing leaf chlorosis and reducing root and shoot development as well as the build-up of dry matter and overall plant production. Storms can increase the windborne distribution of spores, heat waves and drought can make all the plants more prone to disease & flooding can facilitate the transmission of water-borne infections (Abewoy 2018).

1.2.5 Responses of Insects and Diseases to Climate Change

Additionally, climate change affects insect pests'ecology and biology (Jat and Tetarwal 2012). In several insect groups, higher temperatures encourage reproduction and expedite the conclusion of the life cycle of insects with short life cycles, such as aphids and diamondback moths. Consequently, these are able to produce more generations every year than they often do (FAO 2009). Contrarily, certain insects' life cycles might take a long time to complete.

Some insect species that spend all or part of their life cycle under soil likely to suffer more than insects that are present above the soil surface because soil acts as an insulating medium that tends to buffer temperature changes more than the air (Bale et al. 2002). Insect species migrate to higher latitudes as a result of temperature rise, however in the tropics, greater temperatures may have a negative impact on certain nuisance species. High atmospheric temperatures lead to an increase in insect development and oviposition rates, insect outbreaks, and the introduction of invasive species, while the capacity of fungi for biological control of insects increases, the accuracy of economic threshold levels, insect diversity in ecosystems, and parasitism all decrease (Das et al. 2011).

The growth of the Colorado potato beetle, European corn borer, onion maggot, and cabbage maggot will all be accelerated by rising temperatures (Newton et al. 2011). The breeding season will last longer as a result of rising temperatures, which will further boost reproduction. Insects may be able to reach their minimum flying temperature with increased temperatures, earlier, enhancing their ability to disperse, according to studies on aphids and moths (Zhou et al. 1995). Because stored nutrients are used up more quickly at warmer temperatures, the length of an insect's diapause is shortened. Warming in winter may delay the beginning of diapauses in insects, while warming in early summer may hasten their end, allowing the insects to resume active growth and development. This has a significant consequence that, in a global warming scenario, a temperature increases of between 1 and 5 °C will improve the survivability of insects because of population increase, early infestations, decreased winter mortality, and agricultural loss brought on by insect-pests as a result (Harrington et al. 2010; Abewoy 2018).

1.2.6 Adaptive Management Strategies for Climate Change

The implementation of suggested production processes should be prioritised in order to enhance the efficiency of water consumption and adjust to the dry, hot conditions. According to Welbaum (2015), methods like shifting planting or sowing dates should be used to reduce the predicted spikes in temperature and water stress during the agricultural growing season. Increasing nutrient availability can be done by improving soil fertility and nutrient absorption with soil amendments and changing fertiliser application. The two crucial low-cost interventions are conserving soil moisture reserves and providing irrigation throughout key stages of crop growth (Malhotra 2016). The use of plastic mulches and crop leftovers as mulches, among other crop management technique, helps to preserve soil moisture.

Moreover, some colourful plastic mulches also useful for management of insect-pests and diseases in various vegetable crops under climate change scenario (Table 1.1).

Table 1.1 Use of coloured mulches in vegetable cultivation

Mulch colour	Advantages/ Benefits	Vegetable crops
Transparent	Soil solarization, moisture conservation.	Crop raising can be performed in temperate areas/ season
Black	Preventing the soils from sun light, increases soil temperature, suppress weed growth, reduce moisture loss and increase crop yield.	–
Silver	Increase crop output, deters certain aphids and whiteflies, and lowers soil temperature, all of which help prevent or postpone the spread of insect-transmitted viruses.	Okra, chilli and capsicum
Red	Increasing soil temperature, supress weed growth, soil moisture conservation, increasing crop yield, suppression of nematodes and early blight.	Tomato
Blue	The colour is appealing various thrips species which are responsible for transmission of viral diseases in many cucurbitaceous vegetables and potato.	Cucumbers, summer squash, bitter gourd
Green IRT	Supress weed growth, mild increasing soil temperature.	Muskmelon/Cantaloupe
Yellow	Serves as a trap to attracts whitefly, cucumber beetle, aphids and ultimately prevent damage to the main crop.	–

Modified from Chandra (2009)

Growing crops in raised beds could help in situations where too much soil moisture from a lot of rain becomes a serious issue (La Pena and Hughes 2007). The authors also mentioned that growing vegetables might be done using clear plastic rain shelters, which would have less adverse effect on developing fruits and would also result in less flooding of the fields during the rainy season. During rainy season, vegetables which are grown on raised beds produce more because of enhanced drainage, which lessens anoxic stress on the root system (Welbaum 2015).

Increased ability to withstand stress through to grafting: Vegetable grafting was first used in East Asia in the twentieth century to lessen the impacts of soil-borne diseases like fusarium wilt, which lowers the output of vegetables including tomato, eggplant, and cucurbits (Lee et al. 2008). In Asian countries like Japan and Korea, grafting is recognised as a standard practise in the cultivation of vegetables. This practise is an effective, quick substitute for the generally slow breeding methodology meant to increase the ability of horticultural crops, and vegetables in particular, to withstand environmental stress (Martinez Rodriguez et al. 2010). One of the most effective ways to modify a plant‘s root system and increase its resistance to numerous abiotic challenges is by grafting (Bhatt et al. 2013).

Grafted plants are most commonly used in many vegetable crops to increase tolerance to abiotic stresses such as minimum and maximum temperatures, dehydration, salt, and flooding (Martinez Rodriguez et al. 2010). The production of grafted plants in crops like *Solanum lycopersicum*, *Solanum melongena, Capsicum annuum* and cucurbits (melon, cucumber, watermelon, and pumpkin) has expanded recently due to these advantageous effect of grafting (Lee et al. 2010). Grafting began with eggplants in the 1950s, then cucumbers and tomatoes in the 1960s and 1970s (Edelstein 2004). Yetisir et al. (2006) reported that grafted melons were shown to be highly resistance to salt as compare to melons that are not grafted when grown on hybrid squash rootstocks. However, rootstocks' susceptibility to salt varies widely between species, with rootstocks from *Cucurbita* spp. being maximum tolerant to salt than those from *Lagenaria siceraria* (Matsubara 2012). Because certain eggplant cultivars can withstand drought, eggplant rootstocks may offer protection against soil moisture stress in addition to floods. The plant‘s ability to withstand heat stress is improved when temperature-sensitive tomato varieties are grafted onto varieties of more heat-resistant rootstock. According to reports, tomato grafted plants grow more successfully compared to ungrafted plants under heat stress. Additionally, the fruit output of the eggplants (S. *melongena* cv. Yuanqie) increased by 10% after they were grafted onto a rootstock that is heat-resistant (cv. Nianmaoquie). Creating climate-resilient vegetables: The most affordable way for farmers to handle the problems of a changing climate is to develop improved, adaptable vegetable germplasm. (Altieri et al. 2015). However, the majority of contemporary cultivars only reflect a small portion of the genetic diversity that is now accessible, including stress tolerance. It's possible that features that might have helped new varieties adapt or tolerate low input and unfavourable circumstances were counter-selected when they were bred, especially for high-input, intense manufacturing systems in industrialised nations. The production of better varieties with a greater capacity for environmental adaptation may result from the identification of specific genetic variation for tolerance to various biotic and abiotic stimuli. The ability to recognise and create genotypes may be achievable with enhanced properties caused by superior allele combinations at several loci. To find out these enhanced genotypes and related features, particularly in related, wild species that thrive in conditions that are inhospitable to the establishment of their domesticated relatives, cultivated variety, improved selection procedures are required. Plants that are native to areas with substantial seasonality offer opportunities to discover the genes or gene combinations that confer such resilience because of their innate capacity to adjust to changing environmental conditions. Due to the genetic and physiologic complexity of this trait, attempts to increase salt tolerance in crops through traditional breeding programmes had relatively little success (Flowers 2008).

Furthermore, tolerance at one stage of plant growth does not always coincide with tolerance at other stages; tolerance is a developmentally regulated, stage-specific phenomenon. Effective screening techniques, genetic diversity, and the capacity to transfer genes to the target species are necessary for successful breeding for salt tolerance. Only a little amount of variety occurs in cultivated species, and the majority of commercial tomato cultivars are only mildly susceptible to increasing salt (Flowers 2008). In both domesticated and wild tomato species, there exist genetic variations for salt tolerance during seed germination. The capacity of tomato seed to germinate quickly under salt stress is genetically regulated, as demonstrated by a salt-sensitive tomato line (UCT5) and a salt-tolerant S. esculentum accession

(PI-174263) hybrid with a narrow-sense heritability (h^2b) of 0.75 (Fooland and Jones 2011). According to various research, the ability of tomato seeds to tolerate salt during germination is regulated by genes with cumulative effects and might be enhanced through directed phenotypic selection (Foolad 2014). Vegetable kinds that can resist high or variable levels of salinity and are suitable for various production settings may arise more quickly if the mechanism of salt tolerance at different growth phases is understood and salinity tolerance genes are introduced into vegetables. Vegetable varieties that can withstand heat, drought, and salt have been produced in India by the ICAR-IARI in New Delhi, the ICAR-IIHR in Bengaluru, the ICAR-IIVR in Varanasi, the CPRI in Shimla, as well as other recognised organisations and universities (Table 1.2).

1.2.7 Plant Biotechnology

Vegetable crop development has until recently, mostly been limited to traditional breeding methods. These programmes rely on both naturally occurring and purposefully induced random mutations, as well as interspecific hybridization of plants with desirable heritable traits. The insertion of additional genetic information may lead to greater taste, heightened sensitivity to environmental factors, or increased resistance to illnesses. The insertion of genetic material (single or multiple genes) and its integration into a recipient cell, which affects the plant genome, is known as plant genetic engineering, also known as genetic engineering of plants. Transgenic plants or genetically modified (GM) plants are those with altered genomes. The direct biotechnological change of an organism's genome is known as genetic engineering, often referred to as genetic modification. The term "genetically modified organisms" (GMOs) refers to creatures whose DNA has undergone a change that does not occur normally. The field is frequently referred to as "modern biotechnology," "gene technology," "recombinant DNA technology," or "genetic engineering." It makes possibility for some genes to be transferred between unrelated species as well as between different creatures. By using such techniques, GM plants are created, which are subsequently utilised to cultivate GM food crops. In recent years, cointegrate and binary vectors, which are modified versions of the *Ti* and *Ri* plasmids of the hairy root disease bacterium *Agrobacterium rhizogenes* and the crown gall bacterium *Agrobacterium tumifaciens*, respectively, have been employed to transmit genes coding for tolerance to biotic and abiotic stressors (Srivastava 2003).

In order to boost agricultural output in unfavourable conditions, advanced technology will be required to augment conventional tactics, which are usually insufficient to prevent yield losses due to environmental constraints. Genes have been identified, and their roles are now known. As a result, it is now feasible to genetically modify genes that are related to environmental stress tolerance. These instruments are expensive, but they also guarantee quicker and even stunning results. Several efforts use these genetic and molecular technologies, with varying degrees of success. Vegetable stress tolerance has not been extensively studied using

Table 1.2 Vegetable varieties with various stress tolerance released in India for cultivation

Cold tolerance	
Tomato	Pusa Sheetal, Pusa Sadabahar, Punjab Tropic, Pusa Hybrid-8
Radish	Pusa Himani
Potato	Kufri Sheetman and Kufri Dewa (frost tolerant)
Heat tolerance	
Tomato	Pusa Hybrid-1, Pusa Sadabahar
Cauliflower	Sabour Agrim
Bottle gourd	Pusa Santusthi
Cucumber	Pusa Barkha, Pusa Uday
Carrot	Pusa Kesar
Potato	Kufri Surya
French bean	Arka Garima
Garden pea	Arka Tapas, Arka Uttam, Arka Chaitra
Radish	Pusa Chetki
Cow pea	Arka Garima
Ivy gourd	Thar Sundar
Sponge gourd	Thar Tapish
Drought tolerance	
Tomato	Arka Vikas, Arka Meghali
Brinjal	Bundelkhan Deshi
Chilli	Arka Lohit
Potato	Kufri Sheetman, Kufri Sindhuri
Sweet potato	Sree Nandini, Sree Bhadra
Cassava	H-97, Sree Sahya
Onion	Arka Kalyan
Dolichos bean	Arka Jay, Arka Vijay
Pumpkin	Thar Kavi
Drumstick	Thar Harsha
Salt/high soil pH tolerance	
Tomato	Sabour Suphala
Eggplant	Pragati and Pusa Bindu
Okra	Pusa Sawani
Musk melon	Jobner 96-2
Spinach beet	Jobner Green
Onion	Hisar-2

Compiled from Singh et al. (2020), Koundinya et al. (2018), Solankey et al. (2015), Kumar et al. (2012)

molecular markers, although attempts are being made to pinpoint the QTLs that underlie this tolerance. In tomato, QTLs for drought resistance have been found. Based on 13C composition, in tomato species *S. pennellii* three QTLs were shown to be associated with water usage effectiveness. When *S. pennellii* was planted in Israel's wet and dry fields, three distinct yield-promoting zones were found, while

Foolad et al. (2010) discovered four QTLs, two of which were provided by *S. pimpinellifolium*, that were connected to seed germination drought tolerance. Additionally, *S. pimpinellifolium* is being researched in order to develop a salt tolerance. Salt tolerance appears to be quantitatively inherited according to QTL mapping. (Foolad 2014). Lin et al. (2006) discovered RAPD (random amplified polymorphic DNA) markers relating to tomato heat tolerance line CL5915 from AVRDC-The World Vegetable Centre, Taiwan. At the Centre, more research is being done to completely comprehend the genetic basis of CL5915's heat tolerance. Studies show that stress tolerance is quantitatively inherited, and that in some circumstances, it is influenced by the stage of growth of the plant. (Abewoy 2018). The researchers noted several limitations in conventional breeding, which can only be solved by developments in contemporary biology. Vegetable crops have been successfully engineered during the past 10 years to possess a variety of qualities, including resistance to biotic stress, quality, and storage life. Some of these features have already been marketed. Today, it is possible to modify vegetable crops for abiotic stress resistance, quality enhancement, therapeutic uses, and industrial applications.

Although transgenic vegetable crop commercialization has advanced at a rather modest pace, transgenic vegetables modified for nutraceutical and medicinal application will soon make a substantial contribution to value-added agriculture. Vegetable crops have been effectively improved through genetic engineering techniques based on the introduction of transgenes. These techniques primarily focused on increasing crop productivity, improving resistance to biotic and abiotic challenges, and producing vegetables with superior nutritional value. There are two fundamental methods for transferring genes into plant cells. These methods include vector-mediated genetic transformation techniques and direct transformation methods. Although several transgenic vegetables have been field-tested, development of transgenic vegetable crops for commerce is still moving at a glacial pace. Only tomato plants with extended shelf life and insect- and virus-resistant potatoes have been commercialized among vegetable crops. One significant drawback is that, even in industrialized nations, public acceptance of genetically modified food is not very widespread. The dissemination of knowledge regarding the benefits and safety of transgenic crops is crucial. In addition to producing more food to fulfil demand, there is a pressing need to use fewer chemicals in agriculture to maintain environmental quality and safeguard biodiversity. Additionally, this would increase the small farmers and others with limited access to resources' economic security.

In the third world, transgenic vegetables will be very helpful in reducing misery. Using modified veggies will make it simpler to defeat deadly illnesses like cholera, hepatitis, and diarrhoea. For transgenic technology to be used and accepted more widely, some application-related obstacles must be overcome. Environmental risks must be thoroughly evaluated on a case-by-case basis, including the effects of transgenic goods on human health and cross-pollination with closely related wild relatives of agricultural plants. Furthermore, there are several concerns about the use of antibiotic and herbicide resistance genes as selectable markers from the perspectives of ecological and human safety. The public may be more accepting of transgenic crops if alternative techniques are used to generate marker-free transgenic plants (De Vetten et al. 2003) building binary vectors or tiny chromosomes to allow for repetitive gene transfers (Goderis et al. 2002). Our capacity to add features with long-lasting benefit may be further increased through improvements in transformation methods for vegetable crops. Molecular markers have been developed to distinguish between various vegetable types in tomato, potato, onion, garlic, and their relatives. Numerous molecular markers have been used for DNA fingerprinting of cultivars and breeding lines in a range of vegetable crops, including *Solanum lycopersicum*, *Phaseolus vulgaris*, *Capsicum annuum*, and *Solanum tuberosum* (Amin et al. 2010). Major disease resistance in tomatoes has been related to molecular markers, including the powdery mildew resistance gene ol-1 on tomato chromosome 6, the tomato mosaic virus, and *Meloidogyne incognita* (Ansari 2015). The MAS has also been used to support backcross breeding operations in the following ways: either by using markers to select for (or against) a certain background genotype, or by using markers to identify the gene that is to be introgress.

Recombination between the marker and the target gene, a small degree of parental polymorphism with different traits, and decreased precision of QTLs as a result of environmental interaction all restrict the use of the MAS in agricultural plants. Unfortunately, there are currently no molecular markers available for a number of significant features that are regulated by several genes or polygenes. Finding answers to these issues is not difficult given recent advancements in both structural and functional genomics. The availability of high-density genomic and physical mapping enables the identification of markers that are physically closer to the target gene and would reduce MAS failure due to genetic recombination. Furthermore, the construction of allele-specific markers would be made feasible by the cloning and characterisation of the target genes, which is conceivable given their location on the linkage map. By using such markers, any chance of the marker-trait relationship breaking would be absolutely eliminated. Additionally, allele mining in the germplasm resources would be made easier by markers based on gene sequences, allowing for the discovery and use of novel alleles in crop development.

1.2.8 Climate Change in the Future and Its Effects on Vegetable Production

The atmosphere contains a lot of greenhouse gases that are persistent. As a result, even if emissions stopped growing, atmospheric concentrations of greenhouse gases would keep rising and staying high for hundreds of years. In addition, assuming concentrations were maintained and the makeup of the atmosphere today remained constant (which would necessitate a sharp decrease in existing greenhouse gas emissions), the temperature of the surface air would rise further. This is due to the fact that it takes decades for the seas, which store heat, to completely react to growing levels of greenhouse gas emissions. Over, coming decades to centuries, the climate will continue to be impacted by the ocean's response to rising temperatures and concentrations of greenhouse gas (IPCC 2013). By 2100, global temperatures are predicted to increase by 0.5 °F on average, reaching 8.6 °F, with increases of at least 2.7 °F predicted in all save the scenario with the most extreme cuts in greenhouse gas emissions.

The average global temperature is predicted to rise by at least twice as much in the coming 100 years as it did in the previous 100, barring the most drastic mitigation measure thought of. Over land than overseas, temperatures at ground level are anticipated to rise more quickly. It is anticipated that some regions of the world will experience greater temperature rises than the global average (IPCC 2013). In most places, the amount of rain that falls during extreme weather is predicted to rise, while storm trajectories are anticipated to move poleward (IPCC 2013). Through the end of the century, global average annual precipitation is anticipated to rise, although regional variations in precipitation volume and severity will be substantial. Precipitation occurrences' average heaviness is probably going to get heavier. High-latitude and tropical regions, where it is also projected that precipitation would rise overall, will be where this will be most obvious. Tropical storm-related wind speeds are probably going to get stronger. Additionally, it's expected that tropical storms will provide more precipitation overall. It is anticipated that annual average precipitation would rise in certain places and fall in others. The projection of regional variations in precipitation under two emission scenarios is shown in the picture to the right (IPCC 2013).

1.2.9 Conclusions

In order to fulfil the demands of a population that is constantly expanding, the world's agriculture, particularly the production of vegetables, is currently facing a challenging position. From a finite amount of land, we must produce more and more food. Increasing biotic and abiotic forces, deterioration in the state of the environment, and the threat of escalating global warming brought on by greenhouse gases all contribute to the problem's aggravation. The scrumptious veggies are highly susceptible to hot, dry, and flooding weather. The impact of climate change on agricultural growth, development, yield, and quality must thus be thoroughly studied. The development of adaption technology and calculating the crops' ability to reduce emissions should also be priorities. Increased temperatures have a negative impact on vegetable crop production and output by reducing crop length, blooming, fruiting, fruit size, and ripening/maturity.

It will be necessary to modify the present vegetable systems to accommodate the expected effects of climate change in order to boost the production and consumption of nutritious vegetables and reduce hunger and poverty in emerging nations. To lessen the effects of climate change on the quantity and quality of vegetable crop production, develop efficient adaptation techniques. Priority should be given to the development of industrial solutions for more effective water use that can be tailored to the hot, dry circumstances. The use of plastic mulches and crop leftovers as mulches, among other crop management techniques, helps to preserve soil moisture. Raised beds allow for crop cultivation, which is a key solution to the issue of excessive soil moisture brought on by heavy rain. Vegetable germplasm with resistance to drought, high temperatures, and other environmental problems as well as the capability to sustain output on marginal soils must be discovered in order to serve as sources of these traits for both public and commercial vegetable breeding programmes. These genetic materials will contain both domesticated and wild accessions with genetic diversity that is not present in currently popular cultivars. To introgress, uncover genes giving resistance to stressors, and simultaneously produce tools for gene isolation, characterisation, and genetic engineering, genetic populations are being produced. Agronomic practises that protect vegetable crops from adverse environmental conditions and conserve water must also be constantly developed and made widely accessible to farmers in impoverished countries. In addition to employing enzymes and antioxidants as defence mechanisms, secondary metabolism chemicals like phenyl propanoids and hormones that cause morphological and physiological changes in response to external stimuli can also help plants adapt to changing environmental conditions. Since all plants possess these defence systems, these reactions might be referred to as "innate tolerances." In addition to displaying these kinds of reactions, certain plants have evolved the capacity to thrive in challenging environments. This reaction reflects the "memory of stress" in plants and can be viewed as a "acquired tolerance." This reaction allows plants to adjust to periods of high stress followed by periods of low stress and to deal with the reappearance of stress more effectively, increasing their resistance when stress returns (Caplan et al. 2019). Extreme weather events have an impact on many parts of the world, not only those with dry or semi-arid climates. Because of how quickly these processes occur, organisms' genetic diversity cannot produce creatures that can tolerate unfavourable environments. In this situation, it is now possible to create more tolerant species using modern breeding techniques. Their practical implementation, however, takes a long time and is always attempting to keep up with the changing environmental factors, including biotic and abiotic stresses. In this case, cutting-edge agricultural practises like the use of bio-stimulants or well-established ones like grafting might give ecologically friendly tools to increase plants'tolerance to abiotic stress in response to escalating agricultural sector needs. As a result, given that vegetable crops encounter numerous and severe abiotic stressors in the actual world, understanding plant defence mechanisms and implementing eco-sustainable farming techniques may be able to help these priceless commodities survive a fast changing environment. Future research is also required to better understand how plants respond to numerous stressors, particularly when heat, drought, salt, and increased CO_2 levels are present together. Additionally, biotic stressors should also be taken into account. Finally, it is important to extensively screen local ecotypes and landraces to find those that can survive environmental stresses in an effort to understand how plants defend themselves.

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