Chapter

Climate Change and Citrus

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Abstract

Climate change is the change in the statistical distribution of weather patterns that lasts for an extended period. Climate change and agriculture are interrelated processes and affect in many ways. Citrus fruits are one of the largest fruit crops in the world. Yield loss at a drastic level due to abiotic stress annually in which temperature and water stress are the main environmental factors. These factors cause biochemical, anatomical, physiological, and genetic changes in plant structure and lead to defective growth, development, and reproduction, which ultimately cause a reduction in the economic yield of the crop. An increase in temperature and water stress at critical phenological stages of citrus results in reduced tree fruit set, decrease in fruit growth and size, increase in fruit acidity, low tree yield, reduced fruit peel thickness, and pre-harvest fruit drop. Stomatal conductance and net carbon dioxide assimilation in citrus leaves can be reduced by super optimal leaf temperature. Water deficit reduces the transpiration rate, stomatal conductance by stomatal closure associated with ABA content and causes an abrupt decrease in photosynthesis and CO_2 assimilation in citrus which reduce trees overall growth and production. Interventions in agronomic practices, breeding strategies, and biotechnological approaches can mitigate climate change effects on citrus. The groundwork against climate change is compulsory for better global livelihood and food security.

Keywords: Citrus fruits, environment, global warming, abiotic stress, genetic improvement, climatic adaptation

1. Introduction

Citrus and its related genera i.e., Poncirus, Eremocitrus, Fortunella, and Microcitrus belong to the family Rutaceae [1, 2]. Citrus is a prominent fruit tree of tropical and sub-tropical regions that require a suitable climate for quality production. Citrus fruit quality and quantity are inclined by multiple factors including climatic conditions [3]. Change in optimum climate elements like low temperature/freezing, heat stress/heatwaves, CO_2 assimilation, drought/water scarcity, intensive rainfall, and relative humidity, may affect directly and indirectly citrus production [4].

Citrus tree (rootstock and scion) growth, development, fruit production, and fruit quality is reduced under the biotic and abiotic stresses [5]. Citrus with tolerant rootstocks against biotic and abiotic factors improve the growth and productivity of the trees [6]. The potential citrus yield is 18–20 tones ha^{-1}, which goes up to

25 tones ha^{-1} in the developed world; however, the citrus average yield in Pakistan is 10–12 tones ha^{-1} and is affected by abiotic and biotic stresses [7]. The yield gap is due to biotic, abiotic, and general factors, like agronomic practices in countries of climate risk [8].

The productivity and growth of plants are affected by climate change especially drought and high temperatures collectively [9]. Reactive oxygen species accumulate superoxide and hydrogen peroxide [10] is due to water stress and high-temperature stress which reduce the biochemical, physiological, and molecular regulation. Reduction in carbohydrate accumulation affects the flowering, fruit set, and fruit yield. However, to reduce the negative plant physiological stresses, there should be good management practices in citrus orchards. Choice of better scion enhances citrus trees to produce higher yield with good fruit quality [11].

Citrus has a phenological life cycle of the whole year, starting from February to next year January. Flowering starts during February–March in subtropical regions and is generally considered a critical period for citrus production. An increase in temperature and water stress after pollination inhibits ovule fertilization [12], which in return reduces tree fruit set, increases June fruit drop, and reduces tree yield [13–15]. Fruit growth phases from button size to mature fruit are more sensitive to heat stress and deficit irrigation. Citrus under water deficit conditions faces reduced fruit growth and ripening, which is associated with a decrease in fruit size, an increase in fruit acidity [16], and low tree yield [13]. Water stress at the pre-harvest stage in oranges develops fruit peel wrinkles [17]. An increase in optimum temperature at fruit ripening causes pre-harvest fruit drop and reduced yield (**Figure 1**).

To deal with heat and water deficit stress, there is a need to improve agronomic management practices and adopt breeding and molecular approaches. Agronomic management practices encompass factors like irrigation, nutrition, pruning, pests, diseases, and other injuries which have a key role in citrus fruits quantity and quality [19]. Breeding approaches need to search out/develop rootstocks that are tolerant/resistant against abiotic and biotic stresses. Based on breeding techniques, better rootstocks can be developed that can mitigate climate risk and other major biotic factors [20]. Molecular approaches are very helpful to deal with heat and

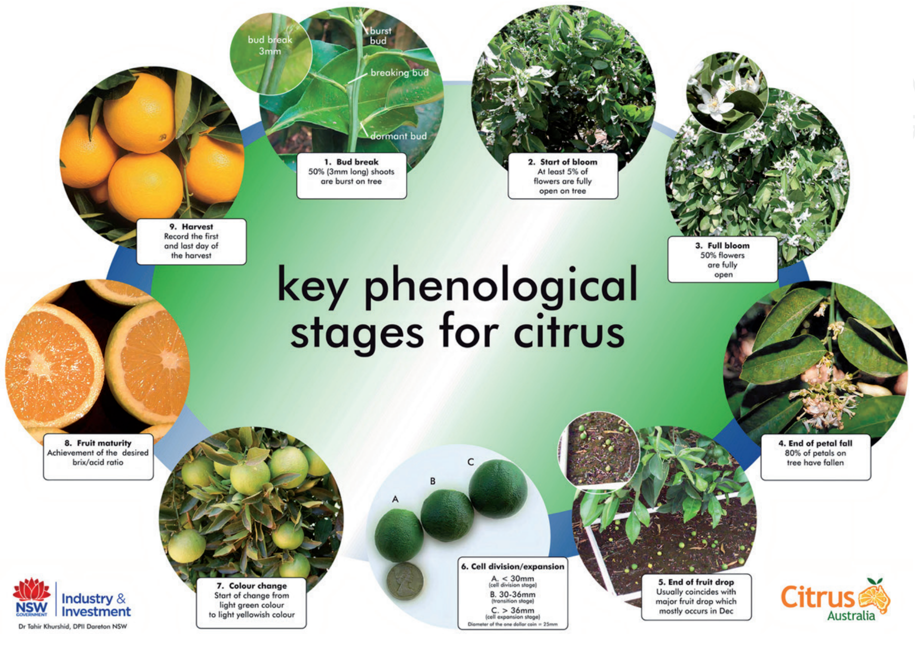

Figure 1.
Key phenological stages and management activities [18].

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water deficit conditions. Modulation in genes and gene expression related to stress help plants to cope and mitigate stress adversity. Henceforth, somatic hybridization, mutation, somaclonal variation, and genetic transformation techniques help to improve trees for thermotolerance [21].

Thus, in this chapter, we present an overview of climate change i.e., heat and drought stress impact on citrus and its management through agronomic, breeding, and molecular approaches.

2. Climate change

The main reason behind climate change is greenhouse gasses; especially carbon dioxide accumulation in the environment. Fossil fuel burning is the primary source of greenhouse gasses emission. The use of pesticides in agriculture and cutting of forests are also contributing to the proliferation of such gasses that cause climate change. An optimum amount of these gasses is necessary for controlling the earth's temperature, but now their concentration is increasing dramatically. From the expected beginning of human civilization about thousand years ago to 1900, the carbon dioxide concentration in the environment was 0.03%, but now due to climate change, it has been reached to 0.04%, the highest in history [22].

2.1 What is the effect of climate change?

The earth's mean temperature has risen for the past hundred years [23]. The increase in temperature of the earth due to climate change can affect the environment adversely. Today, the average temperature is 4°F more in comparison to the last Ice Age [24]. Global warming is causing the melting of polar caps and warming the ocean's water, which is leading to greater storms and frequent floods along with heavy winds and rains. A heat rise is also enhancing the incidences of wildfires, which damage natural habitat and creatures [25]. Climate change threatens the world's population. The world is severely facing the issue of climate change, especially the third world countries. American and European countries are prepared well against climate change [26]; however, the countries of the

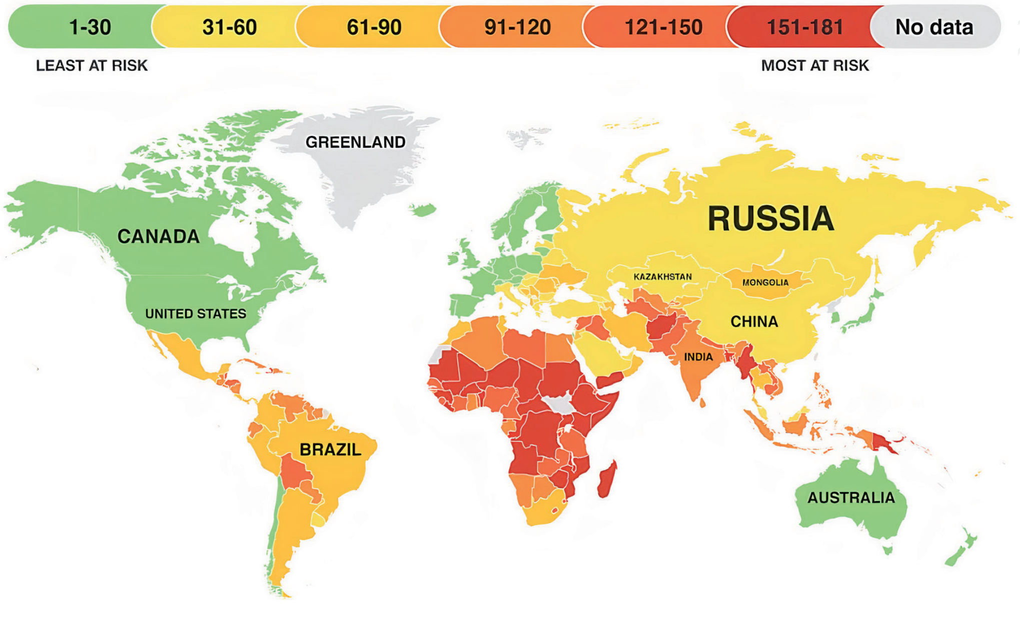

Figure 2.
The map shows the countries most at risk and least at risk against climate change [28].

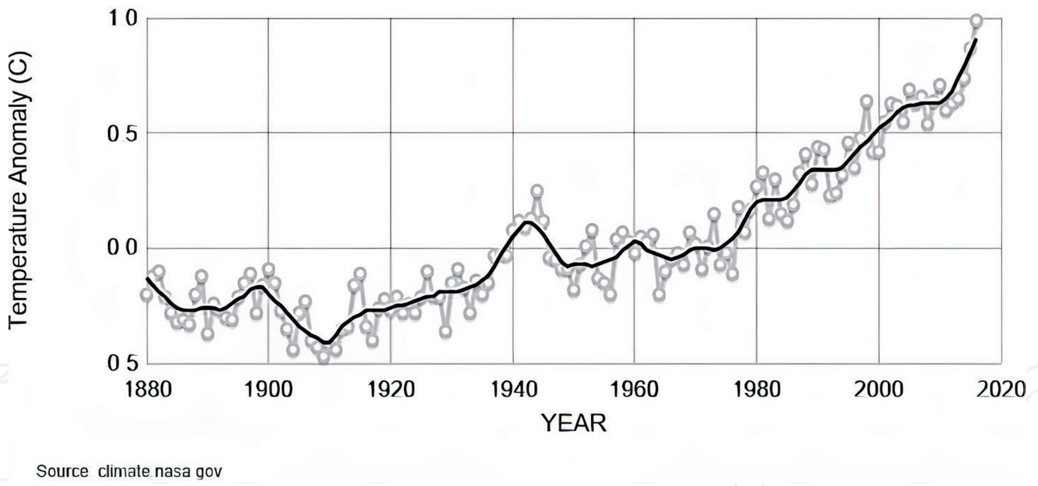

Figure 3.
Global surface temperature anatomy 1880–2018 [28].

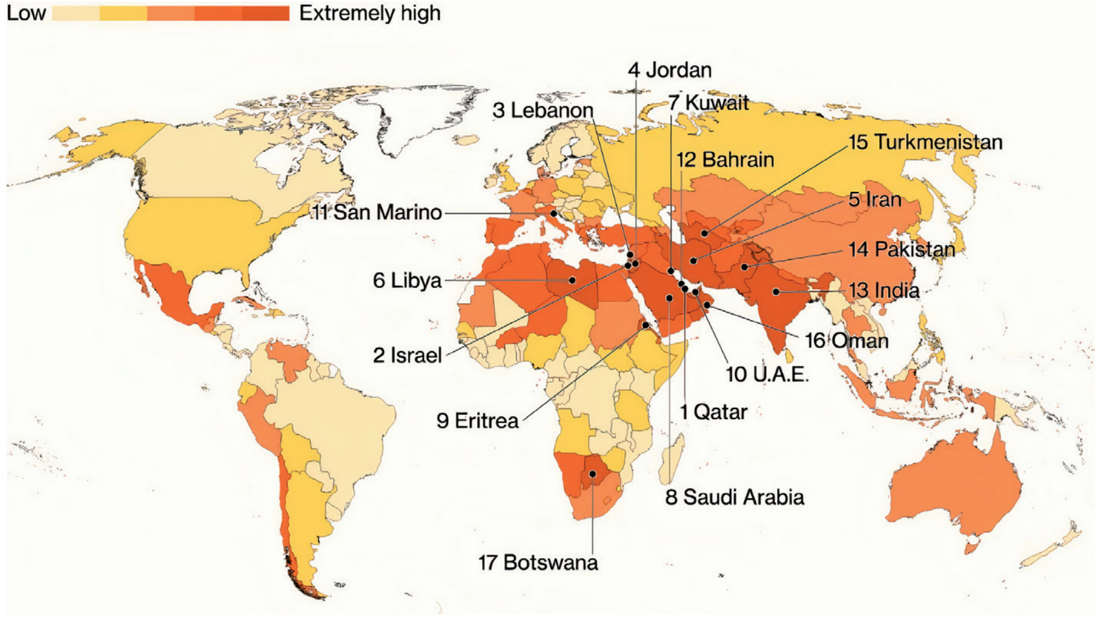

Figure 4.
Top 17 countries facing the risk of extremely high water stress [29].

Middle East, Asia, and Africa are more exposed to environmental changes due to less preparedness and technology to tackle these issues [27]. Norway would be the country likely to survive climate change due to its low vulnerability against climate change. The neighboring countries: Finland (third), Sweden (fourth), Denmark (sixth), and Iceland (eighth) are well prepared. The countries least likely to survive global warming change include the Central African Republic, South Africa, Eritrea, Chad, Somalia, and the Democratic Republic of the Congo. These countries have poor infrastructure, unstable governance, poor health, and food and water scarcity (**Figure 2**).

2.2 Rise in temperature

NASA center graph associated with climate (**Figure 3**) indicates the average global surface temperature during the era of 1880–2018. After 1940, an abrupt increase in temperature was noted for a duration of two years and then continuous high temperature was witnessed after 1980–2016 [28]. The researchers believe that global temperature will rise continuously over the next few decades, mainly due to humans generated greenhouse gases. The IPCC (The Intergovernmental Panel on Climate Change) predicts a rise of 2.5–10°F over the next century [29].

2.3 Water scarcity

Water is highly important for plants and its global importance is not difficult to understand. There is a frequent rise in water scarcity due to changes in climatic patterns. It is expected that the world will face a decrease of 66% in water availability up till 2050. The water cycle is adversely affected by climate change. Due to the changing climate, several areas are getting dry. There are 17 nations under the extremely high risk of water scarcity; out of which 12 are in North Africa and Middle East [29]. India and Pakistan, two Asian countries, fell in the list of 17 countries having a risk of water scarcity (**Figure 4**).

3. Effect of heat and water deficit on tree health

The yield of any crop begins to decrease when the temperature exceeds the ideal temperature range and the water level falls below the ideal water demand of the crop. Temperature and precipitation variables of climate are described as diagrammatic sketch alternatively for intensity and duration of drought, which show a small portion of the climate space presently exceeding tree mortality threshold (**Figure 5**). It is predicted that there will be high temperature and drought due to extreme climate change, which can cause severe damage to agriculture and could become a risk for tree populations [31].

3.1 Tree physiology

Plant physiology includes all the dynamic processes of growth, metabolism, reproduction, defense, and communication responsible for plant survival [32, 33]. Heatwaves affect the plant's physiological processes and responses, their ability to tolerate heat, as well as the effectiveness of strategies used for thermotolerance

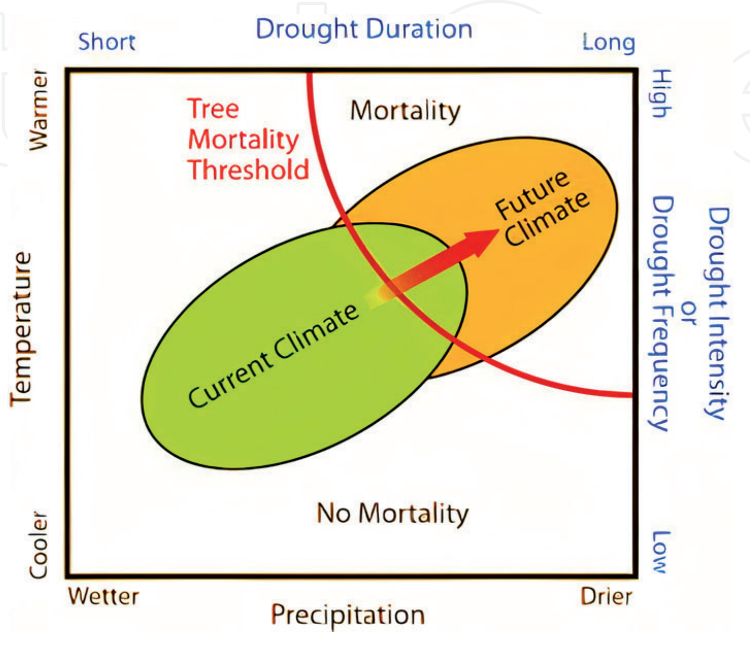

Figure 5.
Climatic variables, temperature, and precipitation, with a range of variability [30].

improvement [34]. In citrus fruits, the temperature above than optimum causes a big difference in the leaf to air vapor ratio as well as high leaf temperature, but the shade conditions can relieve the water pressure and lower the temperature of the leaves [35]. Stomatal conductance and carbon dioxide uptake are reduced by superoptimal leaf temperature and water tension [36].

The gas exchange activity is reduced badly in citrus trees under deficient irrigation [37, 38]. CO_2 assimilation, conductivity, and transpiration rate decrease under water stress, so these gas exchange parameters are a water stress indicator [39–41]. Citrus trees under water deficit conditions reduce the conductivity of stomata and increase photorespiration [42], which reduces the yield, size, and quality of fruits [43]. Under groundwater deficiency, citrus trees lead to stomata closure associated with high ABA content and result in a sudden decrease in photosynthesis [16, 44, 45] and production losses [14, 35]. Chlorophyll *a* is easily damaged compared to chlorophyll *b* due to lack of water. Genotypes/species that maintain stomata conduction under dry conditions also maintain chlorophyll fluorescence and high growth levels [46].

3.2 Tree morphology

Altered temperatures and water deficit conditions affect citrus leaf-to-air vapor pressure during the day in the early morning and midday [8], indicating a vapor pressure of 4.3 kPa at 37–40°C and 6.2 kPa at ≥40°C, respectively. Citrus exposed to the temperature above than optimum (37°C) and vapor pressure deficit (3.6 kPa) at 330 $\mu mols^{-1}$ CO_2 concentration during midday, shows depression in carbon dioxide exchange rate [47]. Swingle citrumelo, a citrus species increased its total biomass when kept under slightly high temperature [8]. Drought stress affects both plant vegetative and reproductive growth parameters [48, 49]. Citrus under water deficit lessens vegetative growth, fruit size and quality and orchards face a major economic loss [14]. Orange trees exposed to prolonged or excessive water deficit can lead to leaf drop, gradual drying of the tips of the branches, and a drastic decline in fruit production due to severe flower and fruit drop [50]. Young lemons exposed to water stress showed a decrease in daily stem diameter and water flow [51]. The growth of plant roots is dependent on the soil water availability. The roots of irrigated soils are well distributed and widespread compared to roots with less irrigation. Valencia orange roots on the Swingle citrumelo rootstock and a significant difference in root distribution between irrigated and non-irrigated trees were observed [52]. Water stress decreases the growth and metabolism of citrus fruits [43, 53] and increases the cost of extracting juice [21]. Dryness also reduces the thickness of fruit peel, making citrus fruits more sensitive to damage during handling and transportation [54]. Irrigation stoppage during initial and final growth phases of Lane Late orange (*Citrus sinensis* Osbeck) significantly reduced yield [55]. General studies of water stress in citrus show that the extent and duration of water stress at critical development stages are more vulnerable to the production of citrus. On the other hand, the cultivar and properties of orchards *i.e.*, soil, climate, and cultivation also play important role in success under deficit irrigation [56].

3.3 Tree water status

The transport of water is determined inside the plant by the availability of soil water and relative humidity. Plant physiological adjustments under changing environmental conditions maintain the turgor pressure of the plant cell. In perennial species, seasonal variations in environmental conditions can affect water relationship. In citrus fruits, the large crown and low hydraulic conductivity of the trunk and roots contribute to severe water scarcity [57]. Transient water deficit in citrus at midday [58] reduces photosynthetic rates [47]. Root hydraulic conductivity decreases under drought stress to prevent the plants from mortality. High temperatures can also increase the loss of root moisture to a harmful level [59]. In plants, heat stress appears as the supply of water is insufficient to meet the evaporation requirement. Heat stress is linked to drought as the plant and soil quickly lose water at high temperatures. It is known that heat stress and drought reduce nutrient uptake and photosynthetic efficiency in plants [60].

3.4 Tree biochemistry

Citrus leaf water potential and leaf abscisic acid (ABA) are the indicator of water stress. Citrus rootstock Rangpur lime grafted with scion Pera orange resulted in decreased leaf water potential and decreased leaf ABA concentration when subjected to water stress [61]. Citrus trees produce endogenous hormones and their regulation by promoting synthesis and accumulation under severe water stress [43]. Plant phytohormones are found in a minor quantity but drought stress accumulates jasmonic acid [62]. Drought synthesizes roots ABA and leaves by transpiration stream [43, 63]. The amount of sugar, like non-reducing sugar (sucrose) and reducing sugar (fructose and glucose), in contrast to the sorbitol content, decreases dramatically over the drought period. Water stress accumulates proline contents, an important osmoprotective agent, and its concentration increases with increasing water deficit conditions in citrus orchard [64]. Proline levels in leaf were recorded in Gada dahi citrus rootstock on day 24 of the water stress in comparison to tolerant rootstocks, which indicated that the accumulation of proline was greater in susceptible genotypes than in tolerant genotypes due to higher stress. Lower accumulation of proline was due to its protective function, removing radicals, maintaining the redox balance, and reducing cell damage [65]. The total phenol content also increases in plants under drought stress, compared to normal irrigated plants [66, 67]. Proteins are involved in several processes that change the plant metabolism under stress conditions and activate the plant defense signal [19, 68]. The protein content of drought-tolerant genotypes is generally higher than that of drought-sensitive genotypes. Carrizo citrange, a tolerant genotype, shows notable soluble proteins in leaves and roots [69, 70]. Higher MDA and H_2O_2 contents observed in plants under water stress indicate greater oxidative damage, which determines the severity of the plant and indicates low efficacy of antioxidant machinery of Carrizo citrange drought-tolerant rootstock [43]. Plants produce several antioxidant enzymes, such as CAT, SOD, and POD to treat the cell damage caused by stress at the oxidative level. SOD is the main enzyme that is expressed under stress, especially under water stress conditions. Carrizo citrange has shown an excellent defense mechanism under water stress with high activity of CAT, SOD, and POD in roots and leaves [19, 68].

3.5 Tree anatomy

Alteration in anatomy by applying heat stress is established. Stress treatment at 40–45°C was given to similar size plants and anatomical changes (size of the epidermis, size of pith, cortex, leaf thickness, epidermal cells, parenchyma tissue) in root, stem, and rhizomes were studied. The thickness of mesophyll, epidermis, and cortex was increased in stressed plants [71]. Some common anatomical changes include increased densities of stomata and trachomatous, cell size reduction, stomata enclosure, and higher xylem vessels in roots and shoots [72]. It has been demonstrated that grafted plant size is reduced on dwarfing rootstock, and such plants are unable to maintain drought or water-deficient conditions [73]. The researchers explain that the vessel density of root and stem are decreased with tree height [74]. The rootstock growth ability is dramatically affected by the number of xylem traits, xylem phloem ratio, vessel size, and vessel density [73, 75]. Maintaining hydraulic conductance of stem, root [74, 76], vessel size and number is the basic factor in hydraulic conductance maintenance [77]. Fewer small vessels may decrease hydraulic conductance, as a result, growth decrease in fruit trees [78]. Water stressed leaf spongy cells have a dense arrangement and reduce the conductivity of leaf diffusion. These results give an idea to understand the direct relationship between mesophilic conductivity and the porosity of the soils [79].

3.6 Tree genetics

Stress-related genes are activated through high temperature and drought, [80], and sugars, different functional proteins, amino acids, and amines are synthesized through these genes [81]. HSPs are the heat shock proteins consisting of a group of genes relevant to heat stress in plants and animals [82, 83]. Heat shock proteins play an important role in maintaining/removing ROS, cell membrane integrity, producing antioxidants, and osmolytes [84, 85]. Heat shock proteins protect plant cells/tissues from drought and heat stress [84]. Citrus HSP70 expression has been examined against water scarcity and high-temperature stress in the *Poncirus trifoliata* rootstock. In *P. trifoliata* HSP70 and HSP90 genes against abiotic stress are upregulated [86]. HSP90s play a vital role in signal transduction, cell cycle regulation, protein breakdown, genomic mutation, and protein trade [81, 87]. Aquaporins are transmembrane channel proteins found in tonoplasts, plasma membranes, and other intracellular membranes and are abundantly expressed in plant roots [88, 89]. Major intrinsic proteins (MIPs) are a superfamily of aquaporins that regulate intracellular water passage [90]. The plasma membrane proteins (PIPs) are the most important group of natural proteins that respond to water transport. Overexpression of PIP under abiotic stress conditions confirms the importance of PIP for heat and water stress tolerance [91] as the combination of heat stress and the scarcity of groundwater generally limits the physiology, growth, and productivity of plants [92].

3.7 Tree productivity

The citrus phenological cycle starts from February to next year January in subtropical regions. Flowering starts during February–March and is generally considered a critical period for fruit production. An increase in temperature and water stress after pollination inhibits ovule fertilization [12] which reduces tree fruit set, increases fruit drop, and reduces tree yield [13]. Phases of fruit growth from button size to mature fruit are more sensitive to deficit irrigation and heat stress. Hence, reduced fruit growth, and delayed ripening occur which are associated with a decrease in fruit size, increase in fruit acidity, and low tree yield [13]. Drought at a pre-harvest stage in oranges develops wrinkle on fruit peel [17]. An increase in optimum temperature at fruit pre-harvest causes fruits drop and reduced yield. Citrus under different phenological stages respond to deficit irrigation or water stress and contribute negatively to yield/production and fruit quality. In an experiment, eleven-year-old sweet orange scion grafted on Carrizo citrange were evaluated against water stress and revealed 10–12% relative yield decline. Gonzalez [37] compared Clementina (*Citrus clementina*) tree performance under 25–50% deficit irrigation during initial fruit enlargement and pre-maturation phases and recorded a significant negative effect on fruit yield [13]. Navelina sweet orange (*Citrus sinensis* Osbeck) yield reduced significantly when irrigation was reduced at 55% with respect to crop water requirement during flowering and fruit set.

4. Management of citrus under climate change

4.1 Agronomic management

Implementation of proper orchard management practices decreases the adverse effects of heat and drought stress. The management includes trees requirement based nutrition and irrigation techniques, organic and synthetic mulches, as well as selecting the most suitable cultivars/rootstocks that are resistant to various stresses.

The selection and development of new rootstocks tolerant to biotic and abiotic stress is inevitable for the stable production of citrus under the scenario of climate change. New and known diseases and environmental conditions also help to force developing new citrus rootstocks according to the demand [93]. Citrus rootstocks like Volkamer lemon (*C. volkameriana*), Rangpur lime (*C. limonia*), and Rough lemon (*C. jambhiri* Lush.) resist water stress and increase the production of cultivars grafted on these.

Fertilizer application can also be helpful to manage plants against abiotic stresses [94]. Application of Ca and K macronutrients and B and Mn micronutrients modify the function of stomata under heat/high-temperature stress [95]. K, Ca, B and Mn activates physiological and metabolic processes that help maintain a high water potential in tissues, which increases tolerance to heat stress [96]. The use of N, K, Ca and Mg also reduces the toxicity of ROS, thereby increase the levels of antioxidant enzymes in plant cells [96].

Plant growth regulators (PGRs) in managing water and heat stress also play an important role. PGRs like cytokinins, abscisic acid (ABA), and salicylic acid play role in resistance to heat and drought. The application of PGRs increases the water potential and chlorophyll content in citrus trees [97]. The exogenous use of ABA increases productivity in the absence of water [98]. ABA formulations are available with commercial manufacturers to improve the drought tolerance of trees [99, 100].

Mulching underneath the trees is often used as a technique for water conservation [101, 102]. Mulches are used to maintain moisture levels high in the soil, control soil temperature, and evaporation [93, 103]; thereby reduce the need for irrigation during growing seasons [104]. The need for water in the soil is decreased and the ability to withstand drought and heat is increased by using mulches [105, 106]. Plastic films are more effective than organic compost for groundwater protection [107].

4.2 Breeding strategies

Citrus rootstock breeding programs are aimed to combine biotic and abiotic tolerance/resistance in new rootstocks. However, conventional plant breeding (**Figure 6**) in mitigating the abiotic stresses has limited success against plant productivity [108]. Similarly, developing better rootstocks through breeding by the conventional method is a long-term approach due to many difficulties, particularly the complexity of citrus biology (high heterozygosity, long juvenility, polyembryony) [109, 110]. Typically, from a breeding program, it takes at least 15 years for a new standard variety to emerge in the citrus industry. Moreover, a sexual hybrid is difficult to identify at an early stage. In this case, trifoliate leaf (a morphological marker) is used as a male parent and unifoliate as a female for identification of sexual hybrid at the seedling stage [111]. The trifoliate trait is dominant, and the

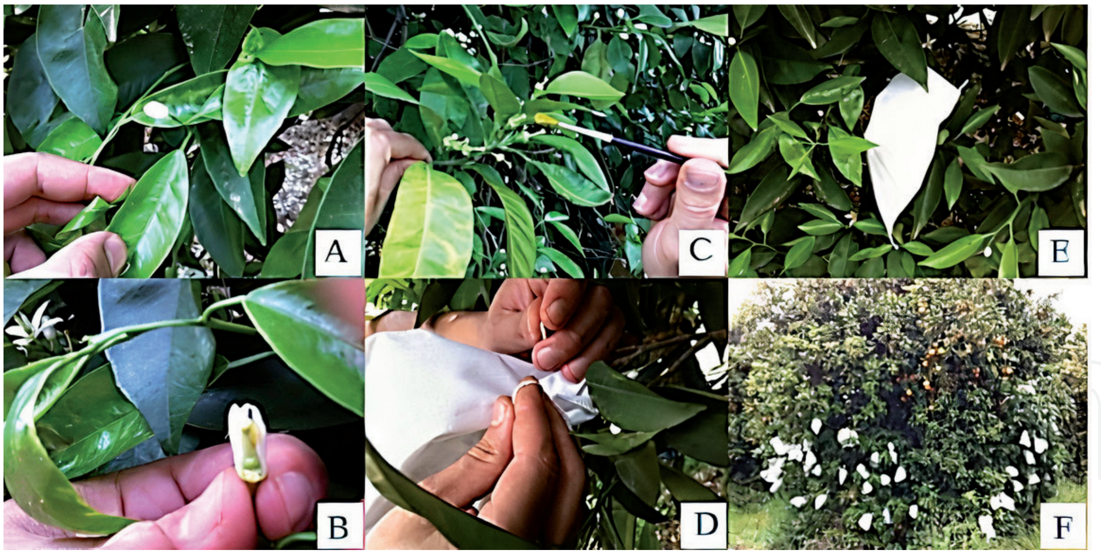

Figure 6.
Traditional cross-hybridization in citrus. (A) a large unopened bud, (B) emasculation, (C) pollination of the emasculated flower, (D) bagging of the pollinated flower, (E) bagged twig, (F) general view of the seed parent after crossing.

seedlings showing the parental trifoliate pollen phenotype are considered hybrids. In absence of a trifoliate pollen parent, the hybrids can be identified by using SSR and RAPD molecular markers [112].

Besides citrus biological constraints, valuable traits like resistance to low/high temperature, root rot, viruses, nematodes, salinity, and drought are important to incorporate in rootstocks. A list of some important biotic and abiotic traits of citrus rootstocks are presented in **Table 1**, which can help in the development of new tolerant/resistant rootstocks.

Several rootstock hybrids have been released to the citrus industry worldwide. Swingle citrumelo rootstock is a hybrid of Duncan grapefruit and Trifoliate orange, crossed by Swingle in 1907 and released in 1974. Since then, it has been used successfully as the standard rootstock for better traits *i.e.*, moderate drought

Rootstocks	Alkalinity	Chloride	Drought	Tristeza	Nematodes	Phytophthora	Fruit quality
Cleopatra mandarin	T	TT	pT	T	S	pT	G
Chios mandarin	T	S	pT	T	S	SS	—
Sweet orange	T	pT	T	T	S	SS	G
Macrophylla	TT	TT	TT	S	S	T	L
Pomeroy Poncirus	SS	SS	S	R	T	T	H
C-35 citrange	S	S	T	R	T	T	H
4475 citrumelo	S	pT	pT	R	T	T	H
Citrandarin	pT	pT	—	R	pT	T	G

Abbreviations in the table: T; tolerant, TT; very tolerant, pT; poorly tolerant, S; susceptible, SS; very susceptible, G; good, L; low, H; high.

Table 1.
Some biotic and abiotic traits of selective citrus rootstocks [113].

tolerance and high fruit quality. Citranges are hybrids of Washington Navel orange and *Poncirus trifoliata*, out of which Carrizo and Troyer are the two main citranges. These can tolerate water shortages and produce excellent quality fruits. Benton citrange is a cross of Ruby blood orange and trifoliate orange developed in late 1940 and is more tolerant to heat and water scarcity [114]. Brazilian sour orange also shows tolerance against heat, drought, and their combined stress [85].

4.3 Biotechnological interventions

Hybridization by somatic approaches is a protoplast fusion process that has become an important tool for plant production, combine (partially or totally) desired cultivars somatic cells, species, or genera, resulting in the development of new genetic combination. In addition to intergenerational mixtures in somatic hybridization, more emphasis has been placed on interspecific mixtures between *C. reticulata* and *C. maxima* [109, 110] to meet the specific needs of the citrus industry. Poncirus is drought-prone, while Citrange C-35 is more drought-tolerant. Among these rootstocks, 4475 citrumelo have the best ability to adapt to the environment. Cleopatra mandarin + *Poncirus trifoliata* and Cleopatra mandarin + C-35 Citrange somatic hybrids have resistance to CTV, tolerance to nematodes, and phytophthora. The Sweet orange + *Poncirus* and the Sweet orange + C-35, as well as the Sweet orange + Citrumelo 4475, can adapt to low moisture soils and tolerate biotic stresses. Macrophylla is a productive rootstock and adapts well to saltwater, limestone, and water stress [115].

In vitro mutagenesis and somaclonal variation are important tissue culture techniques being used in citrus improvement. Somaclonal variation, genetic and phenotypic variation between plants, can be used to improve citrus cultivars under conditions of water and heat stresses. Genetic improvement by *in vitro* selection of Satsuma mandarins (*Citrus unshiu* Marc.) has been made successfully; however, the frequency of somaclonal variation by factors, including genotypes, explant culture length, sources, and environmental composition [116, 117]. Cell lines success stories of some salt-tolerant cultivars are *C. sinensis* cv. "Shamouti" [118], *C. limonium* [119] and "Troyer citrange" [120].

Genetic transformation is an alternate technique for citrus genetic improvement. PEG-mediated genetic transformation of citrus fruits is a direct DNA transfer method [120] that seeks to express an aminoglycoside phosphotransferase II gene in isolated protoplasts from sweet orange (*Citrus sinensis* Osbeck) culture for suspension. The genetic transformation of citrus fruits has mainly been carried out from young materials such as embryogenic cells from the epicotyl segment of *in vitro* germinated seedlings. Excess protein for late embryogenesis (OHL), heat shock proteins, and certain transcription factors that affect the expression of various stress-related target genes have also been used to improve drought tolerance in transgenic plants. Drought-induced genes with different functions have been identified through molecular and genomic analyses in a variety of plant species such as the C/CBF family (Shinozaki) [121]. By regulating stress gene expression and signal transformation, plants indirectly become more stress-resistant [97, 122]. The TDF genes have been identified as drought-induced and the proteins encoded include fructose aldols bisphosphate, a cold-like protein found in WCOR413. The PIP2 protein, an aquaporin specializing in a water channel to transport water across the plasma membrane, and the tonoplast have been observed in sweet orange. TDF21, TDF38 and TDF80 are involved in the regulation of signal transduction and expression of genes. These are sensitive to stress and also regulate the expression of stress-induced genes, possibly induced by drought.

5. Future research strategies

Soil microbiome research offers the opportunity to improve abiotic stress in plants. The mechanisms by which plants recover from drought and/or heat stress can be mediated by microbes surrounding the plant, particularly the roots, and these are involved in various stages of plant growth. Advances in the application of new molecular and genomic tools and technologies have paved the way for the study of plant microbiota, and these promising advances enable the study of the biological functions of various microorganisms both inside and outside the host tissue.

Significant advances in the characterization of the plant genome and the optimization of techniques for manipulating the plant genome have contributed and will further improve our knowledge and ability to develop stress-resistant plants. Ultimately, genetic engineering or transgenic methods must be combined with conventional breeding activities and supported by markers in order to obtain the desired improved varieties.

Plants have developed complex adaptive mechanisms to withstand diverse and complex abiotic stresses. With the advent of new technologies such as genomics and genetic transformation, significant advances have been made in understanding these complex traits in higher plants. However, the commercial application of successful research results requires additional validation of the products or prototypes in the field.

These efforts will lead to tangible practical outcomes that may help mitigate the effects of climate change, especially concerning drought and heat stresses, and will contribute to improved crop productivity and food security.

6. Conclusion

Plants adaptation is considered a striking strategy to manage the impacts of climate change. In climate change, the most important factors are fluctuating patterns of temperature and drought which have an adverse effect on plants physiology, morphology, water status, biochemistry, anatomy, genetics, and productivity. Hence the emphasis should be on the development of production systems for improved water-use efficiency and to adapt to the hot and dry conditions through agronomic practices. Development of climate-resilient citrus rootstocks and scion through genomics and biotechnology are essentially required.

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Conflict of interest

The authors have no conflict of interest with any person or institution.

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