



Review

Influence of Climate Change on Metabolism and Biological Characteristics in Perennial Woody Fruit Crops in the Mediterranean Environment

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Abstract: The changes in the state of the climate have a high impact on perennial fruit crops thus threatening food availability. Indeed, climatic factors affect several plant aspects, such as phenological stages, physiological processes, disease-pest frequency, yield, and qualitative composition of the plant tissues and derived products. To mitigate the effects of climatic parameters variability, plants implement several strategies of defense, by changing phenological trends, altering physiology, increasing carbon sequestration, and metabolites synthesis. This review was divided into two sections. The first provides data on climate change in the last years and a general consideration on their impact, mitigation, and resilience in the production of food crops. The second section reviews the consequences of climate change on the industry of two woody fruit crops models (evergreen and deciduous trees). The research focused on, citrus, olive, and loquat as evergreen trees examples; while grape, apple, pear, cherry, apricot, almond, peach, kiwi, fig, and persimmon as deciduous species. Perennial fruit crops originated by a complex of decisions valuable in a long period and involving economic and technical problems that farmers may quickly change in the case of annual crops. However, the low flexibility of woody crops is balanced by resilience in the long-life cycle.

Keywords: climate change; woody crops; deciduous species; evergreen species



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1. Climate Change Scenario and Production, Mitigation, Resilience of Woody Fruit Plants

1.1. General Considerations

Epidemiological evidence indicates that the consumption of staple foods of the Mediterranean diet, like legumes, grains, vegetables, fresh fruit, derived products such as olive oil and wine is associated with health benefits and a minor incidence of diabetes, cancer, cardiovascular, and neurodegenerative diseases [1]. Traditional Mediterranean crop systems (e.g., olive and grape) provide food commodities in a global market, and climatic changes impact ecological, economic, and social areas of Mediterranean bio-cultural heritage [2]. Mediterranean climate is characterized by hot and dry summers and rainy cold winters, with a high variability depending on the geographical locations and years [3].

In the past decades, data of world fruit and vegetables showed constant increases with a higher and faster growth with respect to the population [4]. This trend is justified by the growing integration of staple foods providing energy with other complementary foods, like horticultural commodities and oils of vegetable origin, in a more complete and variable diet.

The staple foods included in the “Mediterranean diet” are involved in a lower incidence of chronic diseases and improved longevity [5]. In this context where the objective

is providing sufficient and healthy foods for everyone, vegetable production growth is at least twice than fruit yield, and olive oil production only represents 4% of the market of oils of vegetable origin.

Worldwide olive oil production is constantly increasing, despite continuous fluctuations due to uncertainty of climate and irregular bearing [6]. The European Union comprises more than 93% of all the olive oil production in the world with three-quarters of world production concentrated among Spain, Italy, and Greece [6].

Climatic changes may affect the adaptability of temperate fruit trees that account for about 48% of global fruit production [7]. The impact of climate change is variable among countries creating higher food security dangers in low-income ones [8]. The forecast of population increases to about 9.9 billion by 2050 makes food security a social problem due to an unequal distribution of food resources, to an increase of the risks related to soil degradation, biodiversity loss, and mass extinction [9].

Many climate indices are used as a diagnostic tool to understand the potential impacts and evolution in both space and time of climate change on a given region [10–14]. Luh and Chang [15], using the structural Ricardian model, predicted the correlations between seasonal climatic variations and some staple foods in Taiwan (East Asian) under different scenarios. These simulations showed that fruit production was less sensitive than vegetables and rice. In addition, under some scenarios the production was improved due to the increase of precipitations in the South of Taiwan.

Atreya and Kaphle [16], improved the knowledge of the effects of climate change (e.g., global warming, change of seasonal pattern, excessive rain, melting of the ice cap, flood, rising sea level) on tropical, subtropical, and temperate fruit production in Nepal although it is not always possible to isolate the effects of climate change from the effects of environmental degradation. Moreover, the authors have pointed out the need to change the management of the production system adopting conservative agriculture practices and using renewable energy sources, water conservation, and reforestation strategies.

Worldwide anthropological factors are driving weather and climate extreme events: heatwaves, heavy precipitation, droughts, and tropical cyclones as reported in IPCC report, 2021 [17]. Recently, the term “winter weather whiplash” is used by the scientific community to indicate a range of extreme and rapid shifts in weather conditions, such as swings from drought to deluge and hot to cold (or vice versa), which may damage both humans and natural system [18]. In this context, it is essential to reduce the effects of climate change through sustainable land management [19] which involves farmers who should evaluate the aspects related to tillage system, selection of drought-tolerant rootstocks, irrigation technique, and cultivar selection [20]. Moreover, it is essential to preserve the genetic diversity of plant species through germplasm collections as material for breeders under future climate changes scenarios [21].

1.2. Environmental Effects

The major effects of climate change are the increase of temperatures due to atmospheric greenhouse gases in the long-time and the loss of available water [22]. Human activities caused 1.0 °C of global warming, relative to pre-industrial levels and the temperature will further rise by 1.5 °C between 2030 and 2052 considering the current increase rate [23]. Rising temperatures cause severe damage to human and natural systems such as droughts, floods, sea-level rise, biodiversity loss, and spatio-temporal variation in species distribution [23,24]. For example, in the Restinga region in Brazil a comparison between current climate conditions and future climate scenarios projected to 2050 estimated, in a pessimistic scenario an overall three-fold increase of more resilient woody plant species, whereas, at regional scales, the biodiversity loss may reach percentages as high as 19% leading to species homogenization in Restinga vegetation [24]. In addition, in most land regions, frequent heatwaves increase the frequency and the duration of marine heatwaves [19]. The increase of 1.5 °C would also lead to a significant increase in runoff and flood hazards in some regions compared to the current situation [17].

The rate of temperature increases in a given period is more relevant for minimum temperatures than for maximum temperatures, showing a higher sensitivity to climate change [25]. The daily temperature on regional and seasonal scales varied up to 30 °C and may lead to cold anomalies or even to cold peaks despite the global warmer climate [26].

The main greenhouse gases in the atmosphere are water vapor, carbon dioxide (CO₂), methane (CH₄), and ozone (O₃). Deforestation, livestock ranching, and oceanic acidification contribute to the increase of atmospheric greenhouse gases [27]. According to IPCC, 2019 [19], since 2011 greenhouse gases have progressively increased in the atmosphere, with annual averages of 410 ppm for carbon dioxide (CO₂), 1866 ppb for methane (CH₄), and 332 ppb for nitrous oxide (N₂O) in 2019. The human-caused CO₂ emissions are expected to rise to ca. 700 ppm at the end of this century [28] due to melting permafrost and the release of stored methane [9], leading to the acidification of the oceans and affecting growth, calcification, and survival of several species [19]. Other consequences of climate change are the increases in frequency and intensity of heavy precipitations and droughts in several regions [17]. These adverse events have increased since the 1950s in most geographic areas [17]. In some areas, such as the Mediterranean region, medium or long drought periods increased up eight times than in the past [29]. Risks of droughts and precipitation deficits, as well as heavy precipitation associated with tropical cyclones, are projected to be higher with global warming of 2 °C rather than 1.5 °C in some regions [19]. Water stress is caused by a rise of temperatures, loss of soils' water through evaporation, high light intensity, melting glaciers causing water reservoirs reduction, dry wind, and salinity stress.

1.3. Overview on Effects on Woody Crops

Within certain thresholds, it has been shown that increasing CO₂ can have beneficial effects [30]. For example, in grape ripe berries elevated CO₂ may partially mitigate the negative effect of high temperatures on the imbalance between sugars and anthocyanins [29].

As suggested by De Ollas et al. [31] the severity of damages produced by temperature rise in perennial cropping systems is dependent on the phenological stage. Authors reported that in winter the high temperature would affect early phenological events such as flower bud induction and ecodormancy. In spring, they could affect the persistence of already developed flowers, and during fruit development, they could affect fruit yield and quality. More effects on the flowering and fruit development cycle may be expected in the case of subtropical and tropical fruit trees [32]. By a global meta-analysis of numerous studies, Ettinger et al. [33] suggest that spring phenology of woody plants in Central Europe will anticipate due to warming.

Warming due to climate changes causes a reduction in yield and quality of woody perennial cropping systems [34] altering the relationship between primary and secondary metabolites in fruit [28].

Moreover, warmer temperatures compromise the required chilling temperatures to break full dormancy in numerous plants leading to phenological disorders, flowering anomalies, disorders in cross-pollination, low fruit set, and final production [3]. Besides temperatures, the change and the variability of climate directly affect available water resources and atmospheric CO₂ concentration thus modifying crop physiological characteristics and photosynthetic processes [35].

Abiotic stresses caused by climate changes affect the dynamics of plants' natural enemies altering the geographical distribution, virulence, the abundance of the range of host plant pathogens, and the interaction among species thus leading to epidemics of herbivorous parasites [36–38]. In the temperate regions of Europe, considering the climate change scenario, the extension of agricultural pests and diseases is expected in previously non-affected regions [39]. The combination of drought and pathogen stress is a frequent condition whose effects depend on plant genotype, nature of pathogens, timing, severity, and duration of stress [38]. Moreover, the phenological changes due to climatic variability can affect the plant–pollinator interactions leading to pollination depression in

the plant or to pollinator starvation, thus compromising the fruit yield in crops that are not self-fertile [31,40].

Several tree species implement strategies to avoid or tolerate embolism, recovering in the latter case their hydraulic functioning [41]. Plants implement a range of strategies, known as acclimation or physiological adaptation, to mitigate the effects of the high variability of weather events. This response can be affected by several factors (e.g., plant condition and history, and extension of the damage). Insufficient avoidance or tolerance mechanisms to the stresses can lead to deleterious events up to death [42].

The cambial activity of woody plants is very sensitive to drought and temperature. Water stress, reducing turgor pressure of cambial cells, leads to a decrease of cell division of vascular cambium, resulting in reduced plant growth, while vascular cell death is observed in conditions above the threshold temperature [43]. Several mechanisms to avoid water stress include osmolyte accumulation, cellular components protection (qualitative and quantitative changes of pigments), and damage repair mechanisms (scavenging of toxic oxygen species) [44].

Phenotypic plasticity is a key plant strategy in response to abiotic stress [45,46]. Pivovarov et al. [47] studied the woody plants' drought survival mechanism and highlighted some typical morphological and physiological traits associated with drought tolerance: xylem resistance to drought-induced cavitation, easy leaf loss; deep roots and increased access to water, gas exchange regulation to reduce leaf water loss and to maintain photosynthesis at low leaf water potential, and the low leaf area/sapwood area ratio.

The exposure of plant cells to environmental stress conditions and defense response may result in a turning of primary carbon use for biomass production to the biosynthesis of defensive plant secondary compounds [48]. The metabolite biosynthesis is dependent on several factors such as genus, species, genotype, cultivar, environmental factors, developmental stage, and physiological state [48].

The alteration of physiological and ecological functions of flowers due to abiotic stresses compromises fruit production, by affecting the attractive volatile organic compounds released for pollinators, and the biosynthesis of pigments like anthocyanins. Impairment or loss of pollen fertility are also possible events [49]. The biosynthesis and accumulation of plants' secondary metabolites is another survival strategy against the effects of adverse environmental factors [50]. In some cases, a rise of secondary metabolites may be positive, increasing crop quality. On the contrary, a decrease in crop quality is also possible if changes stimulate the biosynthesis of other secondary metabolites including those responsible for off-flavors or food toxicity [51]. Moreover, the active compounds contained in biostimulants can improve plant stress tolerance and productivity in adverse growing conditions [52].

As response to abiotic stress, plants produce ROS (reactive oxygen species) (e.g., superoxide radical, hydroxyl radical, alkoxy radical, hydrogen peroxide). Under optimal conditions, the antioxidant molecules scavenge the radicals, while extreme abiotic stress can compromise this balance [53]. The knowledge of the links between abiotic stresses and plant metabolomic changes is extremely important and may play a key role in breeding projects focusing on plants' performance under environmental stress [54].

This review includes an overview of the literature on the effects of climate change in the last years concerning the main evergreen and deciduous fruit species. In particular, it focuses on the influence of climate change on fruit composition and quality. The fruit quality is directly related to primary (e.g., sugars, sugar alcohols, organic acids, amino acids, and fatty acids) and secondary metabolites composition, like phenolic, volatile, and terpenoids compounds, upon which depend antioxidant, biological, and nutritional properties, as well as flavor and taste [34].

2. Methods

This review studies thirteen woody fruit species distinguished between evergreen and deciduous. Among the evergreen trees, citrus, olive, and loquat were studied while

for deciduous species grape, apple, pear, cherry, apricot, almond, peach, kiwi, fig, and persimmon were selected. The disparity in the number of deciduous and evergreen plants reflects the larger diffusion of deciduous crops in the Mediterranean area as well as the strong definition of the phenological stages of deciduous species with respect to evergreens. Although, the review was primarily focused on the effects of climate change in the Mediterranean area, given the diffusion of many of the selected crops in other temperate or subtropical climates it was decided to include in the review even some countries outside the Mediterranean area.

The literature review was based on the Scopus database. The bibliographical research was carried out considering the last decade (from 2010 to 2021), to take into account the most recent works.

In the search process the following terms and query strings were enclosed: (i) “climate change”, woody, AND plant (1275 documents); (ii) “climate change”, perennial AND plant (977 documents); (iii) “climate change”, evergreen AND plant (707 documents). Moreover, the main search term “climate change” was coupled with generic names of the plants considered in this review, i.e., grape, apple, pear, cherry, apricot, almond, peach, kiwi, fig, persimmon, citrus, olive, and loquat.

3. Evergreen Trees

3.1. Citrus

Citrus species grow in different humid and dry equatorial, tropical, and temperate climatic conditions with moderate ability to adapt to cool temperatures (average temperatures between 0 and 10 °C) depending on the species [55]. For example, *C. reticulata* (mandarins) and *Fortunella* spp. (kumquats) are well adapted to moderately cold areas, while lemons (*C. limon*), pummelos (*C. maxima*), “Key” lime (*C. aurantifolia*), and “Bears” lime (*C. latifolia*) are more suitable for warm areas [55].

A climatic scenario with low precipitations and high actual evapotranspiration rates makes it necessary, as a future perspective, to study the hydrological effects of full and drip irrigation [56]. Many studies focused on the application of deficit irrigation to optimize water use in citrus orchards [56–61].

Water stress in citrus plant causes closure of stomata with consequent lower CO₂ assimilation, increase of photorespiration, flower and fruit drop, and damage to chlorophyll [55]. In addition, it affects the qualitative fruit composition increasing fruit acidity, reducing fruit peel thickness, decreasing reducing and non-reducing sugars, and accumulating sorbitol and proline [62]. Some disorders like fruit splitting and creasing of the peel are also associated with drought [63]. Triploids in citrus have a better ability to recover after water stress than diploid and tetraploid parents although no differences in tolerance were found during the same water deficit conditions. Best recovery capability in triploid varieties was due to greater carboxylation efficiency and low oxidative damages [64].

Some techniques applied during fruit growth may reduce the effects of water stress. The use of top and photoselective nets, for example, has increased the yield production of Valencia orange improving the water-use efficiency as a possible partial solution in view of climate change, especially under arid and semi-arid conditions [65]. Similarly, the use of foliar anti-transpirants increased the water use efficiency preventing fruit drop due to changing climate [66].

A study located in Pakistan on fruit quality of “Kinnow” mandarin (*C. nobilis* Lour × *C. deliciosa* Tenora) reported that in warm humid conditions during maturation a reduction in acids and antioxidant activity was observed with respect to cool areas [67]. In abnormal winters characterized by high temperatures due to climate changes, plants, according to the rootstock, may break dormancy earlier exposing themselves to frost damage [68]. Citrus reproductive biology is characterized by the parthenocarpy that allows the seedless fruit production when combined with other reproductive features such as male and female sterility or self-incompatibility [69]. Aloisi et al. [70] studied the influence of temperature on self-incompatibility in *Citrus* × *clementina* Hort. ex. Tanaka analyzing aspects such as

polyamine content and transglutaminase activity. Self-pollination at 25 °C caused a higher content of spermidine (a polyamine) than that of both cross-pollinated pistils at the same temperature and self-crossed pistils at 15 °C [70].

When exposed to high temperatures, the sensitive “Satsuma” mandarin (*C. unshiu* Marc.) species showed a lower maximal photochemical efficiency of PSII with respect to tolerant “Navel” orange (*C. sinensis* Osbeck). Furthermore, an increase of antioxidant enzymes activities during high-temperature stress occurred as a consequence of Mehler’s reaction in sensitive “Satsuma” mandarin [71].

Low air temperature or long-term cold post-harvest storage may determine physiological and metabolic disorders such as pitting and necrosis in the flavedo tissue of chilling-sensitive citrus fruits [72,73]. The activity of PAL enzyme (*phenylalanine ammonia lyase*) during low-temperature exposure of chilling sensitive citrus fruits and the antioxidant capacity of carotenoids has some protective role against these damages [72,74]. Among citrus species, lemon and grapefruit are more sensitive to chilling injury than orange and mandarin [74]. The excess of light and high fluctuation densities of solar radiation led to sunburn [75], while other abiotic factors such as wind, chilling, and bruising can lead to skin Oleocellosis [76]. Oleocellosis namely also oil spotting is a physiological disorder in citrus fruit that occurs during the harvest and postharvest condition with consequent reduction of the quality [77]. This disorder causes blemishes due to the release of phytotoxic oils (terpenes) oil from oil glands into the flavedo [78].

Direct and indirect environmental factors have greater effects on the abscission rate of fruits before harvesting than on the ripening process, compromising the yield of some citrus cultivars [79]. Khefif et al. [79] observed that a rapid change from low to high temperature at the end of winter would favor abscission by causing a carbon shortage whereas a longer period of lower temperatures would delay carbon shortage thus decreasing the fruit drop.

The chlorophyll concentration can be used as an indicator of plant health stress and nutritional deficiencies [80] because active oxygen species reduce the chlorophyll contents under drought stress [81].

The spectrally modified light altered the physiological responses in citrus, for example the use of a red shade net in “Carrizo” citrange and rough lemon affected nitrogen, phosphorus, potassium, and zinc contents in leaves, plant growth, and root development [82].

Citrus rootstock plays a key role in the resistance to climatic stresses. Balfagón et al. [83] indicated that the higher tolerance of “Carrizo” citrange (*Poncirus trifoliata* L. Raf. X *C. sinensis* L. Osb.) rootstock than “Cleopatra” mandarin (*C. reshni* Hort. ex Tan) under drought combined with high temperatures is related to the accumulation of HSP101 (heat shock protein) and APX (ascorbate peroxidase).

The climate variability interacting with genetic factors can have negative effects also on pollen viability, pollen germination, and pollen tube growth of “Shogun” mandarin (*C. reticulata* Blanco) [84].

Temperature and radiation daily variations, as well humidity can cause citrus fruit peel cracking or creasing that reduce fruit quality and production [85,86]. The cracking is a gradual process that led to deformation of the flavedo, damage of albedo, and visible ridges on the peel surface [62].

Sadka et al. [87] reviewed the effects of warm climate on sugar and acids concentrations during citrus development, indicating an advancement of the maturity index, in warm climates than in cold with sweeter fruit. Moreover, high temperatures are associated with a higher alcohols and aldehydes content and a negative effect on the color break, which requires an amount of cold night-time to occur [87]. Moreover, high temperatures, low relative humidity levels, and low evapotranspiration increased the infestation of *Brevipalpus phoenicis* phyto virus in citrus orchards [88].

The carotenoids are responsible for internal and external ripe fruit color. Moreover, they largely contribute to citrus health benefit effects, and are the precursors of the plant hormones ABA (abscisic acid) and strigolactones [89]. Light and temperature are the environmental factors that most influence carotenoid biosynthesis. Drought and high

temperatures delay the beginning of the color break with the poor coloration of the citrus peel [90].

In the fruit of “Satsuma” mandarin (*C. unshiu* Marc.), the combination of ethylene treatment and the red LED light treatments increase the β -cryptoxanthin and lutein content in the flavedo [91]. Light deprivation produced a down-regulation of the expression of key carotenoids biosynthetic genes, accelerated peel degreening, chlorophyll degradation, and reduced chloroplastic-type carotenoids in “Clemenules” mandarin (*Citrus* $\times$ *clementina*) and “Navelina” orange (*C. sinensis*) [89]. Despite this, the authors did not observe any influence of the light on ABA content. In the post-harvest treatments, the red light and dark shade treatments induce carotenoid accumulation, as total carotenoid, isolutein, zeaxanthin, lutein, neoxanthin, all-trans-violaxanthin, phytofluene, cis- ζ -carotene, and β -carotene concentrations [92]. Moreover, red light and blue light applications increase the total organic acid and citric acid contents [92]. In a study conducted in vitro on “Valencia” orange the treatment of blue LED light led to regreening in the flavedo due to chlorophyll accumulation and variations of carotenoid composition [93]. A decrease of 9-cis-violaxanthin and an increase of lutein, β -carotene, and all-trans-violaxanthin were observed. These findings are of potential interest for the study of citrus fruit sensitivity to climatic changes linked to the radiation availability (cloudiness increase) and type of radiation modifications (UV increase and others).

Regarding red pigmented citrus, it was observed that in red orange (*C. sinensis*) the exposure to low temperatures (4 °C) promoted the anthocyanins accumulation [94]. This is due to the over-expression of phenylalanine ammonia lyase (PAL), chalcone synthase (CHS), dihydroflavonol-4-reductase (DFR), and UDP-glucose flavonoid glucosyl transferase (UFGT) genes (40-fold with respect to control samples at 25 °C). Carmona et al. [95] have observed that cold storage at 9 and 4 °C in the pulp of “Moro” blood oranges (*C. sinensis*) stimulated anthocyanin accumulation, but with the exposure at 9 °C a darker purple coloration was reached due to dihydroflavonol channeling toward anthocyanin production, providing more leucoanthocyanidins [95].

Besides anthocyanins, climate changes affect the production of citrus essential oils. Their synthesis is genetically regulated but may be also influenced by external factors such as diseases, cultural practices, climate, and soil properties [96].

3.2. Olive (*Olea europaea* L.)

The olive tree is the second most important oil fruit crop cultivated worldwide [97]. Olive oil provides health benefits due to its phenolic content and a high percentage of unsaturated fatty acids [98]. Extra virgin oil is mainly composed of fatty acids such as acylglycerides (about 98% of the total weight) and other minor components (2% of total weight) such as aliphatic and triterpenic alcohols, sterols, hydrocarbons, phenols, tocopherols, esters, pigments, and volatile components [99]. Fatty acid profile in olive drupe is also used to verify the authenticity and quality of olive oil [97]. Although olive trees are a drought-tolerant species, the high temperatures have negative impacts and their distribution in arid zones is limited by annual precipitation lower than 350 mm. Moreover, the species must satisfy the cold requirement to come out of dormancy and be released from the endo-dormancy period [100].

The effect of climate change on olive production trend is not clear because of the interactions between crop management and environmental factors, although interannual alternation in fruit yield (typical of the biological cycle of the olive tree) is enhanced by unfavorable environmental conditions [101]. Benloch et al. [102] showed that a 4 °C increase of air temperatures anticipates the date of flowering, increases the flowering period, the ovary abortion, and reduces fruit set as observed during a 3-year experiment. A theoretical model applied until 2100 to a super-intensive olive orchard in the Alentejo region (Spain), considering different climate change scenarios, estimated a delay of the full flowering date between 16 and 29 days [103]. Moreover, earlier bloom in the future will be due to water scarcity. In some areas this could be advantageous, since shifting the critical flowering

time frame from the warmer to the cooler periods would reduce the heat-induced flower drop and, hence, increase the fruit-set rate. However, it is true that in most of the southern locations the expected rise in spring temperatures, especially during flowering, may have a deleterious impact on olive production [31].

The cold temperature in olive is one of the main determinants of olive fruit yield by regulating the release from the endo-dormancy and eco-dormancy periods [100]. For this reason, olive trees in the tropical climate do not usually produce fruits [104]. About 2% of olive flowers bear fruit [105] and a certain chilling temperature is required for normal flowering [100,105]. Climate change projections indicated that the current olive orchard areas in the Mediterranean area are threatened due to insufficient climate requirements [106], and fruiting may be reduced at low latitudes ($<30^{\circ}$) [105]. The response to these changes is cultivar-dependent, and, in this perspective, Fraga et al. [106] suggest the adoption of less chill-demanding varieties under current and future climatic scenarios.

In two studies, Miserere et al. [107,108] observed that the whole-tree sap flow and leaf photosynthetic rate in young olive trees were not affected by prolonged exposure to high temperatures, probably due to the degree of thermal acclimation of olive trees. Baccari et al. [109] evaluated the drought tolerance under severe stress (60 days water shortage) of one-year-old olive plants growing in the greenhouse. They found that some genotypes were still able to photosynthesize at a very low leaf water potential of -4 to -6 MPa maybe as a consequence of an increase of the xanthophyll cycle de-epoxidation and vitamin E. The general trend is an increase of phenolic compounds according to increasing drought stress [110].

Avoidance, tolerance, and recovery capacity are some strategies used by olive trees in response to drought as reported by Brito et al. [110]. Some examples of avoidance strategies are the high root density, high nighttime stomatal conductance, high root/canopy ratio and osmotic adjustment to extract water from the soil, as well as sclerophyllous and small leaves, small stomata, dense trichome layer and stomatal conductance reduction to decrease water losses [110]. Among tolerance adjustments, aquaporins regulation, increase of carotenoids content, enzymatic and non-enzymatic antioxidant activity were observed; while for recovery capacity, slow stomatal conductance restoration, ABA persistence in leaves, aquaporins regulation were included. Rapid plant development, shortening of the life cycle, early flowering, and self-reproduction are other defense strategies [30].

Temperatures ranging from 16 to 32°C affected fruit dry weight and the concentration and the proportion of oleic acid in the oil. Mafrica et al. [111] reported that low temperatures and high rainfalls, typical of high altitude, delay the fruit development and ripening with an improvement of olive oil quality. Benlloch-González et al. [112] reported that a 4°C increase in temperature could lead to a reduction of oil content because of a delay in lipogenesis, a decrease of fruit size, increase of the size of trees, reduction of yield, due to a reduction of fruit set, and increase in ovary abortion.

An increase in water availability was negatively correlated with total phenolic concentration in fresh olive fruit and the extracted oil [113]. Olive oils produced in years characterized by low precipitations showed the highest tocopherol content depending on the cultivar [114]. Tura et al. [115] observed that a warm ripening season and sufficient rain in spring and autumn positively affected the content of volatile compounds as well as the overall sensorial evaluation of the oils. Ben-Hari et al. [116] indicated that fruit development is affected by high temperature during the whole growth period, while oil accumulation and composition are mainly affected after pit hardening. Olive oils obtained in areas at elevated altitudes showed high oleic acid and high phenolic content [117]. Moreover, in table olive, the phenolic content and their antioxidant related-properties are dependent on the interactions among altitude, genotype, and maturation stage [118]. The authors reported that the olive fruit collected in the black coloration at 300 m above sea level. showed an increase of their reducing capacity as compared to those obtained at 10 m. Abiotic stresses like temperature, darkness, and wounding affect the unsaturated fatty acids UFA content of microsomal membrane lipids via modulating the stearyl-acyl

carrier protein desaturase (SAD) transcription. The SAD catalyzes the first desaturation step leading to oleic acid, which can be further desaturated to linoleic and α -linolenic acids [119].

3.3. Loquat (*Eriobotrya japonica* Lindl.)

Loquat is a sub-tropical fruit belonging to the Rosaceae family and is native to south of China but well-adapted to the Mediterranean climate [120]. Loquat is rich in bioactive compounds, mainly phenolics and carotenoids, responsible for its antioxidant and curative properties [121]. In folk medicine, it was used in the treatment of cough, chronic bronchitis, inflammation, diabetes [122]. In temperate areas, loquat rests during summer, the blooming occurs in autumn or early winter, fruit develops in winter and ripens in early spring. The bud break follows summer rest, and no fruits are present at this time [123].

The loquat fruit is very chilling-sensitive and chilling injury occurs at below 5 °C. Symptoms are lignin accumulation, increased fruit firmness [124], flesh woodiness, adhesion of peel to the flesh, leathery and juiceless pulp, and internal browning [125]. Water stress induces changes in leaf metabolism, such as the accumulation of sorbitol in favor of sucrose as a protective defense against leaf dehydration [126]. The purple spot physiological disorder is due to the dehydration process regulated by environmental factors (sunlight exposure and low temperatures) during the color-break stage of loquat fruit [127].

The loquat tree shows good tolerance to the summer dry periods typical of the Mediterranean areas due to a reduction of photosynthetic rate [120]. Stellfeldt et al. [120] indicate that the non-irrigated plants reached a similar value of net photosynthesis rate than full-irrigated plants just a week after the irrigation was restarted.

The water stress in loquat may lead to early blooming depending on the intensity [128]. With early blooming, the loquat fruit needs more days to ripen and, in some cases, a higher heat accumulation [129]. The reduction of water supply did not affect either the fruit yield or the quality compared to full-irrigated plants [130]. Similarly, Ballester et al. [131] indicate that the application of regulated-deficit irrigation leads to early flowering in early and intermediate-maturing cultivars, however the yield and quality of fruit were not affected (firmness, total soluble solids, titratable acidity, and fruit weight).

The climate changes, also, affect the availability of pollinators, whose biodiversity is fundamental to improving the fruit set percentage and the fruit quality, as reported for loquat by Ahmad et al. [132].

4. Deciduous Trees

4.1. Grape (*Vitis vinifera* L.)

Grapevine (*Vitis vinifera* L.) across Europe has a key socio-economic role in Italy, France, and Spain as the main wine-growing countries [133]. Grapevines are cultivated on six out of seven continents and across different climatic conditions such as oceanic, transition temperate, continental, cold continental, Mediterranean, subtropical, attenuated tropical, and arid climates [134].

The integrated model predicts that under different climate change scenarios about 50% of wine growing regions will become climatically unsuitable for viticulture by the end of the twenty first-century [135]. Climatic change has accelerated the phenology of grapevine with respect to three decades ago with consequent changes in berry composition at harvest and wine quality [136]. Microorganisms and mycotoxins proliferation, high alcohol content, high pH, low acidity, and high biogenic amines are some consequences of climate changes for wine [137]. Delrot et al. [136] reported the displacement of viticulture to regions that were so far too cold for ripening grapes or within existing wine regions to higher altitudes, as a consequence of climate change.

The analysis of the impact of climate change on vulnerability and sustainability of systems for grape and wine production has been reviewed by numerous authors in different areas of production in the past years [20,138–140].

Mihailescu and Soares [141] found that the rising temperature at low latitudes affected plant phenology, berry development, and grape biochemistry of the red varieties, increased the incidence of pests and diseases, and suitability of cultivation, while for the higher latitudes it mainly affected biochemistry and suitability of the white grape varieties.

Rienth et al. [135], reviewed the impact of climate change on the biosynthesis and accumulation of secondary metabolites. In the “Tannat” grape cultivar, a low leaf water potential increased the expression of CHS, DFR, and F3H genes and caused anthocyanins accumulation during harvest time [142]. Water stress can promote early and high expression levels of F3H, DFR, and UFGT genes, as well condensed tannins gene expression [143,144]. Xu et al. [145] showed higher total phenols and anthocyanins content in berry of five grape cultivars during the growing winter season than in the summer in subtropical conditions. Anthocyanins are more sensitive to temperature than to light, while an opposite behavior was observed for flavonoids content [146]. Anthocyanins act as antioxidants in protecting berries from extreme high temperatures, while flavonols, flavan-3-ol, and proanthocyanins responses to high temperatures are less clear [147].

Drought in grapevine induced earlier shoot growth cessation, reduced berry size, increased content in skin phenolic compounds, lower malic acid concentrations, and modified aroma precursor profiles [136].

Oxidative stress due to drought and heat stress conditions determined an increase in the activities of both antioxidant enzymes (superoxide dismutase (SOD), catalase (CAT), peroxidase (POX), glutathione peroxidase (GPX), glutathione S-transferases (GST), ascorbate peroxidase (APX) and glutathione reductase (GR) and non-enzymatic antioxidants (ascorbate, glutathione, α -tocopherol, proline), although the response is cultivar-dependent [148]. Increasing temperatures reduced the level of monoterpenes and pyrazines in ripe grapes, while increasing norisoprenoids concentrations [136]. In the white grapevine water stress applied from fruit development until harvest changed the expression of 4889 genes of phenylpropanoid, flavonoid, carotenoid, and terpenoid metabolic pathways, with a consequent increase of derived-products concentrations [149].

In some “Tempranillo” clones, the combined action of high atmospheric CO₂ concentration and elevated temperatures caused a fast grape development, enhanced vegetative growth, and increased the labeled C content in the wood; yield and yield-related parameters were negatively affected, due to high temperature while amino acids levels in ripe grape were unaffected [29]. In a simulation of the effects of mean surface temperature and CO₂ increases, Antolin et al. [28] observed a little effect of elevated CO₂ and high temperatures on phenological phases and old grape quality as demonstrated by the stability of antioxidant properties and sugars and phenolic compounds content [28]. Other authors observed that the effects of elevated temperature and elevated CO₂ on anthocyanin concentration and anthocyanins/TSS ratio seem to depend on water availability [150].

The combined effects of drought and *Plasmopara viticola* were investigated in a drought-tolerant (“Xynisteri”) and a drought-sensitive (“Chardonnay”) grapevine cultivar artificially inoculated with *P. viticola* and exposed to full or deficit irrigation (40% of full irrigation) [38]. Under full irrigation, “Xynisteri” was more susceptible to *P. viticola* than “Chardonnay”. Drought stress increased the susceptibility of grapevine leaves inoculated in vitro, but both cultivars showed resistance against *P. viticola* when inoculated in planta, probably due to abscisic acid.

4.2. Apple (*Malus communis* L.)

The genus *Malus* Mill., belongs to Rosaceae, comprises 25 to 47 species and *Malus communis* L. is one the most important temperate fruit crops, belonging to Rosaceae. Species are generally distributed in the northern temperate zones of North America, Europe, and Asia [151]. Some species, as *M. sieboldii* (Regel) Rehd. show drought resistance.

In apple, global warming hastens flowering and fruit harvesting, limiting the chill unit hours required for flowering [152]. According to Funes et al. [3] in the cold regions of North-Central Europe where winter chill is not a limiting factor, the warming effect

observed since the mid-century may determine an early flowering. On the contrary, in Mediterranean areas the satisfaction of the chill requirement for high-chill cultivars would be incomplete delaying flowering date despite a faster heating phase. Another sequential model predicted early flowering in warm winter sites and late flowering in cool winter sites [153].

Prolonged chill temperatures during the warm season may cause late and extended flowering stage, with negative consequences on fruit quality, as observed by El Yaacoubi et al. [154] during the 2015–2018 seasons in the Fes-Meknes region (Morocco). According to Darbyshire et al. [153] a positive correlation exists between fruit weight, size, and firmness and the satisfaction of chill and heat requirements.

According to Sugiura et al. [155], early blooming and high temperatures during the ripening stage may affect apples' taste and textural attributes and may determine a reduction in acid concentration, fruit firmness, and watercore development.

During 40 years of climate data, an increase in temperature of 0.30 °C/decade did not imply a reduction in winter chill in Asturias (Spain), probably due to the high degree of phenotypic plasticity of some local apple cultivars [25]. Moreover, the authors observed that the early blooming cultivars slightly delayed flowering, whereas a slight advance was observed in intermediate/late and late-blooming cultivars [25]. Information about winter chill changes in areas of different altitudes is a fundamental knowledge to evaluate the process of breaking dormancy depending on the fruit production [156]. Luedeling et al. [156] applying a dynamic model had foreseen, in cold climates, an increase in winter cold whereas a stationary situation and a drastic decrease of chill was foreseen in temperate and in warmer regions, respectively. Similarly, Legave et al. [157] reported a new warming vulnerability in temperate Mediterranean regions due to decline of chill accumulation with consequent late and extended flowering with respect to other climate-contrasting. To evaluate the influence of climate change on phenology in high-elevation areas, Rivero et al. [158] have analyzed the role of climatic data on flowering and morphogenesis time of the apple cultivar "Gravenstein". The authors observed that in these areas the time between flowering and new floral primordia stage is faster than in warmer areas, causing irregular flowering and frequent incidences of alternate bearing in apple trees in the cool Nordic climate [158].

The dormancy process of vegetative and floral buds was evaluated in two areas (one with cold winter and one with mild winter) to assess the role of cold in this process. It was highlighted that cold climate induced deeper dormancy and slower resumption of bud development after winter, while mild winter induced superficial dormancy and fast resumption of development with a short time between endodormancy release and the effective real ecodormancy [159]. Moreover, the weak endodormancy in mild winter may be responsible for the large spatio-temporal heterogeneity of budburst and flowering [159]. The increase in temperatures of +0.6 °C recorded in Klein-Altendorf (Germany) station from 1988 to 2013 brought about an anticipation of pome fruit (apple and pear) phenology compared to the previous thirty years [160]. In detail, the authors observed an advance of 10 days for full bloom, 11 days for harvest, and 4 days for leaf drop in the later phase, resulting in five days longer growing period for "Golden Delicious" at Klein-Altendorf [160].

Some prediction models were used to evaluate the sustainability of apple cultivation in the future. Ahmadi et al. [161] in Iran estimates a loss of apple orchard area and cultivation shifting to higher regions of Iran in the 2090s. The future scenario in India described by Singh et al. [151] indicated a loss of about 80% of production due to water stress and about 20% due to high evaporation rate. Another study conducted in the temperate-continental climate of southern Romania examined the consequences of climate change on four phenological stages in the last 50 years highlighting advances of 13.8 days for the bud swelling, 14.8 days for the budburst, 10.7 days for the beginning of flowering, and only 7.3 days for the end of flowering [162]. Moreover, some models were used to evaluate the impact of climate change on pest distribution [163]. Hirschi et al. [39] evaluated, with multi-model projection, the distribution changes of codling moth (*Cydia pomonella*) and fire blight (*Erwinia amylovora*) under future climate scenarios supposing compensating effects:

warm temperatures favoring infections would be balanced by a temperature-induced advancement of the blooming period, leading to no significant change in the number of infection days. Weber et al. [164] reported that the diffusion of black rot fungus (*Diplodia seriata*) in northwestern Europe is due to warmer temperatures during the vegetation period. The incidence of the agent of crown rot disease *Fusarium pseudograminearum* is associated with an increase in CO₂ level [165].

Climate change issues are perceived by apple farmers that are aware of the need to apply some adaptation strategies like crop diversification and land-use practices [166].

In the “Gala” apple cultivar, moderate water stress applied after the fruit expansion improves the content of total soluble solids and soluble sugar (fructose, glucose, and sorbitol) and reduces the titratable acidity [167]. Dietrich et al. [168] found an increase of sorbitol in pear and apple juice exposed to drought stress with respect to the full-irrigation application.

Poor pigmentation is a problem due to global climate change in some regions. Sunlight and temperature are the most important environmental factors affecting the accumulation of secondary metabolites, like anthocyanins [169–171]. The biosynthesis of anthocyanins in some apple cultivars was positively affected by UV-B radiation [172]; while high temperatures reduced anthocyanins genes transcripts in apple peel [173]. Heat caused a strong reduction of both peel anthocyanin concentration and transcripts factor MYB10, the regulator of anthocyanin genes biosynthetic pathway [174].

4.3. Pear (*Pyrus communis* L.)

The regulated deficit irrigation is an optimal technique to improve fruit production and quality and water use efficiency in arid tropical climates [175,176]. A long-time deficit irrigation schedule in pear orchards, despite reducing fruit size, allowed an improvement of fruit quality in terms of soluble solids content, and a potential increase of storability without adverse effects on plant physiological performances [177]. Lepaja et al. [178] observed that regulated deficit irrigation increased the number of fruits, however, inducing a reduction in fruit size. On the contrary, regulated deficit irrigation had no effect on fruit features such as fruit firmness, chlorophyll and carotenoids, color index, phenols content as well as sugars and acids content [176]. In the leaves, deficit irrigation led to a reduction of LAI (leaf area index) [178].

The increase of drought stress intensity in some varieties of *Pyrus* spp. (*P. biossieri*, *P. communis*, *P. glabra*, *P. salicifolia*, and *P. syriaca*) is associated to a reduction of physiological responses such as a lower leaf relative water content, net photosynthetic rate, stomatal conductance, transpiration rate, and intercellular carbon dioxide concentration. Moreover, depending on the intensity of the drought stress and on the variety, pear plants develop some morphological adaptive responses like the increase of root/shoot dry weight ratio, specific leaf weight and stomatal density per unit of area species [179]. The long-term drought stress caused in “Yulu Xiang” pear a reduction of nutrients accumulation and the inhibition of fruit development due to antioxidant system and increased oxidative stress [180]. In pear the drought resistance has been associated to the presence of osmoprotectant glycine betaine, which plays a role in reducing the ROS build-up and lipid peroxidation and in increasing SOD, CAT, and POD activities [181]. Paudel et al. [182] observed a higher drought tolerance in wild pear (*P. syriaca*) compared to its cultivated relative (*P. communis* and *P. pyrifolia*), which is associated to leaf intrinsic water-use efficiency, and late stomatal closure that allowed the maintenance of carbon gain under decreasing Ψ [183]. Therefore, the wild pear ecotypes grown in semi-arid sites, can be used as genetic resources in breeding programs aimed at increasing the adaptability to warm climates [183]. Other authors suggest the use of cooling techniques to decrease the damage of ROS compounds and to increase fruit yields in high-density pear orchards [184].

Regarding the effect of low temperatures, Horikoshi et al. [185] evaluated the metabolic changes induced by chilling temperatures in Japanese pear flower buds exposed to constant chilling at 6 °C and thermal fluctuations of 6 °C/18 °C (150 h/150 h) during endodormancy.

These authors highlighted that flower buds exposed to constant chilling temperatures showed higher sugar (glucose-6-phosphate in particular) and polyol levels, while flowers subjected to temperature fluctuation showed low levels of several metabolites associated to the failure of endodormancy release [185]. Li et al. [186] indicated that during pear flower bud endodormancy the content of abscisic acid increased, and decreased with endodormancy release, playing a key role in endodormancy release of PpCYP707A-3 gene expression.

To uncover the mechanisms that lead to pear tree tolerance to abiotic stress, transcriptomic studies were carried out on some pear species [187–189]. Zhao et al. [187] reported that β -amylase genes and co-regulatory *PbBAM1a*, *PbBAM1b*, *PbBAM1c*, and *PbBAM3* have a key role in growth and development and response to abiotic stresses in Chinese white pear (*P. bretschneideri*).

Pear fruits, and in particular peels, show a high content of total phenols with high antioxidant activity, [190], and are associated with protection against oxidative damage, [191]. The aroma of pear fruits associated with volatile compounds (esters, aldehydes, alcohols, and ketones compounds) is affected by temperatures [192].

The mature fruit of some *P. communis* L. cultivars showed fully or partially red peel, or blushed, depending on genetic, climatic, and horticultural factors [193,194]. The red coloration of pear (*P. pyrifolia*) is mainly due to anthocyanin accumulation in the fruit peel, and temperature and light are the main climatic factors affecting anthocyanin biosynthesis and accumulation [195,196]. Regarding temperature, generally high temperatures lead to anthocyanin degradation as a result of active enzyme-driven breakdown processes while low temperatures enhance their accumulation [194,196]. Several studies were carried out on the influence of different light qualities on anthocyanins accumulation. The exposure of blue light after 72 h has increased the anthocyanins content in the red pear “Red Zaosu” contrary to the red light that did not affect their content [197].

Anthocyanin synthesis increased with ultraviolet light and components of white light that promote increased transcript levels of regulatory genes that upregulate key anthocyanins structural genes [194].

4.4. Almond (*Prunus dulcis* Mill.)

Sweet almond is a healthy food as demonstrated by numerous epidemiological evidence and clinical trials [198]. It is a valuable source of lipids, mainly unsaturated fatty acids, proteins, dietary fibers, sugars, phytosterols, and several key micronutrients, such as calcium, iron, magnesium, manganese, potassium, selenium, and sodium [199]. Moreover, almonds show a high number of polyphenols, mainly hydrolysable tannins (ellagitannins, gallotannins, and ellagic acid), proanthocyanidins polymer, and anthocyanidins, flavonols, flavanols, and isoflavones [198]. Among almond constituents, tocopherol is implied in the prevention of the peroxidation of polyunsaturated fatty acids. Its concentration in almond fruit is dependent on genotype, orchard management, and climatic factors [200], although Zhu et al. [201] reported a little influence of deficit irrigation on tocopherol concentration.

Different authors carried out studies on the impact of climate changes on phenological stages of almond trees (*P. dulcis* Mill.) and on future scenarios of this crop production. Gitea et al. [202], in Romania, observed earlier blooming of almond in the production year 2016 than in 2009, due to an increase in average monthly temperature of the first 3 months of each year from 2009 to 2016. This anticipation exposes fruit and young shoots to late spring frosts. Di Lena et al. [203] analyzing the almond cultivation in Abruzzo (Central Italy) during the past six decades, suggest that the reduction of spring frost due to climate change is counterbalanced by early almond blooming, thus limiting, the expansion of almond cultivation in some areas. Almond species (*Prunus dulcis* Mill.) is native to Central Asia and largely widespread in the Mediterranean area [204]. It is considered a drought-resistant crop despite irrigation strategies are necessary to improve the yield and quality of nuts [205]. Several studies were based on deficit irrigation strategies to optimize water use and to improve almond quality [206].

Trials of Whole Orchard Recycling in situ in almond orchard [207] have improved soil conditions in terms of nutrient content and water retention. Moreover, this practice sequesters significantly higher levels of C as compared to burning and increases water use efficiency of irrigation.

The kernels concentrations of organic acids, sugars, monounsaturated fatty acids, and polyunsaturated fatty acids were positively affected by sustained-deficit irrigation at different percentages of deficit restoration [208]. Zhu et al. [201] reported that severe deficit irrigation decreases the kernel oleic/linoleic ratio. Čolić et al. [209] reported a negative effect of drought on oil content, oleic/linoleic ratio, oleic acid, and contents of extractable proteins.

On “Vairo” cultivar, moderate deficit irrigation enhanced the phenolic content and the proanthocyanidins concentration of almond skin [205]. The same authors demonstrated that almond plants subjected to water shortage exhibited a high concentration of phytoprostanes (PhytoPs) and phytofurans (PhytoFs), which are plant markers of oxidative stress and own biological properties for human health [206]. Čolić et al., 2021 [209] attribute the drought tolerance of “GF 677” rootstock to the high content of flavanols.

The increase of temperature, due to climate change, may promote the increase of tocopherol content in almond kernels [200].

4.5. Peach (*Prunus persica* L. Batsch)

Peach (*Prunus persica* L. Batsch) as well other perennial crops require, for budding, chilly or low temperatures during dormancy [18,210]. Due to current global change, peach production in the south of the USA is under threat by warm winter temperatures [210]. Without the required chilling accumulation, reduction of flower quality, bad pollination, low fruit development quality and yield were observed [211].

Several authors have investigated the biological activity and positive implications of peach fruit consumption on antidiabetic and neurodegenerative diseases due to its phytochemical composition [212,213].

The quality and quantity of phytochemical compounds, as well as phenotypic variability among peach quality are affected by genotype, geographic, climatic conditions, seasonal and weather conditions [212,213]. For example, the anthocyanins content and antioxidant activity in peach “June Gold” cultivar increases with altitude [213]. Other factors such as seasonal climatic variability, day and night temperature, and wavelengths of solar radiation affected peach fruit development and quality [213–215]. Moreover, the availability of water affected the bioactive compounds, and the use of regulated deficit irrigation in peach cultivation enhanced the concentration of bioactive compounds in early maturing peaches [216,217]. The exposition of growing fruit to high CO₂ concentrations (360 ppm) increases sucrose, lactones, and norisoprenoid concentrations, and decreased malic acid content as compared to fruit control (without carbon dioxide enrichment). Similarly, Xi et al. [218] observed an increase of pyruvic acid, a precursor of volatile compounds, linoleic acid, and linolenic acid with a consequent improvement of flavor quality [219].

A model named “QualiTree” was used to describe the water stress effects on peach vegetative growth, fruit size, and composition [219]. The study showed that water stress reduces the dry mass of sprouts and leads to smaller fruit size. The reduction in fruit size was related to an increase of glucose and fructose concentrations, while sucrose content decreased with water deficit intensity [219]. In particular, water stress is critical during the last fruit development stages (Stage III of fruit development) with a reduction of cell expansion and fruit size, and an increase in soluble solids concentration that in some cases may improve the fruit quality [220].

With the increase in temperature, Hider et al. [221] observed a decrease in stomatal conductance and variation of metabolites such as increase of sorbitol and proline and decrease in glucose, fructose, and sucrose.

Warm temperatures lead to late leaves fall and affect the nutrient resorption and storage in young trees [222], with consequent late start of sap flow and floral bud-break in the following spring [222].

Since peach tree grows mainly on rootstock, Jimenez et al. [211] studied the physiological, metabolic, and transcriptomic response of rootstocks of peach to climate change variability. The authors found that the response to the impact of climate change in *Prunus* species was different; for example, elevated CO₂ increased photosynthetic rates in plants grafted on “GF677”, while in “Adesoto” rootstock acclimation was observed [211]. Regarding the impact of climate change on pests affecting peach, simulation models developed in India and Egypt predicted that the change in air temperature leads to an increase of generations of *Bactrocera zonata* peach fruit fly [223,224].

4.6. Apricot (*Prunus armeniaca* L.)

Apricot (*Prunus armeniaca* L.) is a climacteric fruit species mainly distributed in the northern temperate regions of the globe. In 2020, the world production of apricots was about 3,719,974 tons [4].

Some recent studies focused on physiological (and phenological) responses of the species as a result of climate changes, as well as the pathogen distribution and the influence of fruit yield and quality production [225,226].

The relationship between apricot yields and changes of both monthly temperature and precipitation nine years was studied in the Malatya province of Turkey [227]. Karakas et al. [227] suggested that unfavorable precipitations in April, due to climate changes, could lead to shedding in blossoms, a higher incidence of fungal diseases, and variations of fruit sugar composition, while temperature changes consequences could be loss of yield.

Frost events during bud swelling and bloom stages cause damages in generative organs with a clear consequence loss in fruit production [228,229].

According to Szymajda et al. [230] apricot flower buds exposed to constant low temperatures in winter are more resistant to severe temperature drops than peaches. On the contrary, apricot flower buds, during winters with relatively high temperatures, were more damaged by freezing injury with respect to peaches with consequent lower fruit yield.

The low apricot fruit yield recorded in some situations is genetically regulated but may even depend on seasonal variables like high temperatures during the chilling period [231,232]. Heat requirement, under Mediterranean climate, is necessary to regulate the flowering time [233]. In addition, it was observed that a cycle of chilling and heat requirements after partial chilling accumulation induced earlier budburst [234]. Despite the high variability of species regarding dormancy release period, in early cultivars it seemed to depend on daily minimum temperature while the intermediate and late cultivars, on daily mean temperature [235]. Moreover, vegetative and reproductive apricot buds need different chill requirements during the growing season [236].

The differential thermal analysis under laboratory-based freeze assays was used to evaluate the tolerance of floral organ structures in apricot trees to frost injury during late spring frosts. The response to frost damage was cultivar-dependent and, among flower organs the most resistant to low temperatures were the receptacle, pedicel, petal, stamen, and pistil organs [237]. Post-harvest thermal treatments can lead to losses of product quality but, in some cases, the use of high temperature for short time can improve the total phenols content in particular (–)-epicatechin, ferulic acid, and *p*-coumaric acid, and the color intensity [238]. Finally, warmer temperatures can lead to fruit physiological disorders such as sunburn, cracking, pit burn, and staining on the surface [227,239], as reported in other fruit species [16].

Other studies have addressed the issue of water stress on apricot species and of the use of deficit irrigation on several aspects of the apricot trees. In Mediterranean climate, the interval of water supply affected the trunk diameter, branch length, fruit weight, flesh firmness, flesh/seed ratio, and acidity of the fruit [240,241]. Indeed, the amount of water had significant effects on the cumulative yield and pomological features [240,241].

Bartolini et al. [242] in a study conducted on the most widespread Italian apricot cultivars evaluated the influence on floral morphogenesis, xylem vessel differentiation, and quality of flower buds of summer-autumn water deficit and re-watering. The authors reported that the reduction of photosynthetic processes due to the rise of leaf stomatal limitations can be reconstituted after re-watering of the plant contrary to floral differentiation damage, depending on the stress administration period [242].

The phenological stages timing variation affected pathogen distribution; Tresson et al. [243] using the Climatic Index of cumulated Blight risk with a phenological model suggested that under climate change future scenarios, the early cultivars could see a medium-term increase in blossom blight risk with respect to late apricot cultivars in Southern France. Whereas in late apricot cultivar, the risk may be less due to warmer and dryer blooming [243].

4.7. Cherry Species

About 400 species belong to the genus *Prunus* [244]. Actually, 13,635 *Prunus* spp. accessions (status: 30/6/2016) belonging to European collections are documented in the European *Prunus* Database as reported by Höfer et al. [21]. *Prunus avium* L., known as “sweet cherry”, and *P. cerasus* L., known as “sour or tart cherry” are the most important species from a commercial point of view [245,246]. The main producers of cherries are Asia (43%), Europe (37%), and America (18%) with Tunisia holding a production of 494,325 tons compared to 2.3 million tons total [247].

The phenology of *P.* species is strongly affected by climate. Sarisu, [248] reported that in *Prunus avium* L. a 1 degree increase of air temperature moved flowering and harvest forward by 4 and 8 days, respectively, thus affecting the yield and quality of sweet cherry fruit. Moreover, advanced flowering after the warmer winter months may increase the risk of spring frost [249]. Phenological data collected from 1970 to 2018 on sweet (*P. avium* L., Germersdorfer cultivar) and sour cherry (*P. cerasus* L., “Crisana” cultivar) grown in a temperate-continental climate revealed a phenology advancement. In particular, in the study, advance in bud swelling stage (code 51 BBCH Monograph) was observed with respect to full- and end-flowering stages causing severe risk of exposition to late frosts damages [250].

Even outside the Mediterranean area, climate change led to modifications of cherry trees phenology [251,252]. For example, the rising winter temperatures delayed the dormancy release and the first flowering date of “Yoshino” cherry trees (*Cerasus* × *yedoensis*) in Japan [252]. Nagai et al. [252] reported a possible decrease in the correlation between the first flowering date and latitude under global warming in the future.

The sweet cherry production in the colder climate is less resilient to climate change compared to crops grown in Southern Europe, because of the higher susceptibility to frost due to early flowering [253]. A relatively high amount of chilling during dormancy, followed by heating, is necessary for the flowering of cherry trees [250]. Noorazar et al. [251] suggested that under some climate projections the risks related to insufficient chilling accumulation as well as frost events would be more intense for early blooming crops such as cherry and varieties with relatively high chilling requirements. Moreover, insufficient chilling amount led to abnormal flower and low yields of sweet cherries in warm regions [254,255]. Indeed, for late-flowering cultivars of *Prunus avium* L., flowering dates did not change much because flowering appears to be mainly driven by temperature conditions during the chilling accumulation [255]. In warmer regions, temperatures exceeding the optimal threshold during flower bud differentiation can lead to an increase of double female organs reducing the fruit quality [256].

From the point of view of water stress, recent studies on the application of deficit irrigation were carried out on cherry trees. The deficit irrigation at several intensities applied in a commercial sweet cherry orchard (*P. avium* L.) in South-eastern Spain has not modified blossom, fruit set, growth, and fruit total soluble solids in any of the four years analyzed [257]. However, deficit irrigation decreased vegetative growth and consequently leaf area/fruit ratio [258]. In another study carried out in Spain, pre-harvest-regulated

water deficit caused a lower vegetative growth due to lower stomatal conductance and stem water potential than control (irrigated plants without restrictions at 110% of seasonal crop evapotranspiration) without influencing yield and fruit quality [259]. The sustained deficit irrigation in the same study led to the production of smaller fruits with a higher soluble solid content [259]. With severe water stress ($\Psi_{\text{stem}} < -2.0$ MPa) early defoliation, lower leaf turgor, and a lower vegetative growth occurred in the young sweet cherry plant. Moreover, an increase of the leaf insertion angle as a mechanism to reduce the incident solar radiation can occur [260]. A possible adaptation to a warmer climate might be the application of cherry rootstocks dwarfing that confers drought tolerance through greater stomatal regulation, increased abscisic acid content, and increased leaf and stem water potentials [261].

The precipitations cause the cherry fruit cracking [262,263] while high temperatures increase sunburn and cracking [262].

4.8. Fig (*Ficus carica* L.)

The cultivation of fig tree (*Ficus carica* L.) is widely located in the Mediterranean basin, and Iran is one of the most important producers of figs with about 20% of worldwide annual production [264]. The northern regions are considered for mild tropical fruit [265]. According to FAO [4], the world production was 1,264,943 tons in 2020. Fig fruit contains sugars, mainly glucose and fructose, and malic and citric acids as the main organic acids. Their concentration varies according to fruit pigmentation. Similarly, the anthocyanins content was higher in dark-colored figs as compared to light-colored fruit [266], with a prevalence of cyanidin 3-O-glucoside and cyanidin 3-O-rutinoside [266]. The physiological quality and metabolites contents of the fresh fruit are mainly affected by the temperature of storage after harvest and the combination with maturity stage [267].

Generally, the fig plant has a good adaptive capacity to abiotic stress in semi-arid conditions due to morphological and physiological responses of leaves [268]. Owing to its rapid growth, fig trees are considered drought-stress tolerant plants. Moreover, they show an adaptive behavior to prolonged water stress, responding through large leaf abscission and closure of stomata [269]. Moreover, when exposed to water stress, leaf expansion, thickness, inclination, and gas exchange modifications occurred [270]. Another strategy of defense is the maintenance of cell turgidity and cell membrane function due to increase in osmolytes [264]. The increase of proline content was reported in the leaves of the drought-tolerant fig “Aboudi” cultivar [271]. Abdolinejad and Shekafandeh, 2022 [272] have reported that the tetraploid genotype of Sabz cultivar has a higher water stress tolerance (in vitro) than diploid control plants involving changes at hormonal level (higher levels of abscisic acid, salicylic acid, and jasmonic acid) and in the enzymatic defense system.

Often the adaptation to drought is dependent on CO₂ concentration. The high CO₂ concentration enhances physiological and metabolic activities in the fig plant [264]. Moreover, under water stress an increase of enzymatic and non-enzymatic antioxidant systems [264,273] and pigments like anthocyanins and chlorophyll [274] are observed.

In two Tunisian fig cultivars (“Zidi” and “Bither Abiadh” cv) the imposed water stress for two weeks produced an increase in leaf temperature and leaf abscission and a reduction of photosynthesis rate, stomatal conductance, and transpiration rate, but after re-hydration in both cultivar, emergence of new leaves and restored photosynthetic system was observed [269]. Mlinarić et al. [275] have compared the response to a combination of high irradiation and high temperature in young and mature leaves of Figure. Mainly the authors have found that the acclimation of mature leaves to these conditions have decreased the chlorophyll content with a steady PSII functionality and stable level of Rubisco; indeed, in young leaves the oxidative damage was reduced owing to catalase and peroxidases activities, Rubisco degradation, and increased accumulation of total chlorophyll.

Salinity is another consequence of climate change that affects the yield and the quality of fig species. Fig is a moderately salinity tolerant plant. In the fig “Dottato” cultivar

the moderate salinization (100 mM NaCl for four weeks) improves the accumulation of antioxidants and nutrients. Moreover, in the same work the plants exposed to salinity water stress showed similar content of proline and fruit weight as those not exposed to stress [276]. In young plants of cv. Dottato exposed to moderate salt stress (100 mM NaCl added to irrigation water) a general increase in the transcript levels of genes involved in the synthesis and transport of soluble carbohydrates in the pulp fruit was observed [277].

4.9. Persimmon (*Diospyros kaki* L.)

Persimmon fruit (*Diospyros kaki* L.), belonging to the Ebenaceae family, is known as “Sharon fruit”, “Caqui”, “Kaki”, or “Japanese persimmon”. It is a fruit tree native to Central Asia and largely cultivated in the regions of the Mediterranean basin. Spain is the major European exporter of the fruit. Guan et al. described with a BHCC scale eight growth stages for this species [278]. The persimmon is a fibrous fruit and the pulp, without seeds, can be more or less astringent based on the solubility of tannins. It is rich in bioactive compounds such as fiber, vitamin C and A, carotenoids (as lycopene, b-carotene, and neoxanthin), polyphenols and minerals with benefits for health. Moreover, the nutritional claim of “sodium-free” can be used for this fruit [279]. The astringency of some fruit-type is due to proanthocyanidins, mainly epigallocatechin and epigallocatechin-3-O-gallate, having high antioxidant activities as reported by Butt et al. [280]. The Persimmon tree grown with high temperature and sun exposure, typical of south exposition, showed an increase of ascorbic acid, lycopene, and polyphenols content compared to those grown in the north [281]. In the early developmental stage, cool air temperature acts as a signal for the functional AST gene expression involved in proanthocyanidins pathways [282]. Regarding the effects of water stress, Buesa et al. [283] showed that the use of regulated deficit irrigation did not affect the yield.

4.10. Kiwi (*Actinidia* spp.)

The kiwi is a spontaneous plant in China. The commercial kiwi belongs to the genus *Actinidia*, such as *Actinidia chinensis* var. *deliciosa* (the green-fleshed kiwifruit), *A. chinensis* var. *chinensis* (the yellow-fleshed), and the kiwi berry *A. arguta*. Bardi [284] reported the preference to cold climate and higher altitudes climate for *A. chinensis* var. *deliciosa* and to warm climate for *A. chinensis* var. *chinensis*. Worldwide production was estimated at around 4,407,407 tons (data of 2020) [4].

The kiwifruit Italian production is concentrated in a limited area, and in the last years has suffered a sharp decline due to a syndrome namely “vine decline syndrome” [285,286]. Savian et al. [287] estimate about 25% of the Italian kiwifruit growing areas are irreversibly compromised due to decline syndrome. The rise in temperature during the summer season observed in Italy in recent years has contributed to the syndrome diffusion [284]. This syndrome can develop in presence of water pollution, pathogens, soil contaminants and waterlogging, and can quickly lead to plant death [286].

Although the water supply is necessary for kiwi cultivation, it was found that it is extremely sensitive to root waterlogging and soil anoxic conditions, leading to a plant weakening and pathogenic microorganisms’ attacks with final decline of the plant [287].

Kiwi is widely recognized as a fruit crop sensitive to water stress due to low stomatal regulation [288]. The high temperature of the soil led to a decrease of oxygen, modifying the metabolism of roots and reducing their growth with the formation of fibrous roots [289]. High summer temperatures promote vegetative growth reducing the fruit carbohydrate accumulation and flowering in the following season [290]. Moreover, the mineral fruit composition is affected by environmental conditions depending on phenological stages in *A. arguta* and *A. purpurea* species. The content of phosphorus, nitrogen, magnesium, and sodium in some fruit cultivars of these species was related to the sum of precipitation in the first phenophases, while the sodium content was significantly negatively correlated with the sum of temperatures during the flowering and fruit setting [291].

Due to climate change impact in the Central Himalayan Region, such as warmer winter season, precipitation variability, and frosts and storm, the kiwi temperate fruit crop is replacing the temperate fruit crops in hills that require high chilling [292].

5. Discussion and Conclusions

In the past decades, data on world fruit and vegetable yields showed constant increases with higher and faster growth with respect to the population [4]. This trend is justified by the growing integration of staple foods providing energy with other complementary foods, like horticultural commodities and oils of vegetable origin, in a more complete and variable diet.

The staple foods included in the “Mediterranean diet” are involved in a lower incidence of chronic diseases and improved longevity [5]. In this positive context, characterized by the objective of sufficient and healthy foods for everyone, it is also evident that vegetable production growth is at least twice with respect to fruit yield, and olive oil production only represents 4% of the market of oils of vegetable origin.

Worldwide olive oil production is constantly increasing, despite continuous fluctuations due to uncertainty of climate and alternate-year bearing [6]. The European Union comprises more than 93% of all the olive oil production in the world with three-quarters of world production concentrated in Spain, Italy, and Greece [6].

Perennial fruit and woody industry crops originate by complex decisions valuable in a long period and involving economic and technical problems that farmers may quickly change in the case of annual crops. It is clear also the possibility of a fast reaction to the ecological problems generated by climatic changes is more easily viable in the case of annual crop increasing or reducing the cultivated area of a specific species or cultivar. These adjustments are difficult in the case of woody fruit crops with a life cycle ranging from 20–25 to 40–50 years, such as in the olive industry, where the choice of rootstocks or cultivars originated by a serious and complex preliminary evaluation.

Tables 1–13 summarize the main results of this research considering the main effects of climate changes on physiology crops studied as well as production and quality fruits.

Table 1. Summary of principal effects of environmental conditions variation on the citrus crop.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
Water stress	• Increase of photorespiration • Increase of flower and fruit drop • Damage to chlorophyll	[72]
	• Alteration of fruit composition (increase of fruit acidity; reduction of fruit peel thickness; decrease of reducing and non-reducing sugars; accumulation of sorbitol and proline)	[62]
Drought stress	• Fruit splitting • Creasing of the peel	[63]
	• Lower carboxylation efficiency and higher oxidative damages	[64]
	• Reduction of chlorophyll contents	[71,81]

Table 1. Cont.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
High temperature stress	Reduction in acids and antioxidant activity in Kinnow mandarin	[67]
	Early breaking of dormancy with consequent exposure to frost	[68]
	Higher content of spermidine in self-pollination of <i>Citrus clementina</i>	[70]
	Lower maximal photochemical efficiency of PS2 and increase of antioxidant enzymes activities in Satsuma mandarin (<i>Citrus unshiu</i> Marc.)	[71]
	Increase of rate fruit drop at the end of winter	[79]
	Advancement of the fruit's maturity	[87]
	Higher alcohols and aldehydes content, and reduction of color break	[87]
	Delay in the beginning of the color break with poor coloration of the Citrus peel	[90]
	Reduction of anthocyanin accumulation in "Moro" blood oranges (<i>Citrus sinensis</i> L. Osbeck)	[95]
High temperatures with low relative humidity	Increase of the infestation of <i>Brevipalpus phoenicis</i> phyto virus	[88]
Low air temperature	Pitting and necrosis in the flavedo tissue of chilling-sensitive Citrus fruits	[72,73]
	Anthocyanins accumulation in red orange (<i>Citrus sinensis</i> L. Osbeck)	[94]
Excess light and high fluctuation densities of solar radiation	Sunburn in peel fruits	[66]
	Citrus fruit peel cracking or creasing that reduce fruit quality and production	[75,86]
Low light exposition	- Down-regulation of the expression of key carotenoids biosynthetic genes - Acceleration of peel degreening - Chlorophyll degradation - Reduction of chloroplastic-type carotenoids in "Clemenules" mandarin (<i>Citrus clementina</i>) and "Navelina" orange (<i>Citrus sinensis</i>).	[89]

Table 2. Summary of principal effects of environmental conditions variation on olive species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
Warm temperatures	Increase of air temperature by 4 °C anticipate the date of flowering	[101]
	Increase of the flowering period	
	Ovary abortion and reduction of fruit set	[102]
	Delay of full flowering date (from 16 to 29 days)	
	Increase of 4 °C led to a reduction of oil content due to delay in lipogenesis, a decrease of fruit size, increase of the size of trees, reduction of yield, due to a reduction of fruit set, and increase in ovary abortion	[112]
Drought stress	Influence of unsaturated fatty acids UFA content of microsomal membrane lipids	[119]
	Increase of the xanthophyll cycle de-epoxidation and vitamin E as defense mechanism and phenolic compounds	[110]
Water stress	Early bloom	[31]
	Higher tocopherol content in oil depending on the cultivar	[86]
Low temperatures with high rainfalls	Delay the fruit development and ripening with an improvement of olive oil quality.	[114]

Table 3. Summary of principal effects of environmental conditions variation on Loquat.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
Water stress	• Accumulation of sorbitol in favor of sucrose as a protective defense against leaf dehydration • Early blooming	[126,128,131]
Low temperatures (below 5 °C)	• Lignin accumulation and increase of fruit firmness • Flesh woodiness, adhesion of peel to the flesh, leathery and juiceless pulp, and internal browning	[124] [125]
Sunlight exposure and low temperatures	• Manifestation of purple spot physiological disorder during color-break stage of loquat fruit	[127]

Table 4. Summary of principal effects of environmental conditions variation on grape species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
Warm temperatures	• Influence of plant phenology, berry development, and high incidence of pests and diseases in red grape varieties	[141]
	• Microorganisms and mycotoxins proliferation, high alcohol content, high pH, low acidity, and high biogenic amines	[136]
	• Lower total phenols and anthocyanins content in grape berry	[145,146]
	• Reduction of the level of monoterpenes and pyrazines in ripe grapes, while increasing norisoprenoids concentrations	[136]
	• Reduction of yield production	[29]
Low leaf water potential	• In “Tannat” grape cultivar, an increase of the expression of CHS, DFR, and F3H genes with anthocyanins accumulation during harvest time	[142]
Water stress	• Early and high expression levels of anthocyanins and condensed tannins gene	[143,144]
	• Influence in the expression of 4889 genes of phenylpropanoid, flavonoid, carotenoid, and terpenoid metabolic pathways in white grapevine	[149]
	• Alteration of anthocyanins/TSS ratio	[150]
Drought	• Earlier shoot growth cessation, reduced berry size, increased content in skin phenolic compounds, lower malic acid concentrations, and modified aroma precursor profiles	[136]
	• Increase of the activities of antioxidant enzymes and nonenzymatic antioxidants	[148]
	• Increase susceptibility to <i>Plasmopara viticola</i> in Chardonnay cultivar inoculated in vitro	[38]
High atmospheric CO ₂ concentration and elevated temperatures	• In some “Tempranillo” clones cause a fast grape development, enhanced vegetative growth, and increased the labeled C content in the wood	[29]
	• Little effects on phenological phases and on grape quality as demonstrated by the stability of antioxidant properties and sugars and phenolic compounds content.	[20]
	• Alteration of anthocyanin concentration	[150]

Table 5. Summary of principal effects of environmental conditions variation on fig species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
Water stress	• Leaf expansion, thickness, inclination, and gas exchange modifications	[270]
	• Increase of anthocyanins and chlorophyll pigments	[274]
	• Increase of enzymatic and no enzymatic antioxidant systems	[264,273]
	• Large leaf abscission and closure of stomata	[269]
	• Increase of leaf proline content	[269,271]
	• Changes at hormonal level	[272]
High CO ₂ concentration	• Improve to physiological and metabolic activities	[264]

Table 6. Summary of principal effects of environmental conditions variation on Persimmon species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
High temperature and sun exposure	• Increase of ascorbic acid, lycopene, and polyphenols content	[281]
	• Reduction of signal for the functional AST gene expression involved in proanthocyanidins pathways	[282]
Water stress	• No correlation was found with fruit yield	[283]

Table 7. Summary of principal effects of environmental conditions variation on kiwi species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
Increasing air temperature	• Diffusion of syndrome “vine decline syndrome”	[284–287]
	• Decrease of oxygen modifies the metabolism of roots and reduces their growth with the formation of fibrous roots	[289]
	• Promote vegetative growth reducing the fruit carbohydrate accumulation and flowering in the following season	[290]
Waterlogging	• Plant weakening and pathogenic microorganisms’ attacks with final decline of the plant	[287]
	• The content of phosphorus, nitrogen, magnesium, and sodium in some fruit cultivars of these species was related to the sum of precipitation in the first phenophases, while the sodium content was significantly negatively correlated with the sum of temperatures during the flowering and fruit set.	[291]

Table 8. Summary of principal effects of environmental conditions variation on almond species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
Water stress	• Little influence on tocopherol concentration	[201]
	• Reduction of the kernel oleic/linoleic ratio	[201]
	• Reduction of oil content, oleic/linoleic ratio, oleic acid, and contents of extractable proteins	[209]
Warmer temperatures	• Earlier blooming with higher exposition to late spring frost	[202,203]
	• Diffusion of almond cultivation toward warmer regions and increase of tocopherol content in kernels	[200]

Table 9. Summary of principal effects of environmental conditions variation on cherry species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
Increasing temperatures	• Increase of air temperature by 1 degree moved flowering and harvest forward by 4 and 8 days	[248]
	• Delay in dormancy release and early flowering	[251,252]
	• Increase of double female organs reducing the fruit quality	[256]
	• Increase the risk of spring frost due to advanced flowering	[249,253]
	• Advance of bud swelling	[250]
	• Increase sunburn and cracking in cherries	[262]
Insufficient chill accumulation	• Abnormal flowering and low yields of sweet cherries in warm regions • Influence on blossom, fruit set, growth, and fruit total soluble solids	[163,164, 259]
Water stress	• Decrease of vegetative growth and consequently leaf area/fruit ratio • Lower vegetative growth due to lower stomatal conductance and stem water potential • Production of smaller fruits with a higher soluble solid content • Early defoliation, lower leaf turgor and a lower vegetative growth occurred in the young sweet cherry plant	[259,260]

Table 10. Summary of principal effects of environmental conditions variation on apricot species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
High precipitations	• Flower drop, a higher incidence of fungal diseases, and variations of fruit sugar composition	[227]
High temperature during chill period	• Loss of yield production	[227,230–232]
	• Sunburn, cracking, pit burn, and staining on the fruit surface	[225,227]
Frost	• Damage in generative organs during buds swelling and bloom stages	[228,229]
	• Stamen and pistil organs are the floral organs most susceptible to frost	[237]
Water stress	• Effects on trunk diameter, branch length, fruit weight, flesh firmness, flesh/seed ratio, and acidity of the fruit	[240,241]
	• Effects on cumulative yield and pomological features	
	• Damage to floral differentiation and	
	• Reduction of photosynthetic processes due to the rise of leaf stomatal limitations	[242]

Table 11. Summary of principal effects of environmental conditions variation on peach species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
High temperature during chill period	• Reduction of flower quality, bad pollination, low fruit development quality and yield were observed	[211]
	• Reduction of anthocyanins content	[213,216]
	• physiological disorders such as sunburn, cracking, pit burn, and staining on the surface	[227,236]

Table 11. Cont.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
Water stress	Moderate water stress improves the concentration of bioactive compounds in early maturing peaches	[216,217]
	Reduction of sprouts dry mass	[219]
	Reduction of size fruit with an increase of glucose and fructose concentrations, while sucrose content decreased with water deficit intensity	[219]
	When occurs during stage III of fruit development, reduction of cell expansion and fruit size, and an increase in soluble solids concentration were observed	[220]
Warm temperatures	Decrease of stomatal conductance and a variation of metabolites such as increase of sorbitol and proline, and decreases of glucose, fructose, and sucrose.	[221]
	Cause leaves to drop and affect the nutrient resorption and storage, delaying in the following spring, senescence of young trees with the late start of sap flow and of floral bud-break.	[222]
	Increase of generations of <i>Bactrocera zonata</i> peach fruit fly	[223,224]

Table 12. Summary of principal effects of environmental conditions variation on apple species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
High temperature during chill period	Acceleration of flowering and fruit harvesting	[3,152]
	Early flowering in cold areas while in Mediterranean areas could lead to delay in flowering date despite a faster heating phase.	[153]
	Early blooming may affect apple taste and textural attributes and may determine a reduction of acid concentration, fruit firmness, and watercore development	[155]
	Higher incidences of alternate bearing in apple trees in the cool Nordic climate	[158]
	In Iran was estimated in the 2090s a loss of apple orchard area and cultivation shifting to higher regions of Iran	[161]
	In Southern Romania, in the last 50 years highlighting advances of 13.8 days for the bud swelling, 14.8 days for the budburst, 10.7 days for the beginning of flowering, and only 7.3 days for the end of flowering	[162]
	In cold climate (Germany), it was observed an advance of 10 days for full bloom, 11 days for harvest, and 4 days for leaf drop in the later phase, resulting in five days longer growing period for "Golden Delicious"	[160]
	Influence of pest distribution (as <i>Cydia pomonella</i>, <i>Erwinia amylovora</i>, <i>Diplodia seriata</i>)	[39,164]
	Reduction of anthocyanins genes transcripts in apple peel	[173]
	Strong reduction of both peel anthocyanin concentration and transcripts factor MYB10, regulator of anthocyanin genes biosynthetic pathway.	[174]
Water stress	- Moderate water stress applied after the fruit expansion improves the content of total soluble solid and soluble sugar (fructose, glucose, and sorbitol) and reduces the titratable acidity. - Increase of sorbitol in pear and apple juice exposed	[167]
UV-B radiation	Affects anthocyanins biosynthesis	[168]

Table 13. Summary of principal effects of environmental conditions variation on pear species.

Variation of Environmental Parameters Due to Climate Change	Main Effects on Crops Physiology and Fruit Production	References
Drought stress	- Reduction of physiological responses such as a lower leaf relative water content, net photosynthetic rate, stomatal conductance, transpiration rate and intercellular carbon dioxide concentration - Reduction of nutrients accumulation and the inhibition of fruit development	[179,180]
Temperatures	Flower buds under low temperatures showed a higher sugar (glucose-6-phosphate in particular) and polyol levels	[185]
	Influence on the aroma of pear fruits associated with volatile compounds	[192]
Light	High temperatures lead to anthocyanin degradation	[194–196]
	Influence of anthocyanins accumulation	[194,197]
Water stress	Moderate water stress in an arid tropical climate improves fruit production and quality	[175–177]
	A long-time deficit irrigation reduces fruit and improves soluble solids content and a potential increase of storability without adverse effects on plant physiological performances	[177]
	Increase of the number of fruits a disadvantage of fruit size.	[178]
	No effects were found on fruit features such as fruit firmness, chlorophyll and carotenoids, color index, phenols content as well as sugars and acids content.	[176]
	Reduction of leaf area, surface, and LAI	[178]

However, the low flexibility of woody crops is balanced by many factors of resilience and in the long-life cycle by some elements of adaptability due to a wide range of phenology arrangements and elastic responses to physiology stresses [53], as well as to the possible application of crop management measures aimed to mitigate the climate change effects. According to Vico et al. [293], with the shift toward perennial crops, the greater depth of the roots allows greater use of soil water resources and reduced yield variability compared to annual species but showed higher and more variable irrigation requirements and lower water productivity. Moreover, perennial crops can reduce soil erosion and leaching of nutrients and sequester more carbon in the soil [294]. More than two-thirds of global cropland is occupied by annual crops and the area occupied by annual species continues to expand, with a consequent threat of soil degradation and biodiversity, and more necessity to use fertilizers and pesticides [294].

In the research programs, it is fundamental to evaluate the adaptation possibilities generated by the increase of the natural resilience of existing crops, as well as by a new planning of the crop geographic distribution, with an examination of species and cultivars diversity under a different perspective [295]. In the first case, a good database on the consistency of physical modifications of the growing environment and sufficient intraspecific biodiversity should be available, while optimization of the use of technical tools of environmental mitigation, such as water supply for irrigation and plant cover with films and nets for radiation and precipitations control [296–298], is a complementary objective of this approach. In the second case systematic observation of woody plant phenology [299,300], and careful monitoring of micrometeorological data and physiological stresses symptoms will be the basic elements of the research strategy.

Recent scientific literature showed high availability of data and models applicable to herbaceous crops, which provide most food energy, proteins, and lipids for human nutrition [301–304]. Less information is available on horticultural crops and even less on woody perennial crops. The logical distinction between evergreen and deciduous species

is justified, because of the marked start and end of the rest periods in deciduous, while evergreens showed higher flexibility with respect to anomalous meteorological events.

Species of equatorial and tropical origin [305–309] seem less studied with respect to those of temperate areas, excluding the case of citrus, grapevine, apple, and olive which are the most studied species [31]. Some authors focused on new definitions and calculations of phenology stages [310] and the differences are documented in the new trends. Other studies concerned the stress physiology as an expression of the plant reaction to temperature and rain regimes modifications. Substantially, however, a strong concentration of the research efforts seems still focused in the tentative to measure the consistency of direct effect of climate change on crops [33], while few contributions are oriented to propose and test tools for a response to the adaptation needs. In this direction, it is possible that a more intense elaboration of prevision models for the crop behavior and a wide application of the precision agriculture practice will be useful tools for the future of woody crops as well as of other plants [30,311,312].

In a context of significant air temperature increase, actually one of the most important focuses of the research programs is the possibility to increase the growing areas of some crops with the new establishments in cold regions. This evolution is theoretically possible but should be geospatially, economically, and logically studied in the Mediterranean region, where this translation is mainly possible in the south-north direction. The complex physiology of the woody fruit species supposes adaptative mechanisms that involve not only temperature dynamics but also sensitivity and dependence by radiation intensity and quality. The olive species is probably the clearest example in this direction, with a strong sensitivity to the reduced radiation of the north regions of Mediterranean area where the trees of this species are small and with progressive problems of scarce flower bud differentiation.

The studies on perennial crops highlighted the key role of dormancy on fruit crops production and the influence on it of climatic parameters. Dormancy is a mechanism implemented by most temperate woody perennials to avoid the negative impact of winter season. The effects of climate change on dormancy of perennial crops are a major issue and object of numerous studies and reviews during recent years [234,313,314]. Different approaches such as physiology, genomics, proteomics, and metabolomics were used through the years to study this defense mechanism [315]. The seasonal cycle of perennial crops is divided into paradormancy, vernalization, endodormancy, and ecodormancy of axillary and apical buds and is influenced by photoperiod, temperatures, cold-acclimation, and heat-acclimation [316]. Heat and low water availability stresses reduce the growing period of the crops [313]. The winter rising temperatures can cause different effects on deciduous crops by advancing or delaying phenological stages such as flowering, fruit ripening, or leaf senescence depending on the species [317]. For example, in tropical and subtropical areas, the increasing temperature alters the chill requirement and dormancy breaking. In this condition, Salama et al. [7] reported some tools to allow the adaptation of perennial crops in this area under future climate scenarios, the development of organic compounds with dormancy breaking effect, and improving dormancy and chilling forecasting models are some examples. Chmielewski et al. [318] reported that in cold-climate as in Germany, in the future, due to climate change the dormancy of several perennial fruit crops may be released in advance to ensure a timely start of reproductive development.

Effect of climate changes on plant pathogens and pest diffusion is a strong emergency but studies are still limited; while the study of changes affecting the quality of commodities is increasing only for the big industries of fruit processing, like wine and olive oil. Despite the nutritional importance of fresh fruit and as a consequence of the large variability of species, information on the quality modification consequent to climate changes is now limited [319–322]. Over the past 30 to 40 years, the effects of several environmental factors and/or a combination of factors have been studied with different approaches have been evaluated as reviewed by IPCC [323]. The relationship between pathogens and climate change is non-linear and difficult to predict as well as illness food-derived [324]. The effects

of climate change on plant pathogens and pest diffusion are probably easier to predict for the pest species affected by only one climatic variability than for pests strongly related to more climatic factors [325]. However, a study on single factor experiments does not reflect the complexity of climate change and could provide inaccurate information about the true pattern of pathogen distribution under new climate scenarios [324].

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