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Review

Securing Horticulture in a Changing Climate—A Mini Review

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Abstract: (1) Background: Climate change is on the rise due to continuous greenhouse gas emissions from anthropogenic activities ever since the industrial revolution. Changing weather conditions are likely to have consequences for horticulture. (2) Objective and Methods: A short literature review was conducted, gathering findings on climate change and the impacts on the yield and product quality of special crops. (3) Results: Global warming will result in elevated temperatures and CO_2 concentrations in all seasons. Extreme weather events such as heat waves are also on the increase. In vegetables, physiological processes such as vernalization and winter chilling strongly rely on temperature. Therefore, heat stress may cause irregularities in yield production and planning the harvest. For fruit crops, frost poses a risk that is enhanced through climate change, as does a lack of chilling, as cold temperatures in the winter are required for flowering in the spring. Abiotic disorders in horticulture are also related to changing temperatures and humidity. The nutritional quality of special crops may be threatened by increasing rates of plant development and premature ripening at high temperatures. Quality traits such as sugars, acids, or antioxidant capacity may also shift as well. (4) Conclusions: Adapting to these new climate conditions means developing new climate-resilient varieties to maintain high production levels with superior quality. In this mini review, cultivation measures to mitigate adverse climate impacts are also discussed. Current developments and recent findings are presented, pointing out further steps toward adaptation and sustainable production.

Keywords: bolting; climate change; flower advancement; frost; global warming; tip-burn; vernalization; water use efficiency

1. Introduction

Climate change may be progressing faster than expected, bringing new environmental conditions for growing horticultural crops. Climatic changes are associated with an increase in atmospheric CO_2 through the combustion of fossil fuels, leading to an increase in global mean temperatures [1]. This leads to changes in weather patterns across the globe, with regional differences [2]. Nowadays, extreme weather events such as heat waves or frost are already showing their impacts in some regions. Elsewhere, extended drought periods will become an increasing issue, which is a serious threat to global food security. Climate changes could be positive or negative; however, they will certainly change the circumstances of production and product quality. In a previous review, both the benefits and constraints of climate change on vegetable production were summarized [3]. Moreover, Bisbis et al. [4], Gruda and Tanny [5], and Gruda et al. [6,7] described the effects of protected cultivation on climate change and vice versa, while the interaction between climate change and soilless cultures was described by Gruda [8]. In this paper, we review the implications that are potentially triggered by climate change with the aim of providing ideas for countermeasures to mitigate the negative impacts, and we focus more closely on adaptation to climate change.

2. Materials and Methods

A systematic literature review was conducted, searching the platforms Google scholar, Scopus, and Web of Science for a combination of the following keywords: "climate change", "extreme weather events", "heat waves", "late frost", "horticulture", "elevated CO_2", "vernalization", "winter chilling", "water scarcity", "water-use efficiency", "quantitative trait loci (QTL) for stress resistance", and "disorders and stress". Papers that included the most recent findings on climate change as well as papers that investigated the effects of high and low temperatures, CO_2, and drought on horticultural crops were selected for this review. Furthermore, we included papers dealing with the most recent findings in plant breeding for stress tolerance and resistance. We focused on those papers that were not yet included in previous reviews by Bisbis et al. [3] and Gruda et al. [6,7].

3. Results

3.1. Elevated CO_2 Changes Yield and Produce Quality

Climate change arises alongside the accumulation of CO_2 and other greenhouse gases in the atmosphere emerging from the combustion of fossil fuels. The review by Bisbis et al. [3] showed that increasing atmospheric CO_2 can have benefits by increasing CO_2 influx to the leaf, while concomitantly reducing stomatal conductance. This results in higher yields at a reduced water loss, thereby increasing water-use efficiency. Long-term exposure to elevated CO_2 may also affect product quality [9], e.g., enrichment in sugars, ascorbic acid (vitamin C), and higher antioxidant capacity, but possibly a decrease in some macronutrients and micronutrients in leafy vegetables, such as magnesium, iron, and zinc [10].

3.2. High Temperatures Accelerate Plant Development

High temperatures speed up the plant development rates of vegetables, which accelerates organ development, e.g., from flowering to fruiting. Then, the harvested products often turn out to have undesirable traits. Tomato fruits that grow under high temperature are usually smaller in size with higher dry matter content. In broccoli, heat can cause disorders and malformations such as uneven heads with over-sized flower buds, even at temperatures of only 25 °C [11]. During this head formation stage, heat caused bracting in sensitive cultivars [12], and temperatures above 25 °C at harvest induced premature ripening with loose heads [11]. High temperatures also produced inhomogeneous and less sweet heads, but increased flavonol content and shifted glucosinolate composition in florets [13].

3.3. Winter Chilling in Asparagus

With increasing temperatures throughout all seasons, climate change interferes with the chilling requirements in some horticultural crops. Winter dormancy might be inhibited under the influence of global warming, which can affect the yield of perennial vegetables. For instance, asparagus enters dormancy and accumulates cold temperatures of 0–7 °C over the cold period [14]. Dormancy was described to consist of two phases: (i) the induction of dormancy and accumulation of cold temperatures, and (ii) the breaking of dormancy through the accumulation of high temperatures. Feller [15] showed that a too-warm temperature during the first dormancy phase extended the length of the second dormancy phase, leading to delayed and reduced yields (Table 1). The duration of dormancy was 15 days longer for asparagus when the temperature was increased by 3 °C, i.e., from 2 to 5 °C [14], and the effects on yield were reductions in bud break and spear production.

Table 1. Examples of adverse climate change effects on vegetables.

Incident	Source	Adverse Effect	Affected Crop	Reference
Lack of chilling	Lack of cold temperatures during the winter	Delayed spears Reduced spear growth	*Asparagus*	[15]
Lack of vernalization	Lack of cold temperature during vegetative growth	Delay of head formation	Cauliflower	[16]
Warm and dry periods	Pressure to complete life cycle	bolting	Lettuce	[17]
Warm and dry periods	Lack of Ca transport	Tip burn, blossom end rot	Lettuce, Tomato	[17]

Based on the recent finding of Kaufmann and Blanke [2], more forcing can partially substitute for lack of chilling (Table 2). Warmer temperatures in spring or longer periods of warmer temperatures due to climate change may override the lack of cold temperatures in winter that induce flowering. Growers in countries such as Germany, where asparagus production is widely established, could learn from growers in regions where adequate chilling temperatures are never reached. In Japan, Yamaguchi and Maeda [18] successfully studied breaking dormancy with high temperatures. To completely break dormancy during the forcing stage, high temperatures of 28 °C for four days or more resulted in more rapid spear growth. These results indicated that high temperatures such as 28 °C could break asparagus dormancy within a shorter period than chilling temperatures (5 °C). However, when temperatures persisted too long, e.g., 15–20 days, negative effects on yield were observed due to accelerated sugar depletion. For example, such high temperatures were achieved by heating the soil-dams where white asparagus are grown in, but this would require high energy input and costs. The possibility of heating up the dams through the application of new covering materials could be further investigated. Furthermore, European cultivars must be studied to elucidate their response to higher temperatures and the applicability of these techniques in Europe.

Table 2. Examples of adverse climate change effects on fruit.

Incident	Source	Adverse Effect	Affected Crop	Reference
Lack of chilling	Lack of cold temperatures during the winter	Delayed flowering and increase in risk of frost	Apple and other fruit crops	[2]
Frost	Slight increase in the risk of frost	Damage to flowers and fruitlets, yield loss	Cherry, apple, apricot, others	[19]
Sunny and hot periods	Rise of fruit temperature >50 °C	Sunburn	Apple and other fruit crops	[19]
Warm and dry periods	Insufficient water supply to the fruit	Smaller and softer fruit, less fruit color	Apple and other fruit crops	[19]

3.4. Vernalization in Cauliflower

The accumulation of cold temperatures in young plants is known as vernalization, and is the prerequisite for flowering in some species. Above 12–16 °C, flower induction in vegetables is impaired due to the absence of vernalization, which can be desired or undesired. In cauliflower, head induction occurs only after a period at 7–10 °C, and higher temperatures may induce a delay in heading (Table 1). Head formation occurred 49 days later when the temperature was raised 2.9 °C above ambient [16]. In summer, this frequently causes irregularities in market supply due to the absence of cauliflower heads during extended periods of heat, with a subsequent overload of the market when temperatures returned to their seasonal average [3].

To counteract insufficient vernalization in cauliflower, farmers usually turn on their irrigation system to create a cooling effect. Indeed, Kaiser et al. [20] showed that this practice could temporarily reduce the canopy temperature by about 3 °C. However, the temperature rose back to the initial value a few hours after the treatment. An accelerative effect on curd formation was not observed, despite the cooler temperatures. Furthermore, the excessive amounts of water could cause buttoning as well as nitrate leaching and a subsequent reduction in yield due to the absence of nutrients in the soil [20]. During their experiments, the authors noted that their plots in northern Germany were more suited to grow cauliflower in summer as compared to their plots in the south of Germany. Hence, the choice of the location could become more important in a future influenced by climate change, while cooling irrigation could be omitted to save water.

3.5. Extreme Weather Events Reduce Yield and Produce Quality

3.5.1. Temperature Extremes

Extreme weather events include both extremely hot and low temperatures, and this is to be seen in relation to the season and the mean temperature of the month. As such, frost temperatures in April as well as temperatures above 30 °C in summer are extreme weather events. Extreme weather also includes events that are not directly related to temperature, but rather to the intensity and form of precipitation or wind speed. This can be hail or heavy rainfall during storms or drought periods. Climate scenarios generally predict an increasing frequency of extreme weather events, but with regional differences in their nature and intensity. For instance, in a simulation study on climate extremes under a global warming of 1.5 °C, 2 °C, and 3 °C, Teichmann et al. [21] showed that a substantial increase in dry days occurred mainly in southern Europe, while an increase of extreme precipitation prevailed mainly in mid-Europe and northern Europe under 3 °C warming.

3.5.2. Heat Waves

The probability of heat waves doubled in Europe over recent decades, with likely further increases in their future frequency and duration [1]. Heat spells are characterized by temperatures exceeding 30 °C and intense solar radiation, and can be both extremely humid or dry. In summer 2018, temperatures rose as high as never before, not only in the Mediterranean area, but also in Central and North Europe as well, where otherwise moderate temperatures dominated in summer. For instance, in Germany, the year 2018 was the warmest since the beginning of weather recording, with an annual mean temperature that was 2.2 °C above the mean of the reference period from 1961 to 1990 [22]. Throughout Europe, it was the third warmest year, and temperature elevation ranged from 1 to 3 °C [22]. Figure 1 gives an overview of the distribution of temperature anomalies during that spring and summer. Particularly, July and August were shaken by long-lasting heat waves.

According to Teichmann et al. [21], the number of hot days and tropical nights over Europe was simulated to substantially increase in southern Europe (25.8 days/29.6 nights), e.g., Iberian Peninsula, but under a 3 °C warming, even mid-Europe will be affected (3.4 days/3.8 nights). Scandinavia was the only place where a significant increase in the number of hot days and tropical nights was not observed [21].

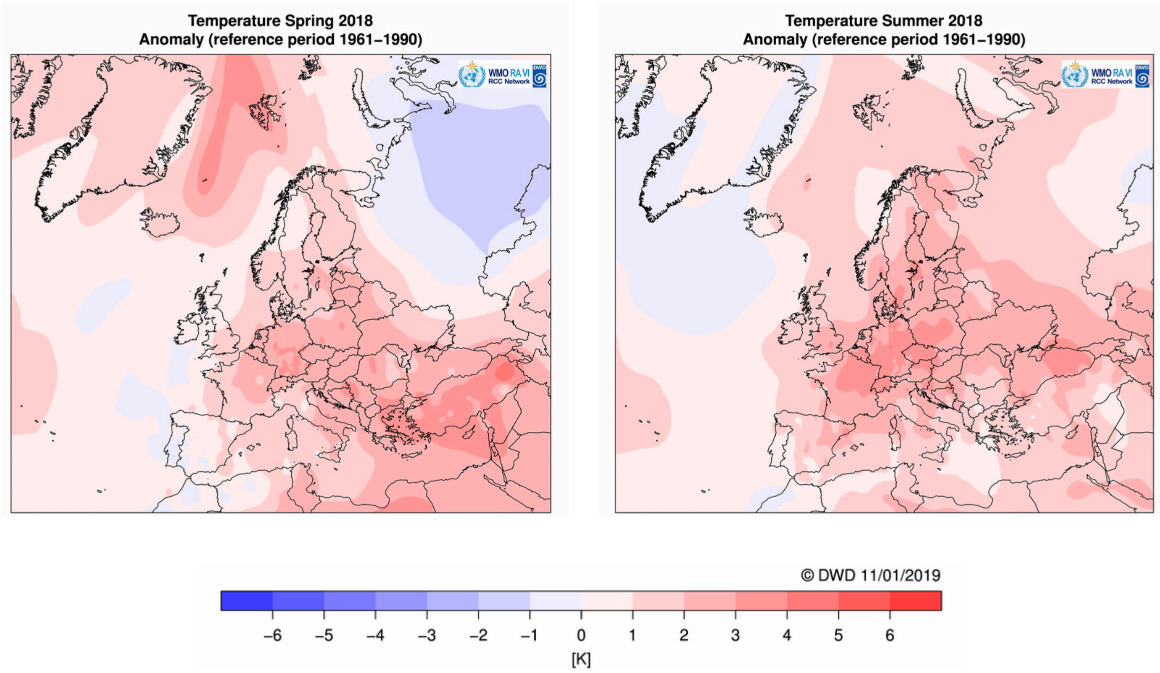

Figure 1. Deviation of the seasonal mean temperature in 2018 from the mean temperature of the reference period of 1961 to 1990, over Europe. Climate maps are provided by the German weather service, Deutscher Wetterdienst, (DWD) [23].

In horticulture, heat waves can have serious impacts on plant growth, yield, and product quality. Open field vegetables are directly exposed to excessively high temperatures and radiation during heat waves. The lack of protection against stress commonly leads to physiological disorders related to calcium (Ca) uptake. Ca is taken up only through the transpiration stream, and has limited mobility within the plant. Under hot temperatures, the plants transpire excessive amounts of water, directing all the Ca in the transpiration stream to the leaves where transpiration takes place. In lettuce, this frequently causes tip burn, since Ca does not reach the growing tip and the enclosed leaves, causing necrosis on the edges of new leaves [24]. In fruiting vegetables such as tomato or pepper, blossom end rot occurs as a result of low transpiration causing a lack of Ca allocation to the fruits.

3.5.3. Droughts

In agriculture, droughts are usually defined as periods where transpiration and evaporation exceed the amount of precipitation. As an example of a drought year, 2018 is presented in Figure 2. In Germany, it was one of the driest years since 1881, with 10 months of insufficient precipitation, producing a deficit of around 200 mm per m^2 [22]. The frequency of such drought years is expected to rise in future scenarios. According to Teichmann et al. [21], the number of dry days over Europe was simulated to substantially increase in southern Europe (13.1 days), e.g., the Iberian Peninsula, but under a 3 °C warming, even mid-Europe will be affected (e.g., 9.4 days on the British Isles). Scandinavia was the only place where a decrease of dry days was observed compared to the current situation [21]. As plants require water for their metabolism, drought periods can have fatal consequences for crop production, as crops could fail completely, or in the best case, reductions in yield and product quality arise. There is a tendency that heat waves and drought will be a phenomenon for 2019 as well. For instance, in Germany and some other European countries, June 2019 was the hottest month ever. If so, we predict that the yield and quality of produce for different horticultural crops will be reduced. Depending on irrigation capacities, the yield of lettuce and carrots is expected to be about 25–30% less than usual. In addition, vegetables and fruits such as peas, apples, and pears will generally be sweeter, but smaller. Thus, consumers and markets will probably have to change their expectations, regarding marketable size.

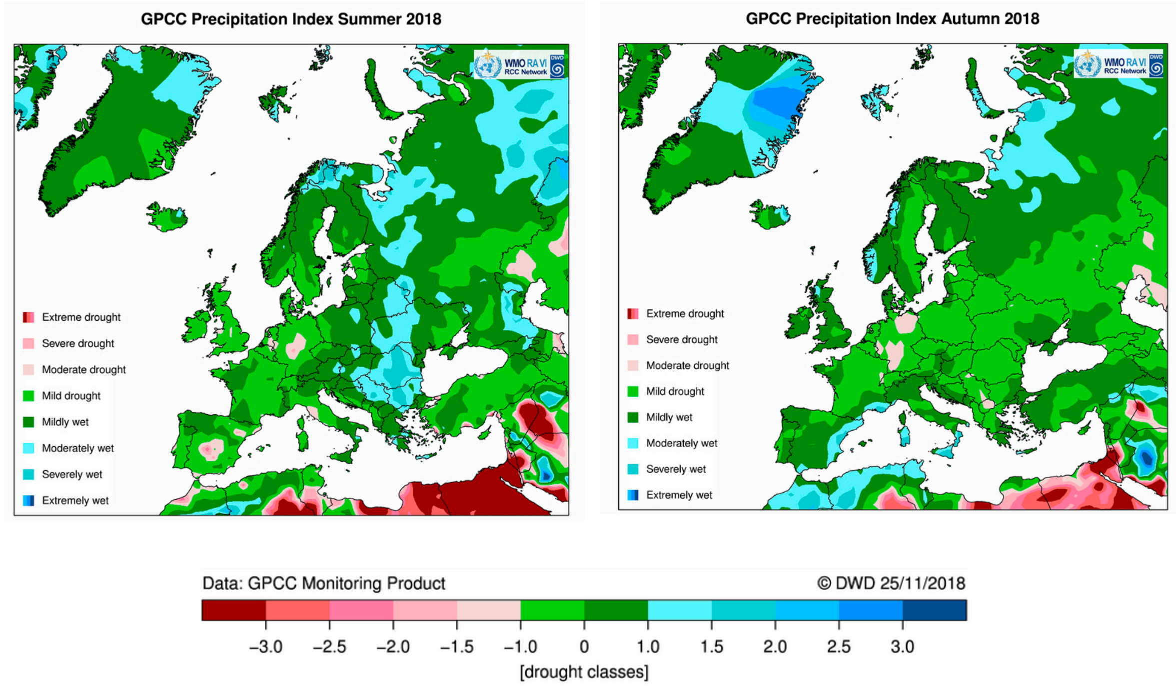

Figure 2. Distribution of the precipitation index (drought index) in summer and autumn in 2018 from the German weather service DWD [22], with permission. The precipitation index is calculated using weather, evaporation, and transpiration data, among others.

Lettuce tip burn is linked to Ca uptake and heat-induced disturbances in Ca allocation within plants are not the only cause for tip burn. Insufficient water uptake from the soil can also cause insufficient Ca uptake. Périard et al. [25] attempted to link the occurrence of tip burn in lettuce to soil water relations, and concluded that soil water flow velocity has a dominant role. At specific thresholds, water flow velocity in the root zone becomes insufficient to meet plant needs, which can lead to tip burn, as shown in romaine lettuce [25]. In experiments with different types of lettuce, Eriksen et al. [17] showed that tip burn occurred most often in crisphead lettuce, while cos and butterhead lettuce was largely tolerant.

Under drought conditions, plants typically reduce growth and reallocate resources to set flowers and seeds to achieve maturity quicker and reproduce before severe drought stress turns out to be lethal. In lettuce, the stage before flower induction is called bolting, and is caused by the elongation of the flowering stalk from the core. Bolting results in an increased bitterness in the lettuce leaves and poor head shape, both of which are less desirable in most lettuce types, excluding stem lettuce. Premature bolting could also occur under high temperatures [26]. Eriksen et al. [17] investigated the effects of drought and heat stress in different types of lettuce, i.e., butterhead, cos, crisphead, green leaf, red leaf, and stem lettuce, and different cultivars of all the latter. Cos lettuce was among the varieties that were most affected by bolting followed by stem lettuce, where it is desired.

From the perspective of pest and diseases, fungal diseases would have more difficulty developing under drought conditions, while pests would have it much easier. First, many insects are thermophilic. Second, fruit trees that are weakened from drought would be generally less resistant to insects and other pests.

3.5.4. Early and Late Frosts

Simulations have shown that climate change may cause an advance of the date of last spring frost in some selected regions such as the Czech Republic, yet the benefits of a reduced frost risk derive primarily from the delay in the date of first frost in autumn [27]. Although climate change extends the season and reduces the incidence of frost events, they cannot be completely excluded in the future [1]. This might cause substantial trouble for producers, as it becomes increasingly difficult to predict such events. Frost that occurs after an initial period of warm temperatures may cause substantial damage to flowering trees and early vegetables (Table 2). A warm early spring in 2017, a result of recent climate change [19], led to a 10–14 day advance in flowering throughout Europe. Then, a late frost on 19–20 April 2017 destroyed most of the apple, pear, cherry, and plum flowers or fruitlets from Poland to France and from Germany to South Tyrol with a resulting 60–65% smaller fruit yield [28]. The type of frost was a radiation frost, so that only heaters and overhead and under canopy sprinklers effectively reduced the damage where applicable, whereas wind machines became redundant. Figure 3 gives an overview of the dimension of the cold wave in 2017.

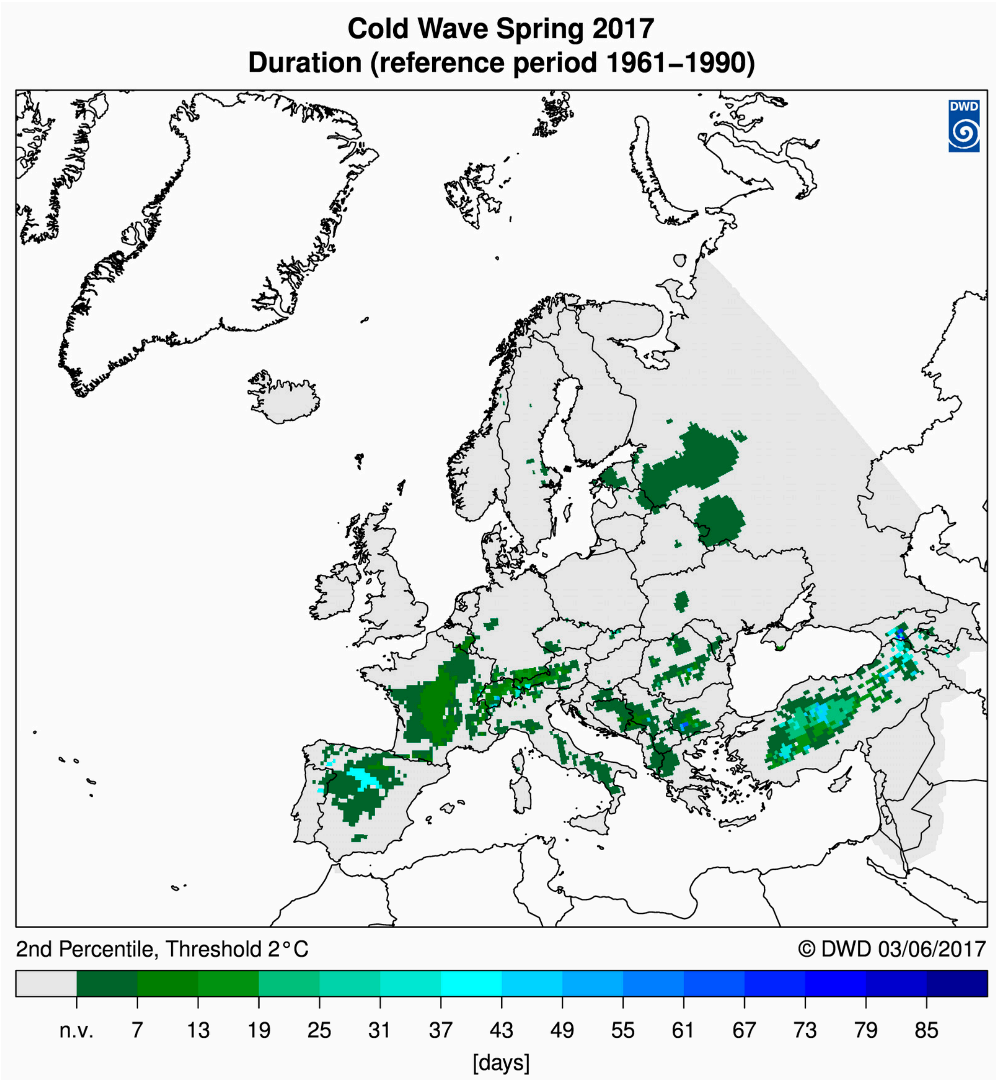

Figure 3. Duration of the cold wave in spring 2017 according to the German weather service, DWD [22].

In conclusion, the effects of elevated CO_2 could positively affect yield, but might also reduce product quality in some cases. Temperature effects as well as extreme weather events turn out to generally have negative effects. These effects are summarized in Table 1 for vegetables and Table 2 for fruits.

3.6. Breeding New Cultivars to Guarantee Yield and Product Quality

The most important issue in counteracting climate change is to breed new cultivars that are resistant to the impacts that heat and drought stress bring. In particular, this means breeding tip burn and bolting resistant cultivars that produce stable yields despite high temperatures. Breeding for tip burn resistance has turned out to be one of the most challenging disciplines, as there are numerous causes for this disorder, and the quantitative trait loci (QTL) are not yet fully resolved. Furthermore, there is a trade-off between resistance and the speed of growth, which results in lower yields of resistant cultivars [29]. Simko and Hayes [26] emphasized that plant architecture could have an enormous influence on the occurrence of tip burn, especially in romaine lettuce. A more open growth leads to less tip burn. However, this is not applicable for all lettuce, i.e., varieties where a closed head is required. For those cultivars, identifying QTL that are independent of plant architecture is a major issue [26]. Premature bolting occurs under drought and high temperatures, and resistant cultivars are known, although the genetic background of the trait remains obscure [26]. Breeding goals may need to include a greater focus on the selection of fruits and vegetable cultivars with low chilling needs and stronger frost resistance.

To address the challenges posed by climate change, there is an increasingly urgent need for the investment of greater resources and efforts in safeguarding the widest possible diversity of plant genetic resources in their natural habitats in situ, on farms and in gene banks ex situ [30]. In addition, new cultivars have to be productive and have an acceptable product quality, and this is not always the case [6]. Therefore, the use of genetic materials coming from local biodiversity is an important issue. In addition, in terms of a self-production concept for small farmers, vegetable seeds could be produced directly from the garden. Since these seeds have been developed in specific environment settings, they would likely be more tolerant to fluctuations in climatic conditions. An expected impact of climate change is an increased occurrence of extreme weather events [6,30].

3.7. Modifying Cultivation Practices

Another approach to reduce the adverse impacts of climate change is to modify the production systems themselves. In lettuce, Uno et al. [29] showed that growing a few indicator cultivars that are tip-burn sensitive could act as an early warning system to rescue the main crop where tip burn occurs a few days later. In a plant factory, the authors applied Ca fertilization after the indicator cultivar showed signs of tip burn. Thereby, yield was raised in a range of 4% to 70% [29]. In the open field, Ca might have to be applied by foliar spray, as mineral nutrients can be absorbed through foliage. However, foliar applications of Ca did not always prevent tip burn due to other factors, such as rapid growth using up the Ca quickly [29]. The authors suggested that factors such as the concentration, amount, and timing of the spray applications should be the subject of further investigations. In regions where bolting in lettuce is a problem, growers could shift to more resistant types and cultivars. For instance, romaine and crisphead lettuce are suitable alternatives to more bolting-susceptible lettuce types [26].

To combat problems with water scarcity, innovative irrigation water management methods such as partial root zone drying and deficit irrigation techniques have to be tested for different horticultural crops [31]. Subsurface drip irrigation could contribute to an increase in water-use efficiency [32]. Furthermore, agroecological approaches such as organic and conservation agriculture or inter-cropping systems are of interest, as they increase crop resilience to extreme weather events and can save water as well as increase yields when managed correctly [33].

4. Conclusions and Outlook

Global warming will result in elevated temperatures and CO_2 concentrations and more extreme weather events. The impacts on horticulture are summarized in Table 1. While increasing CO_2 might increase yields and the antioxidant content of vegetables in the future, elevated temperatures will most likely have negative outcomes. In vegetables, heat stress may cause irregularities in yield and planning of the harvest due to disturbances in physiological processes such as vernalization and winter chilling. For fruit crops, frost poses a risk that is enhanced through climate change as is a lack of chilling. The quality of special crops may be threatened by increasing rates of development, premature ripening at high temperatures, and projected increases of pest populations. Nutritional quality in terms of sugars, acids, or antioxidant capacity will shift as well. Both heat and drought stress cause tip burn and premature bolting in most lettuce cultivars. Climate change will increase the occurrence of heat and drought periods, especially in southern Europe, which implies that in the future, substantial financial losses to producers are to be expected. Adapting to these new climate conditions means developing new climate resilient varieties to maintain high production levels and high product quality. Another more practical approach is the design of new cultivation practices that can be implemented quickly and without major expenses. On the other hand, more sophisticated solutions such as agroecological approaches become increasingly important to improve the resilience of specialty crops in the field.

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