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Editorial

The Adaptation of Crops to the Environment under Climate Change: Physiological and Agronomic Strategies

Rosa Porcel

Instituto de Biología Molecular y Celular de Plantas, Universitat Politècnica de València-Consejo Superior de Investigaciones Científicas, 46022 Valencia, Spain; roporrol@upv.es

As the world population is increasing continuously, there is a constant reduction in global arable land due to an increased demographic pressure. Anthropogenic global warming is having an impact on climate variability, global temperatures, the biochemical and nutritional states of soil, and sea levels. The current measured temperature has been raised by an average of 0.6 ± 0.2 °C since 1900, and is increasing faster than expected. According to the European Copernicus Climate Change Service, the summer of 2022 was the warmest and driest in Europe and the second-warmest in the Northern Hemisphere since climatological records began.

Plants suffer stress mostly as a result of environmental changes, which are considered to be the most deleterious factors affecting agricultural production, not only in low- and middle-income countries, but also in the lowlands of these countries. Climate change increases the presence of carbon dioxide in the air and also the temperature of the environment [1]. The individual climate-change-inducing stressors for plants are abiotic in nature [2], and they impose stress upon most plant species. Some abiotic plant stressors include drought, salinity, elevated CO_2, and temperature (low and high), among others. A higher frequency of extreme events, such as high temperature, drought episodes, and floods, can harm crops and reduce yields. These are major constraints to food supply and a balanced environment, leading most researchers to look for physiological and agronomic adaptation strategies for plants under these conditions. Several solutions have been proposed, including breeding for drought or salt tolerance [3], the use of biostimulants [4], arbuscular mycorrhizal fungi [5], or using nanoparticles to increase the abiotic stress response [6].

This Special Issue, "Adaptation of Crops to the Environment under Climate Change: Physiological and Agronomic Strategies", compiles five original research articles that address different strategies for coping with a climate change scenario. These solutions come from the evaluation of crops' physiological performance under several abiotic stress conditions, the application of compounds to increase stress tolerance or productivity under adverse environmental conditions, and the use of agronomical strategies, such as co-inoculation with two specific microorganisms, to improve the efficiency of an intercropping strategy.

This Special Issue includes contributions by research groups from Denmark, China, Pakistan, Tunisia, and Colombia. As such, it provides new insights into the different strategies that are currently being applied in very different agroecosystems and with different crops.

The paper authored by Zeitelhofer et al. [7] evaluated the physiological performance of different chickpea (*Cicer arietinum* L.) genotypes that were contrasted in their thermal stress tolerances during the flowering phase. In the experimental design, they used different cold and heat conditions, (9/4 °C) and (38/33 °C), and four chickpea genotypes for 3 days. Then, they measured several physiological parameters, such as chlorophyll fluorescence, gas exchange, leaf pigments, and carbohydrates. Their main points were that cold stress reduced the maximum quantum efficiency of photosystem II (F_v/F_m) by 5%, the net

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photosynthetic rate (P_N) by 74%, and the chlorophyll a + b content by 31% on average in all the tested genotypes. Under cold stress, up to a 9-fold increase in the amount of starch was found, indicating that carbohydrates strongly accumulated in chickpeas under such conditions. However, no such accumulation was shown under heat stress. On the other hand, the chickpeas maintained their F_v/F_m and P_N, although their chlorophyll a+b content decreased by 30% on average under heat stress. The authors also found a genetic component. Desi and Acc#2 were cold-sensitive candidates, and Eldorado was a cold-tolerant candidate, whereas Acc#7 and Acc#2 were heat-sensitive candidates, while Desi and Eldorado were heat-tolerant candidates. This study provides important knowledge about the physiological responses of flowering chickpeas under cold and heat stress. This will benefit the identification of stress-tolerant chickpea genotypes, in order to ensure high yields under the novel conditions that are imposed by anthropogenic global warming.

The paper by Zhu et al. [8] proposed the use of foliar applications to enhance the abiotic stress response. Specifically, the authors investigated the effects of spraying wood vinegar on the physiology and biochemistry (growth, photosynthesis, osmotic adjustment, and antioxidant enzymes) of rapeseed seedlings, specifically under low-temperature stress. The authors concluded that the spraying of wood vinegar could alleviate this low-temperature stress by improving the antioxidant enzyme activity (the superoxide dismutase increased by 27%) and the osmolyte concentration (the proline and soluble sugar content increased by 208% and 115%, respectively), reducing the stomatal conductance (which was 9% lower), and enhancing the water use efficiency (which increased by 83%).

Among the abiotic stresses, drought has been shown to have harmful effects on crop productivity worldwide, and this has affected arid and semiarid lands such as the Mediterranean Basin and Asian countries like Pakistan, due to rapid climate change scenarios. Drought interferes with both normal plant development and growth, and has a major adverse effect on plant survival and productivity. In their contribution to this issue, Gul et al. [9] applied melatonin (MEL) as a pretreatment with irrigation water at different doses (0, 100, and 200 μM), using maize plants as the subject of their study. The authors investigated the biochemical responses of the plants, including the responses of the antioxidants, plant pigments, leaf water characteristics, and yields. The findings of their study revealed that the Chl a, b, and a + b contents, as well as the carotenoid concentrations, significantly increased with the MEL applications during severe and mild drought stress. After applying 200 μM of MEL, the leaf water, measured as the relative water content (RWC), leaf water content (LWC), and relative saturation deficit (RSD) increased by 1.9%, 100%, and 71.2%, respectively, during mild drought, and 17%, 133%, and 32% under severe drought. The antioxidant activities of POD, CAT, and APX were remarkably enhanced by the MEL during drought stress. These results showed that the root application of 200 μM of melatonin boosted the seed yield and water productivity by 31% and 38%, and that the plant biomass increased by 32% and 29% under mild and severe drought stressors compared with the plants with no MEL, leading to an increased drought tolerance.

Due to growing demographic pressure, increases in crop yield are a major requirement that is constrained by climate change. An increase in planting density could be an effective strategy to combat this, and has been studied by another paper of this issue. Previous studies have revealed that the ethylene that is produced by plants under dense standing conditions is among the other factors that affect crops' growth performance and reduce legumes' ability to fix nitrogen (N). Toukabri et al. [10] identified a *Pseudomonas thivervalensis* strain T124 as a high ACC deaminase-producing microorganism, and evaluated its potential ability to alleviate the effects of reduced light (RL) and exogenous ethylene (applied as the ethylene precursor ACC) on clover growth and development. These experiments were performed under controlled and field conditions at dense stands of intercropped clover and oats. The authors found that RL decreased the biomass of the clover's roots and shoots, whereas the T124 strain counteracted these RL effects, enhancing the clover's tolerance to shade. On the other hand, when they combined it with the *Rhizobium leguminosarum* strain T618, the T124 strain prevented early nodule senescence by improving the nodule's leghemoglobin and reducing the nodule's nitric oxide levels. An additional outcome of this study was that a co-inoculation with T124 + T618 increased the shoots' N content (+24%) more than the T618 alone. They also found interesting effects under field conditions; for instance, upon the T124 inoculation, the clover's net photosynthetic rate (Anet) and stomatal conductance (Gs) improved with respect to the control and T618 inoculation treatments. Additionally, the clover exhibited an improved growth performance in terms of its branching and nodulation after the T124 inoculation, but surprisingly, the most significant improvements occurred when the two strains were co-inoculated. The data suggest that the co-inoculation of the *R. leguminosarum* T618 with the *P. thivervalensis* T124 potentially decreased the interspecific competition between the clover and the oats by reducing the ACC (ethylene precursor) levels. Thus, we have an elegant description of a biological strategy to enhance the intercropping performance.

Finally, we present a paper on a crop that is very important in the Andean Region and has become popular in western countries over the recent years: Quinoa (*Chenopodium quinoa*). Due to the accelerated expansion of quinoa cultivation in recent years and the great diversity of the cultivars that are available, there are few descriptions of the interactions among these different cultivars, which leads to agronomical problems that affect the cultivar adaptation and, subsequently, the yield. To address this major issue, García-Parra et al. [11] evaluated the physiological performance of seven quinoa cultivars under three altitude gradients in the central region of Colombia (cold, temperate, and warm climates). A highly differential performance between the phenological, physiological, and compositional variables was shown, mainly between the quinoa cultivars that were planted in cold climates and those that were established in temperate and warm climates. It was determined that the altitudinal gradient was the main determinant for the performance of the quinoa cultivars. The results that were obtained support the notion that the physiological performance of quinoa depends largely on the surrounding edaphoclimatic environment, which influences the different agronomic and compositional parameters of the seeds. Another important result of this study was that the authors were able to identify two large groups for the quinoa cultivars. The first group was made up mainly of the Nueva and Soracá cultivars, while the second group included the Nariño and Puno cultivars.

Thus, this Special Issue includes five contributions that bring new insights into six major crops (chickpea, clover, rapeseed, oat, maize, and quinoa) and different agronomical strategies (intercropping, biostimulants, and cultivar selection), in order to enhance yields under abiotic stress conditions, which is a growing concern due to climate change. The papers in this Issue may be of interest, not only for plant physiologists, but also for farmers and breeders that are looking for information to increase their production efficiency.

Data Availability Statement: Not applicable.

Conflicts of Interest: The author declares no conflict of interest.

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