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Editorial

Physiological and Molecular Characterization of Crop Resistance to Abiotic Stresses

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Abstract: Abiotic stress represents a main constraint for agriculture, affecting plant growth and productivity. Drought and soil salinity, especially, are major causes of reduction of crop yields and food production worldwide. It is not unexpected, therefore, that the study of plant responses to abiotic stress and stress tolerance mechanisms is one of the most active research fields in plant biology. This Special Issue compiles 22 research papers and 4 reviews covering different aspects of these responses and mechanisms, addressing environmental stress factors such as drought, salinity, flooding, heat and cold stress, deficiency or toxicity of compounds in the soil (e.g., macro and micronutrients), and combination of different stresses. The approaches used are also diverse, including, among others, the analysis of agronomic traits based on morphological characteristics, physiological and biochemical studies, and transcriptomics or transgenics. Despite its complexity, we believe that this Special Issue provides a useful overview of the topic, including basic information on the mechanisms of abiotic stress tolerance as well as practical aspects such as the alleviation of the deleterious effects of stress by different means, or the use of local landraces as a source of genetic material adapted to combined stresses. This knowledge should help to develop the agriculture of the (near) future, sustainable and better adapted to the conditions ahead, in a scenario of global warming and environmental pollution.

Keywords: salinity; drought; heat stress; flooding; nutrient stress; ROS; cold stress

1. Introduction

Abiotic stress represents the main constraint for agriculture, affecting plant growth and productivity worldwide. Yield losses in agriculture will be potentiated in the future by global warming, increasing contamination, and reduced availability of fertile land [1]. The challenge of the present and future agriculture is to increase the food supply for a continuously growing human population under environmental conditions that are deteriorating in many areas of the world. Minimizing the effects of diverse types of abiotic stresses represents a matter of general concern [2].

The study of abiotic stress tolerance mechanisms is one of the most active lines of research in plant biology, given its undoubted academic interest and practical implications in agriculture. The different types of abiotic stresses imposed by the environment usually are interconnected and often have an osmotic component, affecting plant cell homeostasis [3].

To counteract abiotic stress, plants activate a series of stress responses, which are shared by both sensitive and tolerant plants as they use the same basic effectors [4]. The knowledge of the limits of tolerance to abiotic stress of different crops, and the understanding of their mechanisms of response to increasing environmental constraints are gaining importance in agronomic research [5]. Research on crop abiotic stress responses is diverse, as plants undergo specific changes in their gene expression, metabolism, and physiology in response to different environmental stress conditions [6].

In this Special Issue, 22 research papers and 4 reviews are presented covering different aspects of the responses of plants to abiotic stresses and their mechanisms of tolerance. However, what is considered abiotic stress? We can define it as any physical or chemical constraint to the potential development and growth of a plant not involving interactions with other living organisms. Abiotic stress in plants is a vast subject, which can be addressed from different points of view and includes many different components, mainly environmental factors, for instance: soil, water, climate, irradiation—even the moon influence! Plants have evolved a series of physiological and molecular mechanisms of response that may (or may not) allow them to adapt to and survive this broad range of stressful conditions. Understanding those mechanisms will help us to improve our interventions towards a more sustainable and efficient agriculture.

2. Drought and Salinity

Drought and salinity are major abiotic stresses that affect agricultural yields worldwide. The more frequent, longer, and more intense dry periods in many regions of the world, due to global warming, are associated with increasing salinization of land cultivated under irrigation. About 20% of irrigated land in the world, producing one-third of the global food, is affected by secondary salinization of the soil [7]. Drought and salinity have a common osmotic component and early responses to these two types of stress are practically identical [8]. Besides, salt stress causes ionic stress and Na^+ toxicity [3]. Like other types of stress, drought and salinity or their combination may trigger growth inhibition, including, for example, disturbances in mineral nutrition, alteration of membrane permeability and cellular osmotic balance, generation of oxidative stress by increasing reactive oxygen species (ROS) levels, or inhibition of different enzyme activities [9–11].

In the Special Issue is included a review on physiological changes under drought conditions that influence yields in several vegetable crops summarizing changes in the stomatal conductance and chlorophyll content of leaves for individual plants, but also the utility of water stress indices and spectral vegetation indices for predicting yields [12]. An overview by Ketehouli et al. [13] on the effects of salinity on plants and their tolerance mechanisms with particular emphasis on K^+ and Na^+ homeostasis and transport and their regulation is also here included.

Plants defense against abiotic stress starts within their roots [3], and a well-developed root system is essential to provide water uptake [12]. The ability of plants to change their root anatomy was found to improve water uptake and transport in peanut and, therefore, may be considered as a relevant drought tolerance mechanism in this species [14].

This Special Issue includes several papers on morphological, physiological, and biochemical responses to these two types of stress or their combination, and their use in screening for stress-tolerant cultivars. Increased activities of ROS-scavenging enzymes and a more balanced Na^+: K^+ ratio was reported as the main mechanism of tolerance in wheat and barley [15]. Accumulation of proline and monovalent cations was related to salt tolerance mechanism in cultivated eggplant and its wild relative *Solanum insanum* [16]. Of special interest is the screening of neglected varieties and local landraces, as they can be a valuable source of allelic richness. Landraces evolved due to selection of traits specifically adapted to local conditions, often suboptimal or even highly stressful [17]. Therefore, such genotypes may enhance agronomic production under the foreseeable restrictive conditions imposed by climate change [2]. Proline was the marker used for screening of beans tolerant to water and salt stress [18], or antioxidant for salt-tolerant tomatoes with high nutraceutical value [19]. Proline and chlorophyll contents, in combination with several morphological and physiological traits, are optimal markers for screening drought tolerance in provitamin A maize, used in sub-Saharan Africa to combat vitamin A deficiency [20].

The irruption of transcriptomics, metabolomics, high-throughput DNA sequencing and high-density microarrays in the analysis of plants' responses to stress have brought new insights and allowed a better understanding on plants reactions to stressful conditions [21]. The stress-responding genes and their regulation pattern under drought were analyzed in common buckwheat cotyledons and roots [22] and female panicles in maize [23], and under salinity in roots and leaves of pomegranate [24].

Others papers published here deal with mitigation of the effects of drought in different crops, such as the synergistic effect of silicon and inoculation with an arbuscular mycorrhizal fungus on strawberries [25], transfer of a LEA gene of a Vietnamese maize landrace to transgenic maize and tobacco [26], and that of salinity by salicylic acid, yeast extract, and proline in sweet pepper [27].

3. Other Significant But Less Studied Stresses

Global warming alters the rainfall regime in many areas of the world [28], leading to increased floods and poorly drained, waterlogged soils; these conditions have a negative effect on crops by reducing oxygen availability for roots and soil microorganisms [29]. Escape and resilience strategies under flooding stress are presented in an extensive review, concluding that plants maintain their internal homeostasis by balancing hormonal cross-talk under excess water stress [30]. Besides, some treatments can help plants to cope with the stressful effects of waterlogging, for example, seed priming by sodium azide (NaN_3) was found to enhance the performance of okra plants under waterlogged conditions [31].

Extreme temperatures pose another challenge for crops. Irregular weather patterns have increased their occurrence in the present climatic conditions; for example, more frequent heat waves are now reported worldwide [28]. One paper deals with the effect of heat stress in alfalfa and extensively discusses the effects of heat on plants [31]). In addition, cold is also a common stress which triggers sophisticated events that alter the biochemical composition of cells in order to protect them from damage [32,33]. Again, some treatments can reduce the negative effects of low temperatures. This is the case of studies on the physiological performance of plants, in which cold stress was alleviated by chitosan via enhancing the photosynthesis and carbon process in tea plant [34], or by 5-Aminolevulinic in cucumber [35].

4. Combination of Different Stresses

Usually, abiotic stresses come together. The association of drought and salinity is well known, but also that of drought with high temperatures. When different stresses combine, plants need to adjust their physiology to those specific conditions. Landraces, through their long process of farmers' selection in a pre-intensive agriculture period, offer a great opportunity to find appropriate combinations of genes and phenotypes tolerant to complex situations. The most stressful period in the Mediterranean region is summer, when drought is associated with increased temperatures, including heat waves, which are increasingly more frequent in recent years [36]. A comparative study on the responses of local landraces and a commercial cultivar of *Phaseolus lunatus* L. to different temperature and water stress regimes is presented here. The results indicated a better response and a marked competitiveness of one local cultivar [37]. Effects on agronomic traits of the same stresses and their combination was analyzed in African landraces of maize compared with drought and/or heat-tolerant lines [38], and some local landraces proved to be good candidates for improving stress tolerance in this crop.

5. Soil Constrains

Besides soil salinity, discussed above, there are several other soil constraints with an important impact on agriculture [39]. Of special interest are those related to nutrient conditions in the soil, such as soil P immobilization. Phosphorus is an essential element for plants, but is lacking in 40% of arable land. This nutrient is normally applied as P-enriched fertilizers, which contribute to increased eutrophication of water bodies [40]. Therefore, screening for cultivars with a good performance under low P-input conditions is of interest, as shown by an analysis of morphological traits in relation to P accumulation in pepper cultivars [41]. Zinc is a microelement necessary for plants, animals, and humans; when it is not present in the soil in sufficient amounts, it is necessary either to use varieties with a better uptake of this micronutrient, or its external application in the form of fertilizers and foliar sprays [42].

However, when in excess it has a toxic effect for plants [43]. Morphological and physiological traits, in combination with the transcriptional regulation of aquaporin isoforms expression, were analyzed in pak choi subjected to two Zn concentrations [44].

Nitrogen is necessary for plant development; it is required in large quantities and, therefore, supplied to crops in fertilizers [45]. Nevertheless, an excessive N application was reported to decrease ROS scavenging ability, and to cause significant metabolic changes in wheat [46]. In the same species, the use of new ecofriendly polymeric-coated urea fertilizers insured a balanced proportion of N with beneficial effects [47].

Another paper deals with abiotic stress in crops imposed by treatments with herbicides and explores the possibility to control weeds with three natural compounds, analyzing the phytotoxic effects that they produce in weeds. The tree products demonstrated great possibilities as sustainable tools for integrated weed management [48].

Finally, this special issue also includes a review on some questions and beliefs that still impregnate a large part of agricultural traditions and agronomic practices, according to which the different lunar phases are beneficial or stressful to plant growth and development [49]. To address the possible link between the phases of the moon and agriculture from a scientific perspective, the authors analyzed physics and biology research papers and handbooks, focusing on those abiotic factors that have a proved influence on plant growth, searching specifically for any that could explain the influence of the moon on plant growth. They did not find any reliable, science-based evidence for such a relationship.

6. Conclusions

The papers included in this special issue cover a broad range of topics related to the effects on crop plants of different types of abiotic stress, at the morphological, physiological, biochemical, and molecular levels, and the mechanisms of defense of the plants against these stresses. The methods employed were also diverse, from the analysis of agronomic traits based on morphological characteristics to omics approaches and the use of transgenics. Special attention was given to the screening for stress tolerance in local landraces, stress alleviation using different strategies, and the proposal of practical solutions for the agriculture of the (near) future, threatened by global warming and environmental pollution.

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