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Cereal drought adaptation strategies

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Abstract

Water stress prevents all cropping systems from reaching their production potential. This stress is likely to be amplified by increased climate variability. Cereals, food crops and staple foods for most of the world's population are significantly affected by drought. By 2050, grain production must increase by about 70% to meet global food needs. However, current studies of adaptive strategies to mitigate the effects of water stress remain limited. Varietal adaptation and the development of new ones, as well as the adoption of appropriate cropping practices, are among the solutions being considered. To reinforce and support these approaches, new ecological and natural methods, including the use of biostimulants, could be adopted for efficient management of production systems and to limit yield losses under stress conditions. In this context, this review focuses on the main cereal adaptation strategies to drought.

Keywords: Adaptation; Cereals; Drought; Management

1. Introduction

In Tunisia, cereal farming is the main speculation of the agricultural sector due to the importance of the fields it occupies and its contribution to food security of the country. It is one of the main sources of calories in the human diet [1]. However, cereal production is characterized by very large regional and annual fluctuations and is subject to several biotic and abiotic environmental constraints [2]. Among these constraints, drought is the most limiting factor of plant production, especially in a semi-arid climate characterized by low annual rainfall (200–400 mm), erratic and generally poorly distributed. In Tunisia, this constraint is exacerbated by the increased occurrence of extreme weather events, high and low temperatures in spring [3]. An average annual temperature increase of 1.1°C and an acute annual decrease in precipitation will be observed in future years (GTZ 2007) [4]. According to Amamou et *al*. [3], water resources will decline by 28% and arable land by 20% by 2030. Faced to these climate changes, the adoption of several techniques for water and soil conservation (crop rotation, use of cover crops, crop residue management, seeding density, pest and weed control, soil fertility management, and proper equipment selection) do not appear to be effective. Drought management measures are very important and must focus on extracting available soil moisture and increasing biomass and grain yield. In order to mitigate the impact of these climate changes, especially drought, new strategies can be considered, such as cultivation practices (precision agriculture, crop association, etc.), genetic selection and varietal creation. Other complementary alternatives can also be considered to mitigate the negative effects of drought stress, including the use of growth regulators, osmoprotectors and biostimulants, etc.Thus, this review describes the drought adaptation strategies.

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2. Selection of tolerant varieties for water stress

2.1. Conventional and traditional breeding method or classical breeding

Drought tolerance is a complex trait, controlled by multiple genes and its expression is affected by the environment, genotype and environment interaction. Therefore, improving this character requires the integration of diverse selection and breeding strategies [5]. Over the past decade, several efforts have been made to develop drought tolerant wheat varieties through different breeding methods. In wheat breeding programs, research into high-yielding varieties under water deficit conditions has been a priority to improve their drought tolerance [6]. The selection of durum wheat for water stress tolerance is based on the evaluation of yield potential of lines tested by multi-environment screening. Such an evaluation will provide the opportunity to select stable yield lines.

Several morphological traits were useful in plant breeding programs: plant height, harvest index, precocity, etc. [7]. In addition, various drought tolerance indices such as drought susceptibility index (SSI), stress tolerance index (STI) and geometric mean productivity index (GMP), for the selection of the most drought tolerant varieties might be used [8]. Using grain yield under stressed and non-stressed conditions, these indices are effective tools for selecting high-performing and stable varieties [9, 10]. In fact, on this basis, Fernandez[11] and Etminan et al. [12]classified genotypes into 4 groups: i) high-performing genotypes under stressed and non-stressed conditions, ii) high-performing genotypes under stressed conditions, iii) high-performing genotypes under non stressed conditions, and iv) low-performing genotypes under stressed and non-stressed conditions.

According to Ayed et al. [13], tolerance indices and genotype ranks are also useful tools for screening drought-tolerant genotypes with a high adaptation capacity to contrasting environments

2.2. In vitro selection

Improving drought tolerance requires the integration of some biotechnological techniques [5]. The *in vitro* culture is considered as an important complementary approach to select drought-tolerant genotypes[14]. This technique facilitates the selection of tolerant varieties at early growth stage [15]. Compared to conventional field selection, *in vitro* culture minimizes time and space requirements and environmental variations [16, 17]. In wheat, Kacem et al. [18] reported that various plant cells, tissues or organs (mature and immature embryos, anthers, apical meristem, etc.) were used to study the cal*in vitro* response to water stress. These authors have shown that mature and immature embryos appear to be the most effective technique. In addition, Haliloglu et al. [19] reported that immature embryos exhibited better cal embryogenic induction compared to mature embryos. Several parameters such as callus morphology, callus induction and growth rate were used for genotype screening under water stress induced by thePoly Ethylene Glycol (PEG),an osmotic substance that is not penetrable and non-toxic to plant cells[16, 20, 21].

3. Complementary irrigation

The scarcity and variability of rainfall, as well as the need to mitigate the effects of drought, have led to the emergence of the concept of complementary irrigation [22]. In recent decades, it seems to be an appropriate alternative that has the potential to improve crop productivity and reduce yield variability [23, 24]. In fact, cereal complementary irrigation has become a necessity rather than a choice [25, 26]. It is an efficient technique that saves water and takes into account precipitation amount, soil water storage and crop needs during different growing stages [27]. Irrigation based on crop needs is an important way to reduce irrigation water loss and to improve water use efficiency [28]. In addition, complete supplemental irrigation is intended to provide a quantity of water equal to the difference between crop water requirements and effective precipitation. It provides favorable conditions to produce maximum yield if the other inputs are optimal. This can be achieved by monitoring soil water and irrigating just before water stress begins. This strategy can provide maximum benefits to the farmer when water resources are available and can be delivered at low cost. Indeed, Sharma et al.[29] found a substantial improvement in yield (by 50%) with additional irrigation in dry rainfed areas. In addition, irrigation done once or twice can increase grain yields by 37.5% and 84.55%, respectively [30]. However, in areas where water is scarce, additional irrigation is not recommended as it is not sustainable [31].

4. New approaches for improving drought tolerance

New ecological and natural methods, based on healthy and natural tools for the environment and living organisms, could be an alternative to overcome the impact of this stress. Among these new strategies, the use of biostimulants. Biostimulants are not considered fertilizers because they do not provide enough nutrients. In general, they can be classified into different groups: (i) humic substances, (ii) complex organic matter (obtained from agro-industrial and urban waste, sewage sludge extracts, composts, and manure), (iii) beneficial chemical elements (for example, aluminum [Al], cobalt [Co], sodium [Na], selenium [Se] and silicon [Si]), (iv) inorganic salts, including phosphite, seaweed extracts, and (v) beneficial microorganisms such as mycorrhizal and non-mycorrhizal fungi, bacterial endosymbionts (for example, *Rhizobium*) and plant-growth promoting rhizobacteria (PGPR)[32]. Biostimulants may be products containing a mixture of vitamins, antioxidants (glycines, prolines, protein hydrolysates, as well as certain amino acids), and/or osmoregulators, with possibly other components, having a combined action of growth stimulation and protection against abiotic stress [33].

4.1. Use of growth regulators

Exogenous application of growth regulators could be another important approach to improve plant tolerance to abiotic stress. The use of these substances could help plants to maintain water balance and fair chlorophyll content during drought [34]. For example, Kareem et al.[35] showed that foliar application of salicylic acid and molybdenum improves the performance of two Iraqi wheat varieties under water deficit conditions. In the same context, Dwivedi et al. [36] found that foliar treatment of growth regulators such as thidiazuron, paclobutrazol and ascorbic acid improved grain yield and its components in wheat. These regulators showed a positive interaction and a synergistic effect on photosynthetic machinery and yield under water stress. In addition, abscisic acid (ABA) plays an important role in drought tolerance [37]. Its exogenous application has resulted in increased grain weight in wheat cultivars [38].

4.2. Use of osmoprotectors

Compatible osmoprotectors or solutes are small molecules of low molecular weight, electrically neutral, highly soluble and non-toxic at molar concentrations [39]. These compatible solutes can stabilize proteins and membranes to prevent cell dehydration [40]. They can be classified into three groups: osmoprotectors containing ammonium compounds (polyamines, glycine betaine, b-alanine betaine, etc.), osmoprotectors containing sugars or alcohols (trehalose, fructane, mannitol, etc.) and osmoprotectors containing amino acids and their derivatives (proline and ectoin) [41]. They play an adaptive role through osmotic adjustment and protection of cellular structures in stressed plants. According to Slama et al. [42], not all plants accumulate these compounds in sufficient quantities to avoid the harmful effects of water stress. Inhibition of endogenous synthesis of polyamines limits stress tolerance in wheat, but their exogenous application restores it [43]. Ebeed et al. [44] reported that exogenous application of polyamines protects wheat plants from water stress by increasing water content and accumulating osmoprotectors in plant cell. Similarly, foliar application of proline and gamma-aminobutyric acid is chosen as a useful approach to optimize wheat performance under terminal drought [45]. These solutes improved chlorophyll levels, stomatic conductance, accumulation of proline and glycine betaine, and reduced malondialdehyde levels in plants under water stress conditions [46]. Similarly, application of glycine betaine improved the weight and number of grains and consequently the grain yield [47].

4.3. Use of algae and plant extracts

The class of seaweed extracts represents a large group of biostimulants that come from the transformation of various species of seaweed, most often macroalgae (seaweed). The used species vary in their composition and how they are used as biostimulants [48]. Algae can be applied directly on the soil as compost. Empirical effects on plants such as increased growth and yield were attributed to improved soil structure with increased water retention, better availability of nutrients resulting from the degradation of organic molecules brought by algae [49].

Plant-based biostimulants are also effective in improving growth, yield, quality and bioactive content of various crops. The application of moringa extract (*Moringa oleifera* Lam.) has increased wheat yield and growth [50]. These extracts have also improved plant tolerance to various abiotic stresses such as drought.

4.4. Silicon

Several studies highlighted the potential of applying silicon (Si) to improve drought tolerance in different species [51, 52] including wheat [53]

Most wheat studies have shown that Si can mitigate the adverse effects of drought at different levels of crop development and growth under laboratory and field conditions [54, 55, 56], although other studies report no significant effects, either on wheat [57, 58] or on other species [59, 60]. These observed Si effects can be attributed to growing conditions, plant growth stage, application method (seed priming, foliar application and soil incorporation), and/or plant species variation (depending on the Si accumulation capacity) and genotypes [61, 62]. Si benefits are more evident in the varieties/species that accumulate this element at the leaf level and especially at the root level [63, 64].

This effect was explained by the formation of a silica gel layer, which is deposited on the leaves surface, stems and other organs to protect the plant from various stresses [62]. Si foliar spray has been shown to stimulate photosynthesis by improving leaf erection, preventing lodging and improving gas exchange, water transport, leaf water potential and chlorophyll levels [57, 65]. In addition, Si has been shown to reduce oxidative damage, by increasing the trapping capacity of reactive oxygenated species [66, 67]. Under drought stress, Si fertilisation can also improve water use efficiency [53] through an increase in stomatic conductance, which in turn improves the performance of the photosynthetic activity [68]., or a decrease in transpiration, which may occur through a reduction in cuticular water conductance[69].

4.5. Use of microorganisms

Among microbial biostimulants, *Bacillus* and *Pseudomonas* are the predominant rhizobacteria promoting plant growth (PGPR, Plant Growth Promoting Rhizobacteria) widely used as biofertilizers[70]. However, Bacillus-based bio-fertilizers are more active than Pseudomonas-based bio-fertilizers[71]. This was attributed to the production of more effective metabolites and sporulant character of *Bacillus*spp. which increases cell viability in formulated products. Beneficial *Bacillus* spp.associate with roots or rhizosphere and develop biofilms, allowing the assembly of cells in a matrix composed of exopolysaccharides and proteins that indirectly protect plants by inducing a systemic resistance thatimprove plant growth and final yield [72]. The *Bacillus* spp. manipulate the intracellular metabolism of phytohormones through the synthesis of indole-3-acetic acid (IAA), gibberellic acid, cytokinins and 1-aminocyclopropane-1-carboxylate (ACC) deaminase[73, 74, 75, 76]. In particular, AIA has significant effects on growth[77] and root architecture (Vacheron et al., 2013) [78], while ACC deaminase secretion inhibits ethylene synthesis in cultivated plants and promotes cell division and elongation in root and leaves[75, 79].

Some biostimulants may also contain beneficial fungi such as *Trichoderma* spp. which are free fungi common in the rhizosphere and soil (Harman et al. 2004) [80]. *Trichoderma* spp. are considered to be the most important filamentous fungi in biological control strategies[81, 82]and an excellent plant growth promoter fungus (PGPF, Plant Growth-Promoting Fungi)[83, 84]. *Trichoderma* spp. are present as an active ingredient in more than 200 products worldwide, such as biopesticides, biofertilizers, biological growth promoters (Fiorentino et al., 2018; Woo et al., 2014). The *Trichoderma* spp. are well known for their ability to produce a wide range of plant growth promoting substances (secondary metabolites, phytohormones [for example, IAA and their analogues], vitamins and enzymes) [89]. These *Trichoderma*-induced mechanisms can influence many aspects of plant development, including root growth and architecture (increased lateral and primary root length) and nutritional status (Increased nutrient uptake and utilization efficiency) [84, 85, 89, 90].

Biostimulants can also include arbuscular mycorrhizal fungi, called endomycorrhizae, which are obligate symbiotic fungi that predominate in the roots and rhizosphere (Smith et al., 2011) [91]. In this symbiotic relationship, plants provide lipids and/or sugars to their symbiotes, providing fungi with a source of carbon for their metabolic needs [92]. In contrast, fungi provide benefits to their associated hosts [93]. This symbiotic fungus promotes plant growth by producing metabolites and increasing the acquisition of immobile nutrients such as phosphorus, zinc and copper beyond the reach of plant roots *via* their hyphae[90, 93]. In addition, other factors associated with colonization by these fungi can influence plant resistance to drought. These factors include changes in leaf elasticity, improved leaf moisture and turgidity potential, maintenance of stomate openness and transpiration, increased root length and depth, and adventitious root formation [94, 95]. Several species of mycorrhizal fungi, such as *Glomus intraradices*, *Glomus mosseae* (renamed *Funneliformis mosseae*), *Rhizophagus irregularis* and *Rhizophagus fasciculatus*, have been used to improve crop performance [90].

5. The different methods used to improve drought tolerance

Several methods of applying biostimulant can be used, including seed coating, seed priming or soaking, soil incorporation and foliar spraying[54, 67, 96, 97].

Seed priming is one of the short-term approaches that could overcome the effects of drought. It is a process where initial exposure to moderate stress allows plants to be more tolerant to subsequent stress events [97]. This is a technique by which grains are partially hydrated to a point where germination-related metabolic processes such as respiration, weakening of the endosperm and degradation of reserves (starch) begin, facilitating the transition from quiescence (dormancy) of dry grains to germination [98, 99]. Treated seed typically has a higher uniformity and germination percentage as well as stronger plants [100].

Several seed priming techniques have been developed, including hydropriming, osmotic priming (osmo-priming), chemical and hormonal priming, to improve grain germination and promote drought tolerance [100]. For example, hydropriming involves soaking the grains in water before sowing.. This is the simplest approach to hydrate grains and minimize the use of chemicals [102]. In addition, osmo-priming refers to the soaking grains in a solution of sugar, PEG, etc., followed by air drying before sowing. Hormonal priming is the treatment with different hormones such as gibberellic acid, kinetin, ascorbate, which promote the growth and development of seedlings. Seed priming effects depend on many factors such as plant species, seeding media, concentration, priming duration, temperature, and storage conditions [41]. In wheat, hydro-priming and gibberellic acid priming increased the germination percentage under water deficit conditions [103]. According to Mirza et al. [104], hydro-priming with distilled water for 24 hours proved to be the best treatment under drought conditions, with a 35% increase in root length, compared to osmo-priming using potassium nitrate (KNO_3) and sodium chloride (NaCl). In addition, the use of $CaCl_2$ decreased the drought-induced losses. This substance has improved grain yield, allometric parameters such as leaf area, and plant growth rate [47]. Ulfat et al.[105] reported that hormonal seed priming using salicylic acid and gibberellic acid increased yield under normal conditions and overcame the effects of drought stress.

Also, fertigation or soil incorporation has proven to be an effective technique to improve wheat growth, especially at the tillering stage [55, 67]. Comparing different application methods (for example, seed priming, fertigation and foliar spraying), Bukhari et al. [55] and Zhou et al. [67]noted that Si or Se fertigation has proven to be the best method to fortify wheat plants, while Othmani et al. [106] and Subramanyam et al. [107] indicated that seed priming and foliar spraying were the most effective methods, respectively. In fact, the effectiveness of application method may depend on the growth stage. Fertigation performed well at tillering stage for wheat plants under water stress, while foliar spraying was more effective at anthesis stage [55].

6. Conclusion

Globally and with climate change, abiotic stress, mainly the water deficit, poses a real threat to food security and agricultural sustainability production. Water deficit will be more severe and prolonged. It can affect plants throughout their development cycle, which hinders their productivity and increases the gap between the potential and obtained yields. To cope with the adverse effects of drought, several approaches have been used. Various breeding methods and appropriate agricultural practices have been adopted. Apart from improving plant tolerance to water deficit, new approaches such as the use of growth regulators, osmoprotectants, algae and plant extracts, silicon as well as microorganisms applied with various methods, receive more attention. However, their effectiveness remains relative and depends on several factors including the soil and climate properties of the environment, genotype, etc.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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