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# Physiological Responses Of Plants Under Conditions Of Drought Stress: (Review Article)

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## ABSTRACT

Water stress is a global problem with wide-ranging economic and social repercussions. The roots of water stress stem from an unbalanced conflict between supply and demand; as the demand for water rises in all sectors, the amount of easily accessible, good-quality water at low-cost decreases rapidly, particularly in the Middle East and North Africa, which is the driest region in the world. With regard to the impact of plants on the amount of water available, there are three levels of water stress, namely mild stress, in which the water potential of the cells decreases by a very small amount of units of water potential (MPa), followed by moderate stress, in which the water potential of the cells drops to the range of (-1.2 to -1.5 MPa). Severs stress represents the highest level of stress, in which the water potential of the cells decreases by less than (-1.5 MPa). The vulnerability of plants to drought conditions depends on which of the above three levels they are exposed to during their growth and production stages.

***Keywords*:** Plant; drought stress; Physiological responses; Growth; Production.



## Introduction

Many environmental stresses negatively affect the growth and development of plants in their natural environments. The most prominent of these stresses are dehydration, salinity, high temperatures and others. Such extreme conditions disrupt the physiological processes of the plant, such as photosynthesis, water absorption and nutrients. They may also reduce plant productivity and crop quality. Studying the impact of these stresses and developing strategies to address them is critical to ensuring food security [1,2,3].

Water stress is a type of abiotic environmental stress that occurs when soil water decreases due to insufficient rainfall or when water loss through transpiration exceeds the amount absorbed by the roots, leading to changes in the plant's natural environment (such as a decrease in soil water potential) and affecting its physiological and biochemical functions [4]. A number of terms and expressions can be used to describe a state of dehydration or lack of water, such as drought stress or desiccation stress. The term water stress as a result of water deficit stress has also been used, but the term water stress is often used to express the state of water deficiency, but the latter term can also mean increased water, i.e., flooding stress [5].

The effect of drought on a plant depends on the severity of stress, on when it occurs, on how long the plant is exposed to it, and also on the stage of plant growth. It is the physiological processes that are sensitive to drought that are affected by stress. The first effect of drought includes a lack of water content in the soil and a change in the water content in plant tissues, including a change in the water potential and its components, followed by an increase in the resistance of stomata to the movement of gases and water vapour, a decrease in photosynthesis, inhibition of plant growth, a lack of plant production, and an increase in the rate of leaf ageing and fall [6].

Much research indicates the extent of the impact of drought on the growth of many plants, as it inhibits the growth of all plant organs, and the degree of inhibition depends on both the type and plant variety, the type of plant organ, the stage of growth and development and the rate of decrease in water potential in both the environmental medium and plant tissues. Dehydration of plant growth occurs due to a decrease in turgor pressure. It is expected that with abundant and surplus irrigation of the plant, symptoms of severe stress appear on the plant, followed by rapid death, and the reason for this lies in poor soil aeration, which causes anaerobic conditions that hinder the processes of respiration in the roots, which results in a decrease in the energy required for absorption. Despite the presence of ample nutrients surrounding the roots [7,8].

The saturation of the soil with water leads to the formation of carbon dioxide, which causes a lack of permeability and oxygen in the soil and thus affects the process of respiration and absorption in the root environment. The weakening of the plant's ability to absorb also dehydrates the plant, which results in the closure of the stomata as a result of the accumulation of the stress hormone (ABA), which negatively affects the prevention of gas exchange ($O_2$ and $CO_2$), i.e., the decrease in photosynthesis and respiration rates [9].

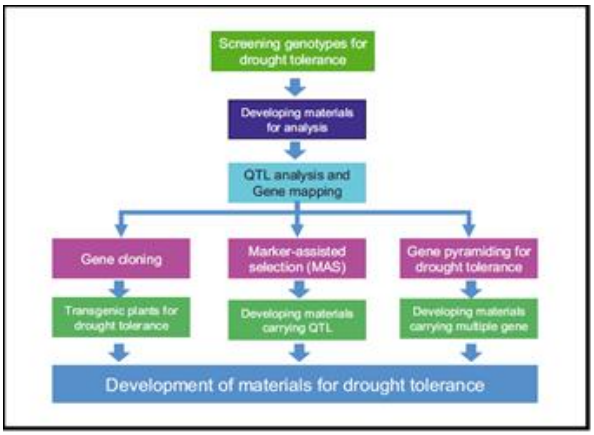


Figure (1). Evolution of drought resistance processes (mechanisms) of plants. [10]

1. Seed germination: It is natural that the process of entering the water into the seed is based on the difference in water potential between the external water surrounding the seed and the restricted water voltage inside the seed, the external water voltage is higher (lower osmotic pressure) than the restricted seed water voltage (higher osmotic pressure), so the seed absorbs water initially under the potential difference of the external and internal water [11].

If the seed receives sufficient moisture to stimulate the embryo to release the bound hormone gibberellin, this hormone subsequently influences the synthesis and diffusion of hydrolytic enzymes such as alpha-amylase, lipase, and others from the aleurone layer (in seeds with cotyledons) to the embryonic tissues. These enzymes decompose complex compounds into simpler substances, which play a vital role in increasing the osmotic pressure within the cells of the embryo and the seed as a whole. This osmotic pressure exceeds the cell wall pressure [12], enabling faster water absorption and leading to seed coat rupture and gas exchange, which initiate oxidation processes (catabolism of germination inhibitors) and aerobic respiration. Moreover, the role of gibberellin in releasing enzymes that degrade cell walls should not be overlooked, as this reduces wall pressure and facilitates water movement and entry into the cells to a greater extent [13].

When over-irrigated, some seeds follow the path of the theory of the scientist Pasteur, which indicates that there are types of seeds that can breathe anaerobically under conditions of lack of oxygen or when its concentration is lower than the minimum in their surroundings, i.e. approximately 2 as a kind of resistance to begin germination and then rupture the pot to begin aerobic respiration if available in the growing environment [14]. In the case of prolonged immersion of seeds in water for a long time, the germinating seeds cannot continue to resist the stress of high humidity to increase the concentration of dissolved carbon dioxide in the growth medium and reduce the percentage of dissolved oxygen, which deprives them of breathing and the continuation of the growth process and causes them to the phase of physiological mutations associated with germination [15].

In general, little information is available on the mechanisms governing seed germination during stress, but it can be predicted that the onset of cell division and growth may be the most stress-sensitive point, although the process of decomposing the saved food and moving it to the embryo is also stress-driven but not as sensitive [16]. In Arabidopsis, a mutagenic model that can germinate has been isolated in concentrations of sodium chloride (saline stress) and mannitol (osmotic stress) intolerable to wild types. This mutagenic model lacks the dominant gene for protein kinase kinase (MKK9). This dominant gene may inhibit the activation of stress-tolerant genes and thus make the plant more tolerant when it loses it [17].

2. Plant growth: The living mass of the plant increases with time under natural conditions of growth. However, when plants experience varying degrees of stress, their growth rate begins to decrease; this decrease is slight during mild stress, indicating that the plant has adapted to grow under these conditions, albeit at a lower rate than normal [18].

In the presence of extreme stress, growth may stop and the plant's goal under these conditions is only to survive. The plant may then tend to reduce the rates of biological processes to the lowest possible level and remain in this state until the stress is gone [19]. If severe stress persists or worsens, the plant's weight may decrease due to premature ageing and falling off of leaves or even parts of the stem, which can eventually lead to the plant's death. This happens if the plant is subjected to constant stress, In the case of temporary stress, the plant can restore its normal growth rate if it is subjected to minor stress for a brief period, although the total live mass may be lower than in the ideal case. If the plant is subjected to severe and

temporary stress, its growth rate is often lower than normal later and the loss of living mass is greater than in the case of minor stress [20].

Water stress may hinder the process of cell division by its effect on hormones such as abscisic acid (ABA). Cyclin-dependent kinases (a type of protein) that regulate the cell cycle in cooperation with kinesin can be reduced due to certain proteins that can inhibit kinesin. These proteins are called kinesin inhibitors, and one of these inhibitors is (ICK1) which inhibits the action of histone kinase. It was found that the concentration of this inhibitor increases if the plant is treated with abscisic acid (ABA) [21]. Water stress also increases the concentration of this acid in cells, so it may slow down the rate of cell division by having an effect on ABA acid, which in turn controls cell division inhibitors.

Not only that, but ABA inhibits the process of replication of genetic material (DNA) and thus prevents cells from dividing if the cells are exposed to it at the end of the first growth phase before the start of the DNA replication phase. Water stress conditions generally negatively affect the plant. Depending on the type of plant and environmental conditions, the decline in plant growth under these conditions is attributed to inhibition of the process of cell division, which would decrease the number of cells, as well as inhibition of the process of cellular dilation, which contributes to reducing the size of cells [22].

3. Plant productivity: Plants produce It is difficult to determine an accurate mathematical relationship between vegetative growth and productivity. Productivity is the ability of plants to produce seeds, although some plants are grown to produce vegetative aggregates rather than fruits or seeds. We have previously described the effect of water stress on vegetative growth. Since it is necessary for the plant to have the vegetative growth phase take place before the formation of fruits and seeds, it is expected that any negative impact on vegetative growth will negatively reflect on productivity as well [23].

The productivity of plants is affected by many factors, including their genetic makeup, the date of planting, the availability of nutrients in the soil, and others. Assuming all these factors are constant, water stress can affect productivity by affecting the plant's ability to accumulate substances necessary for fruit and seed formation during vegetative growth or the plant's ability to move these substances in time from the vegetative parts to the fruits, or both [24,25].

The impact of water stress on productivity depends on several factors, including the intensity and timing of stress, i.e. the evolutionary stage in which the plant is exposed to stress and its duration. As we mentioned earlier, water stress during vegetative growth negatively affects productivity according to the intensity of stress, so that the loss in productivity increases as the intensity and duration of stress increase. Conversely, exposing wheat plants to slight water stress during seed formation has been found to improve productivity by accelerating the transfer of saved food to cereals, which also accelerates grain fullness and increases productivity [26]. However, plants generally respond differently in wheat than in soybeans, where productivity is negatively affected when exposed to brief periods of drought during seed filling, where seeds are smaller than those from plants growing in abundance of water [27].

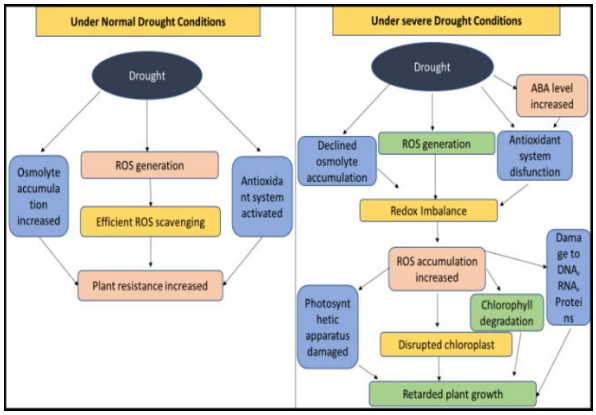


Figure (2). Different responses of plants when exposed to drought stress

4. Stomata: The stomata are closed completely or partially and the change in the gas exchange process implies this, which negatively affects the processes of photosynthesis and respiration [28]. The process of closing stomata due to water stress has been studied in many plants as it turns out that there are physiological and biochemical processes taking place in guard cells. Water stress causes an increase in ABA acid, which contributes to pumping potassium ions from guard cells and thus closing the stomata. In addition to that, water stress causes a shortage of malates due to their transformation into starch with little osmotic activity. The stomata are surrounded by two specialized epidermal cells, known as guard cells, which control the opening and closing of stomata [29,30].

When the stomata are fully opened, it is estimated that they are about (3 to 12 microns) wide and about (10 to 40 microns) long [31]. The number of stomata on the leaf surface varies from species to species and in some species each cm2 contains approximately 1,000 stomata, while others contain about 60,000 stomata. Despite this enormous number of stomata on the surface of the leaf, when fully opened, they represent only (1-2)% of the total surface of the leaf. Stomata are usually on the leaf's underside, but some species, have them on both sides. The following table represents the number of stomata on both

leaf surfaces in some plant species.

Some reports have indicated that water stress may stimulate the activity of certain genes responsible for producing ABA under water-stressed conditions, which accelerates the closure of stomata to maintain the plant's water level [32]. However, this process could hinder gas exchange and also affect various physiological and biochemical aspects due to the inhibitory effects of ABA. Additionally, this inhibition may occur through the suppression of gibberellin action, which stimulates alpha-amylase synthesis, ultimately leading to reduced starch degradation [33].

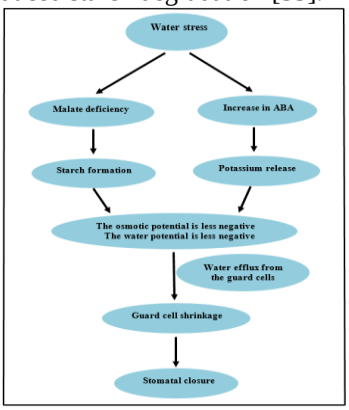


Figure (3). Physiological processes that take place inside guard cells that explain the closure of stomata under water stress.

5. Photosynthesis: Water stress causes inhibition of photosynthesis reactions, the most important of which are Hill reactions and a decline in photosystems, as well as a decrease in the content of photosynthesis pigments such as chlorophyll [34,35]. As for photorespiration, different studies have indicated different responses, with some research showing a decline in this process, while other studies have confirmed the stimulation of the glycolate pathway with the accumulation of the reactive oxygen compounds (ROS) during drought [36].

Moisture stress results in an increase in the decomposition of processed carbohydrates, and an increase in the hydrolysis of starch as well as a lack of its manufacture have been found in plants exposed to moisture stress, which was accompanied by an increase in the proportion of free sugars as sucrose increased in the leaves [37]. Carbohydrates are of great importance to plants because they are used as starting materials for the production of ATP and reducing power in the form of enzyme reducing companion NADH or NADPH, and the process in which this reaction takes place is known as oxidation – reduction reaction, it's called respiration.

An important aspect during carbohydrate metabolism is that carbohydrates are not usually completely broken down, but are used as assets for building other substances besides the respiration process, and this indirectly leads to the process of forming cell wall raw materials, nucleic acids, proteins, lipids, plant hormones, pigments, etc. It should be noted here that anabolic or energy-producing reactions in metabolic processes have a close biochemical relationship with the biotransformation that occur in plants.

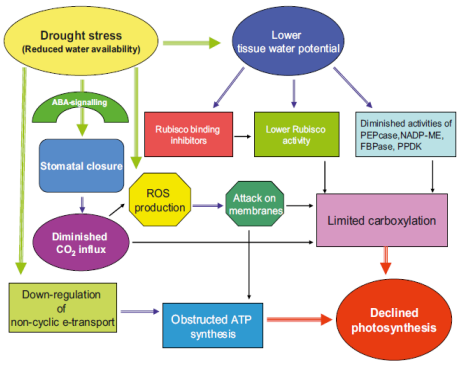


Figure (4). Photosynthesis under water stress conditions [10]

6. Respiration: Water stress causes significant disturbances in the vital pathways associated with the respiration process, which include a sharp decrease in oxidative phosphorylation and oxygen consumption ($O_2$ ), in conjunction with the stimulation of glycolysis reactions and pentose phosphate pathway, in response to a change in energy state within the cell [38,39]. In cases of severe water stress, some plants show an initial elevation in respiratory rate, due to increased activity of enzymes associated with respiratory chains, such as pyruvate dehydrogenase, succinate, and mitochondrial electron transport

chain enzymes [40]. However, this rise is soon followed by a sharp decline in respiratory activity as the water potential continues to decrease, as a result of damage to the mitochondrial structure and the decline in the supply of respiratory substrates [41],

7. Different plants tend to lower the osmotic potential (ψs) or solute potential when exposed to water stress, and this phenomenon is known as osmotic adjustment, a mechanism that helps maintain a gradient in water potential in favor of water absorption from the soil into plant tissues [42]. This process is an important biophysiological response that enables the plant to adapt to drought conditions. Osmotic regulation involves the accumulation of inorganic ions such as potassium ($K^+$ ), calcium ($Ca^{2+}$ ), magnesium ($Mg^{2+}$ ), and sodium ($Na^+$ ) [43].

Soluble organic compounds also contribute significantly to osmotic modification, including organic acids such as malic, citric, and fumaric, as well as amino acids such as proline, glutamine, and phenylalanine, where proline accumulation has been found to be an important biological indicator for drought tolerance [44]. In addition, soluble carbohydrates (sucrose, glucose, and fructose) are osmotic pressure regulating compounds that are stored in cells to help retain water. Quaternary ammonium compounds such as betaine and choline also accumulate, they play a role in protecting proteins and membranes from dehydration damage and maintain cellular structure under low osmotic pressure [45].

8. Hormone imbalance : One of the important metabolic disorders caused by water stress in the plant is hormonal imbalance, often represented by an increased concentration of growth retardants such as abscisic acid (ABA), a decrease in the concentration of growth promoters such as auxins, gibberellins, and cytokines, or both, [46]. Scientific indications of this phenomenon began in the late fifties, when researchers observed that the inhibitory effect of mannitol, an osmotic compound, on lettuce seed germination could be reversed by treating seeds with gibberellin, suggesting a key role for hormones in regulating physiological responses under osmotic stress [47].

Studies have since concluded that treating plants growing under drought conditions with growth-stimulating hormones, such as gibberellin and cytokinin, improves metabolism and increases protein and RNA levels, reflecting the reactivation of vital processes in cells [48]. Thus, higher levels of growth stimulants or reduced growth inhibitors may be necessary to restore the vital activity of plant cells during and after exposure to stress by affecting the regulation of gene expression, building proteins, and promoting cell growth.

9. Disturbance of the content of nucleic acids and proteins: Many studies confirm that the exposure of plants to stress conditions, such as lack of water, leads to significant imbalances in protein content, and these effects can be analyzed from two main aspects: protein synthesis and protein breakdown.The negative effect of water stress has been associated with a decrease in the content of polyribosomes, changes in the properties of plasma membranes that regulate metabolic activities, as well as the accumulation of protein-building inhibitory compounds such as glutathione disulfide (GSSG), a decrease in ATP levels, and a change in gene expression pattern, leading to the production of unusual proteins, or inhibition of the synthesis of natural proteins [49,50].

On the other hand, the decline in protein synthesis leads to an imbalance between the construction and catabolism processes, in favor of catabolism, as the degradation of proteins contributes to the release of soluble compounds that have a role in osmotic adjustment [51]. Poor protein synthesis is also attributed to disruption of nucleic acid metabolism, through increased RNA dissociation due to high RNase activity under stress, reducing the availability of mRNA necessary for protein construction [52]. Enzymatic activity shows differentiated responses under conditions of water stress. Some studies have shown a decrease in enzymatic activity due to reduced enzyme structure, altered structure, lack of intermediate compounds resulting from photosynthesis, or degradation of enzymatic systems [53]. Other studies have shown an increase in the activity of some enzymes, especially analytical ones (e.g., proteases and lipase), as a result of a change in the internal distribution of enzymes within organelles (compartmentation breakdown) or a shift in the pattern of isoenzymes [54]. Recently, research has focused on studying gene expression associated with coping with water stress, and has found that certain proteins are built exclusively under drought or salinity, the most famous of which are osmotins, their construction is also stimulated by the use of ABA. Work is underway to link the production of these proteins to plant drought resistance through genetic modification or bioremediation [55].

**Drought Resistance**

The study of drought resistance in different plant species and varieties is of great importance, especially in arid or semi-arid zones, where the sustainability of cultivation depends on the tolerance of cultivated varieties to conditions of water shortage [56]. Drought-resistant plants exhibit a clear survival, both through the protoplasm's ability to tolerate drought without permanent damage and through structural and physiological properties that enable the plant to avoid or tolerate water deficiency [57].

1. This trait is common in algae, lichens, and some seed plants, where the protoplasm can survive even after losing a large amount of water (dehydration) without suffering permanent cellular damage [58]. This tolerance is attributed to several physiological and structural mechanisms, including the accumulation of protective solutes such as sugars and late embryogenesis abundant (LEA) proteins that stabilize cellular membranes and proteins during dehydration. It is also associated with antioxidant activity that minimizes oxidative stress caused by water loss. Morphological adaptations, such as the presence of leathery and small leaves covered with thick trichomes and a dense cuticle-as seen in many desert grasses

and shrubs like the olive-reduce transpiration and enhance resistance to leaf dehydration, allowing these species to maintain metabolic integrity under extreme drought conditions.
2. Avoid dehydration or delay its occurrence: This factor is not as important as cellular tolerance, but it is observed in many temperate plants (mesophytes). This occurs by multiple mechanisms [59], including:
A- Modification of the growing season: as in the case of desert annuals that grow and bloom shortly after rainfall, completing their life cycle before the onset of drought [60].
B- Diffuse root system: The breadth and depth of the roots is an important factor in drought resistance. Plants such as deep-rooted and dense tomatoes show higher tolerance compared to superficially rooted plants such as potatoes and lettuce [61].
C- Control the rate of transpiration: by closing the stomata early at the onset of water stress, and reducing water loss. Qtel plays an important role in this mechanism as well [62]. A plant that can reduce transpiration efficiently has a higher ability to delay or avoid drought, and this category includes many species with high adaptation to arid environments.

**Mechanisms of drought resistance in plants**

Types and degrees of drought resistance among plants can be divided into four main groups associated with disparate physiological and structural mechanisms [63]:
1. Drought-intolerant plants: They die quickly when water is lacking, such as shade plants.
2. Succulents: They store large amounts of water and lose it slowly thanks to properties such as skin thickness and lack of stomata (CAM), as in aloe vera [64].
3. Plants that are attractive to drought: The protoplasm of their cells is likely to dry out without permanent damage, such as mosses [65].
4. Plants that tolerate drought in an intermediate way have structural features that reduce water loss and enhance their ability to absorb water; these plants; include most crops.
Water stress resistance mechanisms fall into three types:
A. Drought escape: The life cycle ends quickly before drought, as in desert annuals [63].
B. Drought avoidance: includes water retention (closing stomata, thickening of the epidermis...) and rapid absorption by deep or active roots [66].
C. Drought tolerance: includes two types: dehydration prevention (osmotic regulation and cell wall elasticity) and tolerance to water loss through the production of amino acids and antioxidant auxins [67,68].

**Hardening**

Hardening can be defined as treating plants or their seeds by exposing them to moderate water stress one or more times, giving them the ability to survive under drought conditions without permanent injuries compared to untreated plants [69]. Major physiological changes include increased water-binding capacity, protoplasm abortion, and decreased cellular permeability [70]. These concepts have led to an attempt to improve drought resistance by treating seeds before planting (seed priming/hardening) by soaking them in water or brine and then air-drying them [71]. Characteristic traits such as increased root-to-vegetative ratio, small leaf size, and increased thickness of cuticles reduce transpiration [72]. Although moderate stress temporarily reduces growth, re-irrigation afterwards often induces faster growth than untreated plants, due to the use of carbohydrates and amino acids stored during tempering [73].
There are two types of localization:
1. Adaptation genotypique: Permanent genome modification through mutations and selection that leads to better genetic expression for survival [74].
2. Adaptation phenotypique: Restorable changes in appearance and cellular functions without alteration in the genome, as a reaction to environmental conditions such as drought [75].

**Protein metabolism during water stress**

Plants have genetic and physiological flexibility that enables them to adapt to the environment, since they are stationary organisms that are unable to transition to a better environment when exposed to water stress. Therefore, adaptation by regulating the activity of genes and enzymes in the organ and the developmental stage is essential. When a plant is activated under stress, gene expression is reprogrammed to prioritize stress-handling genes at the expense of genes related to rapid growth [76].

The UPS system plays an essential role in resynthesis of proteins during water stress by metabolizing proteins that are no longer necessary, or that have been damaged in order to reuse their amino acids to synthesize new proteins more suitable for stress conditions [54,77].

Studies show that E3 ubiquitin ligases regulate this process by targeting regulatory proteins associated with stress signals such as transcription factor ABI5 or RLKs such as LRR1 and KIN7, enhancing the plant's ability to resist drought and loss of water pressure [78]. In cases of stress, UPS activates proteins such as PUB11, KEG, and SDIR1 to break down specific enzymes or hormonal signaling molecules associated with oxidation and water (ABI5 and ABI3); this allows the plant to dilute growth-oriented energy and promote survival mechanisms such as osmotic pressure regulation and cellular damage repair [79].

**Protein metabolism and its effect on water stress**

1. Removal of damaged proteins: Proteins are damaged during water stress as a result of the formation of active oxygen compounds and the loss of vacuum structure, and their presence becomes dangerous if they accumulate, therefore, plants metabolize these proteins, even if it is energy expensive, to reuse their amino acids in the manufacture of new proteins, especially when cell division is slow and accumulation is difficult to mitigate [80].
2. Regulation of metabolism: During stress, the plant increases the production of compatible solvents (such as proline and glycine-betaine) for adaptation. Removing unnecessary enzymes is a faster way to regulate metabolic pathways than stopping gene expression alone, because protein survival prolongs metabolic activity after transcription stops [81].
3. Ubiquitin–Proteasome (UPS) system: This system functions through three main steps — activation of ubiquitin by the enzyme E1 (ubiquitin-activating enzyme), its transfer to E2 (ubiquitin-conjugating enzyme), and then attachment of ubiquitin to the target protein via E3 (ubiquitin ligase). The tagged protein is subsequently degraded by the 26S proteasome complex [82]. UPS plays a crucial role in removing damaged proteins and regulating enzymes, such as E3 ubiquitin ligases (PUBS, KEG, SDIR1), which break down stress-related transcription factors such as ABI5 or RECEPTOR-LIKE KINASES, enhancing drought resistance [83].

**Conclusion**

Water stress is one of the most prominent environmental challenges that threaten agricultural production globally in light of rapid climate changes. Water scarcity affects the physiological and biological processes of plants, from the absorption of elements to the efficiency of photosynthesis. Studies have shown that plants' responses to this stress rely on complex adaptive mechanisms, including morphological, biochemical and molecular modifications. The role of phytohormones in regulating water stress responses has become a key focus in research to improve endurance. Integrated water management and sustainable irrigation practices provide effective means to mitigate the negative effects of drought. Furthermore, advances in genetic breeding techniques and genetic engineering have contributed to the development of plant varieties that are more tolerant of limited aquatic conditions. It is crucial to promote interdisciplinary scientific research to understand the relationship between water stress and other environmental factors. Applying the results of this research in the field will help ensure food security, especially in arid and semi-arid areas.

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# مقالة عن الاستجابات الفسيولوجية للنباتات في ظل ظروف إجهاد الجفاف.

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الخلاصة

الإجهاد المائي مشكلة عالمية ذات مضاعفات اقتصادية واجتماعية واسعة النطاق. تنشأ جذور الإجهاد المائي من صراع غير متوازن بين العرض والطلب؛ فمع تزايد الطلب على المياه في جميع القطاعات، ينخفض بسرعة مقدار المياه الجيدة النوعية وسهلة الحصول والمنخفضة التكلفة، ولا سيما في منطقة الشرق الأوسط وشمال إفريقيا، التي تُعدّ أكثر مناطق العالم جفافًا. وفيما يتعلق بتأثر النباتات بكمية المياه المتاحة فهناك مستويات ثلاثة للإجهاد المائي تتمثل بالإجهاد الطفيف *Mild stress* والذي ينخفض فيه الجهد المائي للخلايا بمقدار قليل جدا" من وحدات الجهد المائي (ميجاباسكال) ، يليها الإجهاد المعتدل *Moderate stress* والذي ينخفض فيه الجهد المائي للخلايا الى المدى (-2.1 الى -1.5 ميجاباسكال) ، في حين يمثل لإجهاد القاسي *Severe stress* أشد مستوى للاجهاد اذ ينخفض فيه الجهد المائي للخلايا بمقدار أقل من (-5.1 ميجاباسكال). ويعتمد تأثر النباتات بظروف الجفاف على أي من المستويات الثلاثة أعلاه التي يتعرض لها النبات أثناء مراحل النمو والانتاج.

الكلمات المفتاحية: النبات ، اجهاد الجفاف ، الاستجابات الفسيولوجية ، النمو ، الانتاج.