

Drought Stress Impacts and the Role of Endophytic Fungi Combating Abiotic Stress on Wheat

¹N. M. George, ¹E. Abdelhaliem, ¹G. H. Ali and ¹A. A Bolbol

¹Botany and Microbiology Department, Faculty of Science, Zagazig University

Corresponding author: nellytadrous56@gmail.com

ABSTRACT: Wheat is a sizable grain crop that is grown all over the world. However, under the stress of drought, wheat productivity declines dramatically in many growing places around the world. Wheat yields significantly decrease due to water shortage during the crucial period of growth. Wheat growth, from germination through maturity, is impacted by drought stress in every way. The stress of a drought impairs a variety of plant metabolic functions. There is a reduction in both photosynthesis and the amount of chlorophyll in the leaf. In addition to having extra effects on a number of physiological systems, increased generation of reactive oxygen species (ROS) damages RNA and DNA through oxidative deterioration. This detrimental effect of dryness can be reversed by the endophytic fungi (EF). The use of endophytic fungi can improve plant development in drought-prone environments by modifying hormonal balance, maintaining nutritional status, and producing plant growth regulators. This function of fungi influences physiological and biochemical characteristics favorably, increasing the number of leaves, water content, photosynthetic pigments, and ascorbic acid. Fungi reduce drought effects by boosting antioxidant defense mechanisms and boosting plant growth and production to promote sustainable agriculture. Different consequences of drought stress on wheat are covered in this paper, as well as how the consortium of endophytes may be able to enhance wheat's ability to adapt to drought

KEYWORDS: *Triticum aestivum*, Endophytic fungi, drought

Date of Submission: 12-03-2023

Date of acceptance: 02-04-2023

I. INTRODUCTION

Due to its large cultivated area and low crop yield, Worldwide, wheat is a major grain crop. More than 2.45 billion people, or 35% of the world's population, rely on wheat as their primary source of diet, and 30 million people work in wheat cultivation, making it an essential crop [1]. The most significant and strategically important cereal crop in Egypt is regarded as wheat. It accounts for roughly 10% of the value of all agricultural produce. Wheat is a polyploid crop that self-pollinates and has been cultivated for a variety of distinct end-use quality features [2]. Given its significance, for people all across the world, particularly in Egypt, yellow gold is without a doubt one of the most significant consumables. Nearly one-third of the global population's caloric, protein, and carbohydrate requirements are satisfied by wheat [3]. Nourishing staple diet, wheat grain provides a number of nutrients and factors that are helpful for your health [4,5,6]. The fact that wheat can be processed into flour, semolina, and other fundamental components of bread and other bakery products, as well as pasta, makes it important because it serves as the majority of people on earth's primary source of nutrition [7]. Hard, soft, and durum wheat are the three categories that are based on how the grains are processed. Because wheat quality varies depending on the employees (from farmers to those in the processing business) and the intended application, it is difficult to characterize (from flour to bread, pasta, or cookies) [8]. Botanists have historically classified and distinguished genotypes within plant species using morphological characteristics. Wheat has evolved through a combination of artificial and natural selection over the course of 10,000 years of agriculture, with many of the types being hybrids. The taxonomy of wheat varieties has been greatly muddled by this variation [9]. Sessile flowering spikelet that alternates on the opposite sides of the rachis to form a genuine spike are characteristic of the grass family *Poaceae* (Gramineae), which includes wheat. The *Triticineae* subtribe includes ryes (*Secale*) and wheat (*Triticum*), as well as the plant *Aegilops*, *Agropyron*, *Eremopyron*, and *Haynalidia* [10]. It is a member of the *Triticum* genus. There are 27 wild and domestic species in this genus. *Triticum aestivum*, *Triticum durum*, and *Triticum dicoccum* are the three varieties of wheat. One of these cultivated kinds of wheat is common wheat (*Triticum aestivum*), also referred to There are three different types

of wheat: *Triticum aestivum*, *Triticum durum*, and *Triticum dicoccum*. *T. aestivum*, popularly known as bread wheat is one of several cultivated wheat varieties. Common wheat makes up around 95% of all wheat produced worldwide and is the crop with the highest financial output. Common wheat, the crop with the highest financial yield, accounts for approximately 95% of the total amount of wheat produced universally [11;12]. Agricultural plants are vulnerable to multiple environmental stressors, which all affect their development and growth and lower their output. It is believed that drought, the most harmful environmental stress, has the largest damaging effect on agricultural productivity [13]. One of these abiotic components is, drought stress is a severe barrier that drastically lowers wheat production and significantly affects its productivity [14]. Agricultural drought is brought on by a persistent decrease in precipitation (meteorological drought) and increased evapotranspiration demand [15]. When there is not enough rainfall for plants to develop regularly and finish their life cycle, a drought occurs in agriculture. As a result of water constraints, droughts are becoming more frequent in arid and semiarid areas, in many of these locations, jeopardizing plant growth and crop output [16;17]. More than half of arable lands are anticipated to experience drought pressure by 2050, While more wheat needs to be produced to meet the increasing global food demand, according to studies from the United Nations Environment Program (UNEP) and the World Bank. [18]. When the water supply to a plant's roots is compromised or when the rate of transpiration increases, the plant is stressed by insufficient water. Arid and semi-arid climates frequently coexist with these two conditions [19]. Drought significantly reduces crop growth rate and biomass accumulation, having a negative impact on plant development. Wheat yield is influenced by the length and severity of stress, so it's crucial to increase drought resistance and water usage efficiency [20]. Drought is a key stressor that climatic change because it happens when a plant loses more water through the transpiration of its leaves than it can take in through its roots. This can have a substantial influence on agricultural output [21]. The best wheat production may be achieved in an environment free of stress, however abiotic factors including drought, excessive water, heat, salinity, cold, and chemicals also have an impact on wheat production, reducing wheat yield by up to 71 percent as a result [22].

II. Influences of dryness on the wheat's morphological characteristics

The most delicate stages appear to be the flowering and grain-filling stages. In light of this, drought stress that occurs during one of these two developmental stages is referred to as a terminal drought. Depending on the stress's intensity and duration, significant losses in agricultural yield occur, which lowers the success of reproduction [23;24]. Every developmental stage, including grain filling, maturity, tillering, booting, heading, and germination, is impacted by a lack of water. Drought stress has an effect on plant life, affecting root growth, extension, depth, and partitioning of dry materials [25]. Water stress lowers turgor pressure, which in turn restricts cell proliferation and expansion during the first stage, seed germination [26]. While drought affects all stages of wheat growth, it is most severe during flowering and grain filling. The severity and length of the drought impact the productivity losses in wheat, which are caused by reduced photosynthesis, stomatal closure, lower metabolic activity, and poor grain formation [27]. Dryness affects different growth phases of wheat. It is widely understood that uniform germination necessitates enough soil moisture, which is why ideal soil temperature may be crucial for drought-sensitive kinds. This is due to the fact that, between wheat types, germination-related factors such as the emergence index, emergence rate index, energy of emergence, and relative cell damage (RCI) vary greatly under both normal and water-limited circumstances. During the germination and early seedling period, increasing stress has a detrimental effect on the germination rate, seedlings, coleoptile, shoot, and/or root length [28,29]. Water stress results in numerous morphological changes in the plant, but when the stress is too great, functional damage and plant component loss occur. Wheat needs water during the crucial stages of jointing, tillering, and anthesis [30]. Although plants undergo a range of morphological changes in response to water stress, in acute stress situations, plants endure functional degradation and the loss of plant components. The root enlarges to seek out water when there is a scarcity of it, but the growth of the shooting component is slowed [31]. However, it was discovered that moderate and severe dryness impeded wheat root growth, shortening plant height due to the prolonged drought effect. Drought was demonstrated to reduce plant biomass in spring wheat, which led to a lower yield [28]. Stress prevents plumule from extending and reduces seedling vigor, which results in shorter coleoptiles and poor stand establishment. In order to achieve better stand establishment, it would be appropriate to choose genotypes with longer coleoptiles [31]. Accrual of plant biomass. It has been found that abiotic stressors cause a reduction in dry biomass production [32]. Due to assimilate partitioning, which encourages starch buildup and root system growth, perennial cotton demonstrated drought resilience. The seedling's dry weight, which varies depending on the species, is a reliable sign of a healthier seedling stand [33]. Increases in abscisic acid (ABA) concentrations in the roots and shoots are connected with an increase in the ratio of roots to shoots in response to drought stress. Drought stress increases the transport of dry materials to roots in order to maximize water absorption [34]. A plant's height. It is a notable agronomic measure that depicts how crop plants respond to inputs and stressful

environments in terms of their vegetative development [35;18]. It is connected to restricted seedling development, lodging, and weed control in particular crops like wheat. The reduction in cell growth and elongation is principally responsible for the reduction in plant height. Numerous studies on wheat have demonstrated that drought stress lowers plant height dramatically. The length of the stems under drought stress was somewhat shorter than in environments with adequate water supply [36,37]. Stem diameter, some plants with stems instead of shoots have reduced stem diameters due to changes in the turgidity of their cells while under drought stress. Variations in stem diameter are mostly regulated by the water potential of the soil and the leaves with the former being strongly linked to variations under delayed drought stress. Maximum stem diameter and leaf area were seen in well-watered conditions, and these values steadily decreased with increasing water stress. In plots with only one watering [38]. In any event, the water budget is reduced by leaves falling off due to drought stress at the expense of yield reduction [39]. Leaf area is a key factor in the drought's effects. Leaf growth and development are more vulnerable to dryness than root development since expanding a plant's leaf area can increase its vigor and photosynthetic potential [40]. Leaf area flexibility is a vital tool for maintaining control over water use during drought stress. Stem anatomy, phenology, leaf emergence rates, and future leaf size all affect how many leaves are present. Additionally, it increases the crop's water use effectiveness to reduce water use. Wheat plant architecture and yield potential are influenced by flag leaf employing morphological indicators. Some wheat genotypes' flag leaves contribute 45–58% of photosynthetic activity under ideal conditions, and after flowering, they make up 41%–43% of the grain filling [16]. For plant growth, development, spike development, drought adaptation signal, and photosynthesis during the reproductive stage, flag leaf provides assimilate. Characteristics of flag leaf like size, width, length, and flag leaf tilt are positively connected with cereal crop productivity [41]. In dry conditions, water loss through leaf rolling can be reduced yields from wheat genotypes with smaller, more upright flag leaves can be higher than those with loose leaves function, and features of flag leaves are closely related [14]. The primary source of assimilates for the wheat plant during the grain development period, accounting for 30 to 50% of all assimilates, is the flag leaf. Wheat grain yield declines as a result of drought stress because it hastens the senescence of leaves [42]. Wheat plants experience a persistent water deficit, which leads to leaf senescence. Stress due to drought results in leaf senescent ions, which lower grain production. When wheat grains are developing, flag leaves absorb their parents' extra water (30–50% of the total) [43,44].

Samples

III. Impact of drought on wheat's physiological and metabolic pathways

Drought increases the production of ROS (reactive oxygen species) in plant tissues, including singlet oxygen ($1O_2$), hydroxyl radicals ($HO\cdot$), superoxide ($O_2\cdot^-$), and hydrogen peroxide (H_2O_2). The impact of drought on wheat's physiological and metabolic pathways peroxide (H_2O_2). These ROS destroy macromolecules, photosynthetic pigments, and enzymes through oxidative stress, which interferes with normal cell metabolism [45]. The act of photosynthesis is essential to plants, and research has linked maximum crop growth and yields to potential leaf photosynthesis. Water stress during the grain-filling stage reduces the time required for grain-filling, which accelerates the withering of the leaves and decreases photosynthetic activity [46]. Drought primarily affects physiological processes by reducing photosynthesis. By limiting the amount of carbon dioxide that can enter mesophyll cells, drought prevents plants from fixing carbon. Metabolism is directly impacted by decreased ATP synthesis, ribulose 1,5-bisphosphate carboxylase/oxygenase (Rubisco), and ribulose bisphosphate regeneration (RuBP) availability [47]. Protein degradation, enzyme inhibition, oxidative damage to nucleic acids, and membrane lipid peroxidation are just a few of the cellular processes that are impacted by increased ROS generation and result in cell death [48]. Reduced CO_2 inflow, which diminishes the photosynthetic apparatus's capacity to absorb carbon, is one of the earliest impacts of drought stress [49]. Most of the responsibility for this can be placed on stomatal closure brought on by converging factors like guard cell water content restriction, decreased external humidity, or the production of phytohormones linked to drought, like abscisic acid (ABA)[50].

[51] It has been hypothesized that a drop in plant water content results in an increase in cellular viscosity and a greater concentration of all cellular components, both of which can be toxic and detrimental to enzyme performance. Lowering turgor delays cell elongation due to decreased water transport from the xylem to elongating cells. Proline, glycine betaine, polyamines, polyols, soluble carbohydrates, and ions are only a few examples of the soluble substances known as osmolytes that are created and stored by plant cells to aid in osmotic adjustment (OA) (for example, potassium). These substances build up in stressed plants and lower the water potential of the cells, increasing water retention without interfering with normal metabolism. As a result, it was discovered that there is an association between osmotic adjustment and grain yield [52]. The two key

enzymes of the ascorbate/glutathione scavenging pathway, (APX), and (GR), become more active in response to drought stress. Plant cells not only produce enzymes but also non-enzymatic antioxidants such as ascorbate or glutathione that help to scavenge or prevent ROS. Higher levels of glutathione and ascorbate, two substances linked to improved drought tolerance, were found in wheat exposed to drought stress. The most well-known antioxidant enzymes are catalase (CAT), superoxide dismutase (SOD), glutathione peroxidase (GPX), ascorbate peroxidase (APX), and glutathione reductase (GR), all produced by wheat plants to protect against oxidative stress [53]. Wheat plants have the ability to produce more antioxidants [54]. Enzymes that fight free radicals support proper cellular activity and guard against oxidative stress [55]. The study of [56] decided that these enzymes take part in the destruction of ROS and, as a result, in the upkeep of crucial plant cell functions. Wheat plants also produce tocopherol, carotenoids, and glycine betaine as antioxidants [50]. In reaction to water stress, proline content rises in plant components. Proline is a protein that plants create when they are under stress, and it has functions that help them deal with stressful situations, such as redox potential in the cell, free radical destruction, osmotic correction, and sub-stability [57]. Proline supports normal cell biochemical reactions and aids plant survival during stressful conditions. Proline and carbs may also aid in stabilizing proteins and cell structures, especially when the stress is severe or lasts for a long time. To make proline, the plant body takes the glutamic acid route [58]. When wheat is sufficiently hydrated, the proline level rises after 15 days without water from approximately 1.mol.g of leaf dry weight (DW) to 11.mol.g of the leaf, a rise in proline content of up to 90% after 7-day drought stress (DW) [59]. The increased expression of proline-producing genes, which supports osmotic adjustment and subcellular component protection, may be a contributing factor to the observed increase in free proline [60]. Because of the breakdown of proteins during drought stress, cells' stores of other amino acids grow which contributes to OA (osmotic adjustment), but also as a result of de novo amino acid synthesis [61]. Wheat's biochemistry is significantly altered by drought stress because it has less total soluble sugar (TSS), total carbohydrate (TC), and enzyme activity. A vital physiological process called photosynthesis uses chlorophyll, a critical component of chloroplasts. The primary cause of photosynthetic inactivation is chlorophyll shortage [62]. Depending on the degree, duration, and rate of the stress, wheat's photosynthetic response varies [63]. Low Photic system II (PSII) activity results from the destruction of PSII reaction sites, the oxygen-evolving complex, and quinine acceptor activity. Additionally, it hinders transpiration and lowers stomatal conductance, which results in inadequate gaseous exchange and lowers the rate of photosynthetic activity. Drought also has deleterious effects on the structure of the stomata, chloroplasts, and chlorophyll pigment, which further reduces photosynthesis [64]. Plants produce phenolic compounds, including flavonoids, as the bulk of their secondary metabolites. In plants, these substances perform a wide range of physiological and molecular tasks, such as acting as signaling molecules, enhancing plant defense, regulating auxin transport, acting as antioxidants, and scavenging free radicals. A class of phenolic chemicals called flavonoids also has antioxidant effects. [65]. Phenolic acids (PAs) are the primary class of phytochemicals found in wheat grains. [66] found that phenols and flavonoids, among non-enzymatic antioxidants, play a significant part in plant salt tolerance by scavenging free radicals in various tissues. Both free and bound polyphenols can be found in plant materials. The majority of the polyphenols in baked goods and cereal grains are phenolic acids, with about 75% of them being readily available in bound form.[67], found that genotype, environmental factors, and their interactions affect the production and accumulation of phytochemical components in plant tissues. Under controlled settings, the amounts of phenolic and flavonoid chemicals in the grains of various wheat genotypes were assessed. As a result of the water shortage,

phenolic and flavonoid compositions overall drastically rose [68].

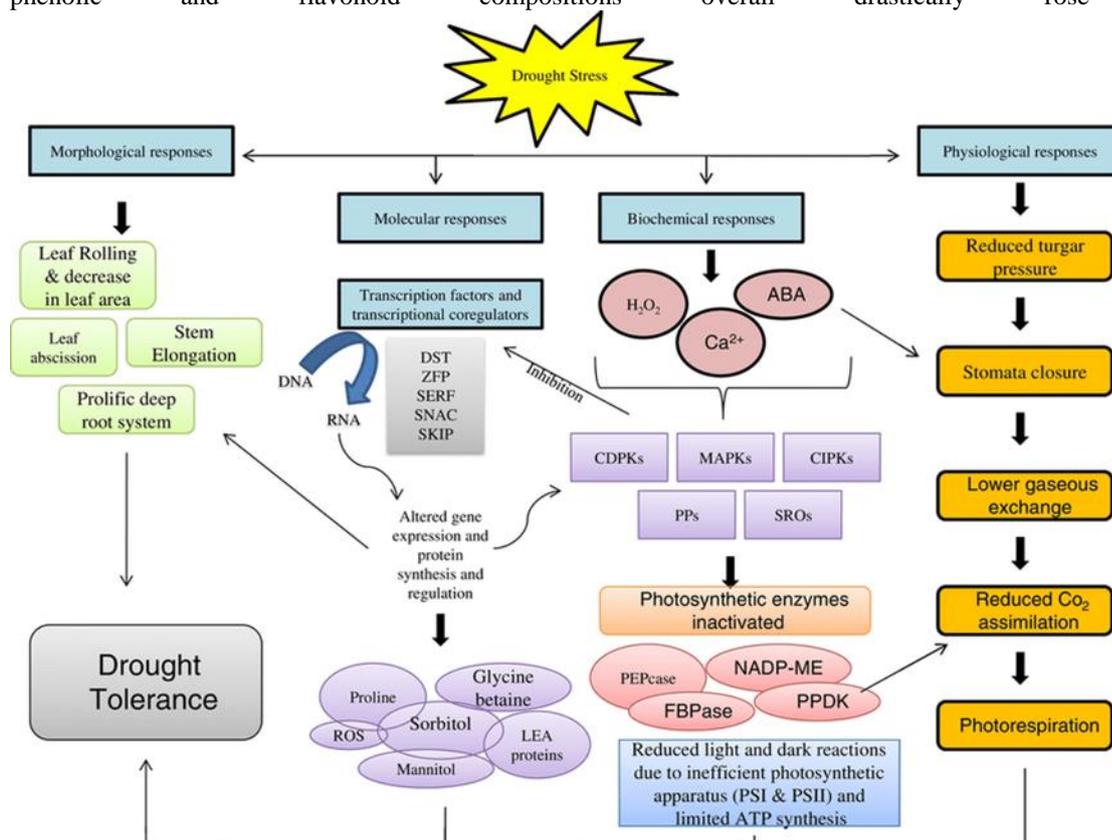


Figure 1. Demonstrates the impact of stress caused by drought on physiology, morphology, and molecular response [69].

IV. Effect of dryness on DNA and assessment of damage

Drought also affects the plant genome, leading to irreparable DNA strand breakage brought on by oxidative stress. For instance, genomic instability is caused by DNA strand breaks brought on by oxidative stress [70].

Environmental pressures affect plants in several ways, such as drought stress, which causes genotoxic and oxidative stress, damages DNA and proteins, and lowers plant growth and productivity [71].

[72], Positive evidence that epigenetic modifications like DNA methylation and histone abnormalities caused by drought have an impact on gene expression. Given the disastrous impacts of drought, especially on wheat, which is the most produced and consumed grain in the world, it was imperative to look into the role of DNA methylation in wheat. In addition, distinctive DNA methylation patterns in wheat genotypes that were drought-sensitive and drought-resistant were found [73]. Drought affects gene transcription via epigenetic alterations such as DNA methylation and histone modifications. Numerous studies have shown that water stress causes cytosine methylation in crops like wheat [74], rice, and peas [75], among others.

[76], analyzed bread wheat utilizing the ISSR RAPD markers in both normal and drought circumstances. He found that the lines beat the Sahel1 check cultivar in terms of yield and other important metrics. The most notable yield component characteristics across all seasons were seen in the lines L2, L7, and L8. Additionally, Lines L2, L4, L5, L7, and L8 demonstrated drought resistance by scoring highly in agronomic criteria and having a low drought susceptibility index. For ISSRs and RAPDs, the polymorphism rates were 39.3 and 53.2%, respectively. As compared to UBC-846, which belonged to di-nucleotide repeat sequences, UBC-881 belonged to pentanucleotide repeat sequences (GGGTG), which provided the largest level of variability (CA).

V. Expression of genes and drought

Although QPCR is one of the most effective methods for quantifying gene expression and is capable of recognizing mRNA at low levels of expression, variations in how the workflow described above is handled by various laboratories can have an impact on the quality of the results [77]. A reference gene's expression may vary within a species in response to various treatments or plant tissues [78]. The transcription of genes that respond to stress is regulated by transcription factors (TFs), which bind specifically to cis-elements in their promoters. Either transcription is activated or repressed as a result. The outcomes of TF and transgenic crop

enhancement demonstrate that this strategy can serve as the foundation for the next generation of biotech crops.[79]. Dehydration Responsive Element Binding, a transcription factor, mediates abiotic stress (DREB). Drought stress activates these genes, which encode transcription factors from the family of proteins called ethylene-responsive factors (ERF) [80]. Acetyl-CoA Carboxylase, a crucial enzyme in lipid metabolism, and other proteins like aquaporins can both be produced more quickly as a result of ABA. ABA-dependent pathways come in two different varieties. First, new proteins must be made transcription factors. The second, however, does not [81]. On wheat chromosomes 3A, 3B, and 3D, there are genes called Dreb 1. On the 3BL chromosome, the DrebB1 gene was found to be situated between Xmwg818 and Xfbb117. Dreb1/Dreb2 genes from *Triticum aestivum* were discovered [82]. *TaWRKY2* boosted the expression of STZ and RD29B and bound to their promoters, as shown by [83], *TaWRKY2* and *TaWRKY19* bind to the *DREB2A* and Cor6.6 promoters and induce expression of genes downstream, improving plant resistance to abiotic stresses. ABRE (ABA-Responsive Element) is an ABA-responsive element with an incredibly precise sequence that can be phosphorylated by ABA-activated proteins to stimulate gene expression [84]. Dehydrin (*DHN*) genes are late Embryogenesis-Abundant (LEA) Protein members that are up-regulated in wheat in response to stress, such as climatic changes, whereby cells become dehydrated [85]. DHN proteins, which are involved in defensive systems, are encoded by genes in wheat. Due to the fact that many DHNs are activated by the plant hormone abscisic acid (ABA), they are also referred to as associated proteins (Rab) and are important regulators of vesicle transport proteins (responsive to ABA). The partially dehydrated protein surfaces on which DHN proteins bind may prevent denaturation by shielding the surfaces from moisture. They might have the ability to scavenge ROS as well. Dehydration response element-binding proteins (DREB), which code for transcription factors from the ERF protein family, are stimulated by drought stress [86]. [87], identified the genes in charge While *TaRZF74* and *TaRZF59* were expressed at the highest levels in the wheat embryo and endosperm during water stress, *TaRZF38*, and *TaRZF70* RING-H2 were elevated in the leaf and downregulated in the roots. Large gene family of transcription factors known as (MYB)genes are found in both plants and animals. They are also crucial for growth, development, and stress response. The R2R3-type MYB protein is encoded by the *TaMYB30* and *TaMYB30-B* genes, which were discovered [88]. As a result of the stress brought on by the drought, genes that are susceptible to it begin to produce proteins. Particularly helpful to plants in dealing with drought stress is the latter protein class. Some of these proteins include the enzymes responsible for osmolytes production, late embryogenesis-abundant (LEA) proteins, and chaperones [60].

VI. The defense mechanisms used by wheat plants to stave off drought stress

Next, through morphological, biochemical, and molecular mechanisms, it will be examined how wheat plants protect themselves against the consequences of drought stress [89]. The ability of a person to survive or thrive in a water-stressed environment as a result of dehydration avoidance, dehydration tolerance, or drought recovery is the most frequently accepted definition of drought resistance [90]. Pick less drought-sensitive crop species, cultivars, and genotypes [69]. The two main coping methods used by plants to deal with drought are drought tolerance and drought avoidance. Physiological, biochemical, morphological, and molecular strategies are all used by plants to increase their tolerance to drought. Contrarily, some plant species avoid water deficiency circumstances by, for example, ending their life cycle prior to or during a drought phase, whereas other plants have developed adaptations to improve water intake and minimize water loss in order to avoid its detrimental effects [91]. Plant root systems are becoming more and more popular as a morphological marker for yield improvement. Breeding for high yield with high input results in narrow genetic germplasm and the loss of well-adaptive markers. Wheat has been shown to be more drought tolerant when the root system is stronger. When water availability varies, the first plant organ to perceive it is the root system [92].[93], accordingly, the size, density, and multiplication of the roots as well as their rate of development are important factors that affect how plants respond to drought stress. At the morphological level, one of the major water movers is the root. Perennial plants, which have deep root systems, are more drought resistant than annual plants. Wheat seedlings demonstrate that selecting genotypes with a better-developed root system boosted plant yield in light of the aforementioned information. Drought-avoidance early-stage plants that are subjected to drought stress gradually develop improved drought tolerance mechanisms, including the generation of appropriate solutes, an enhancement in antioxidant defenses, and other physiological reactions intended to maximize water usage efficiency. By closing their stomata, lowering evapotranspiration, and increasing water usage effectiveness, plants reduce water loss [94].[95], shown that root markers affect root function and architecture in nature and are polygenic. As the hydraulic conductivity rises due to deeper root systems and crops drawing water from depth when the grain fills, breeders are continuously looking for root producers that enable plants to adapt to drought situations. According to [82], the angle between seminal roots should be optimized, and small root diameter, big specific root length, and root length density all have a part in drought resistance. K^+ concentration, water use efficiency, and drought tolerance are all intimately associated with plants because K^+ can increase plant total dry mass and photosynthetic rate. K^+ can also control SOD (super oxidase dismutase) enzyme activity to reduce ROS-induced cell membrane damage [96]. Plant hormones, secondary metabolites, and other

essential molecules, such as carbohydrates, amino acids, and polyamines, alter membrane stabilization, osmoregulation, ROS scavenging, decrease leaf area, and abscission, promote root development and lessen ion leakage to significantly contribute to stress tolerance mechanisms and increase plant adaptation capacity [97]. By shielding plants from the oxidative stress brought on by a lack of water, increased antioxidant defenses also aid to promote drought tolerance. As a result, choosing cultivars or individuals with an improved antioxidant system enables the selection of those with a higher likelihood of surviving and performing well under water-restrictive conditions [98], wherein the increased activities of superoxide dismutase, ascorbate peroxidase, and glutathione reductase significantly benefited plant drought tolerance [99]. By lowering lipid peroxidation, protecting cell redox potential, and reducing ROS levels, proline increase helps maintain the integrity of membranes [100]. When proline levels are higher, *Triticum aestivum* plants produce more biomass, survive longer, and yield more grain. Similar to non-structural carbohydrates, some genotypes are more drought resistant. Additionally, during drought stress, trehalose helps to stabilize biological macromolecules like lipids, proteins, and other molecules, increasing photosynthetic efficiency and fostering drought resistance [101]. According to [102], proline accumulation and drought resistance have a positive relationship. Different wheat genotypes also exhibit varying degrees of drought tolerance. A diagnostic for drought-tolerant plants is proline accumulation in several wheat genotypes. [103] asserts that an increase in ABA (abscisic acid) in guard cells set off a signaling cascade that resulted in guard cell K^+ outflow and a drop in turgor pressure, both of which led to the closure of stomata.

[104], illustrated by activating a number of signaling systems, ABA (abscisic acid) lowers the amount of H_2O_2 required for plants to react to and adapt to drought stress. A study that was published in the Journal of Plant Physiology and Development (JPDD), [105], ABA-related gene function and ROS metabolism drought tolerance studies have shown that plants can adapt to drought by producing less reactive oxygen radicals (ROS).

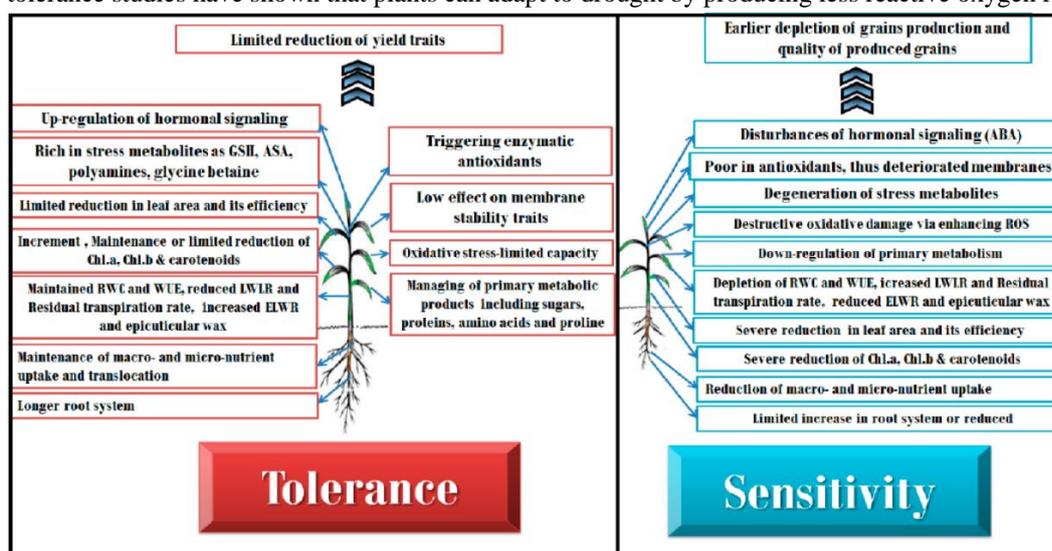


Figure 2. demonstrates how the physiology of sensitive and tolerant wheat and barley genotypes is affected by drought stress [106].

The gene for grains Resistance to salt and drought, detoxified reactive oxygen species (ROS), and TaMYB33. Additionally promoting drought resistance is the wheat gene TaMYB2. Expensing protein from wheat (EXPB) is necessary for the expansion of cell walls during growth. In response to water stress, the TaEXPB23 gene is expressed. Rht genes cause low height in wheat [107]. [108], According to reports, in order to cope with drought and other abiotic issues, plants have evolved a very complicated stress response mechanism. These response systems frequently contain transcription factors (TFs), which function in signal transduction to activate or repress genes connected to the response to drought. These TFs engage in intricate network connections and undergo reversible phosphorylation to fulfill their functional requirements [109]. As a result, information is given concerning co-regulatory networks that either simply involve TFs or involve TFs and miRNAs in addition to reversible phosphorylation of TFs by various protein kinases/phosphatases. It has been established that the MYB-CC transcription factors (TFs) genes regulate a number of Pi starvation-inducible genes and are implicated in the response to inorganic phosphate (Pi) scarcity. They have not been studied for their significance in bread wheat under drought stress [110]. V-PPase is essential for plant growth and abiotic resistance, and wheat V-PPase genes contribute to drought tolerance [111]. Drought resilience depends heavily on genes like, *Rht 8*, *Dreb 1*, *Dreb 2*, *TaRZF38*, *TaRZF70*, and *TaRZF74* [111]. *TaMYB2* family [112]. *TaMYB30-B*, *R2R3-MYB*, *TaWRKY19*, *TaWRKY2*, *TaSIP*, *TaSRHP*, *TaHPS*, *TaASRI*, *TaNAC2a*, *TaNAC13*, *TaNTL*, *TaNAC7*, *TaNAC4a*, *TaNAC6a*, *TaNAC7a*, *TaNAC4a* and *TaNAC6a* [113]. *TaWRKY10*, *TaWRKY1*, *TaWRKY33*,

TaWRKY93, and *TaERF5* [107]. *Xgwm166-7B*, *Xgwm148-3B*, *Xgwm148-3B* and *Xgwm148-3 B*, *TaSnRK2.7-a*, *TaSnRK2.7-b*, *TaSnRK2.7-c*, *TaSnRK2.7-d*, and *TaSnRK2.7-e* are the *TaSnRK2.7* family of proteins [82].

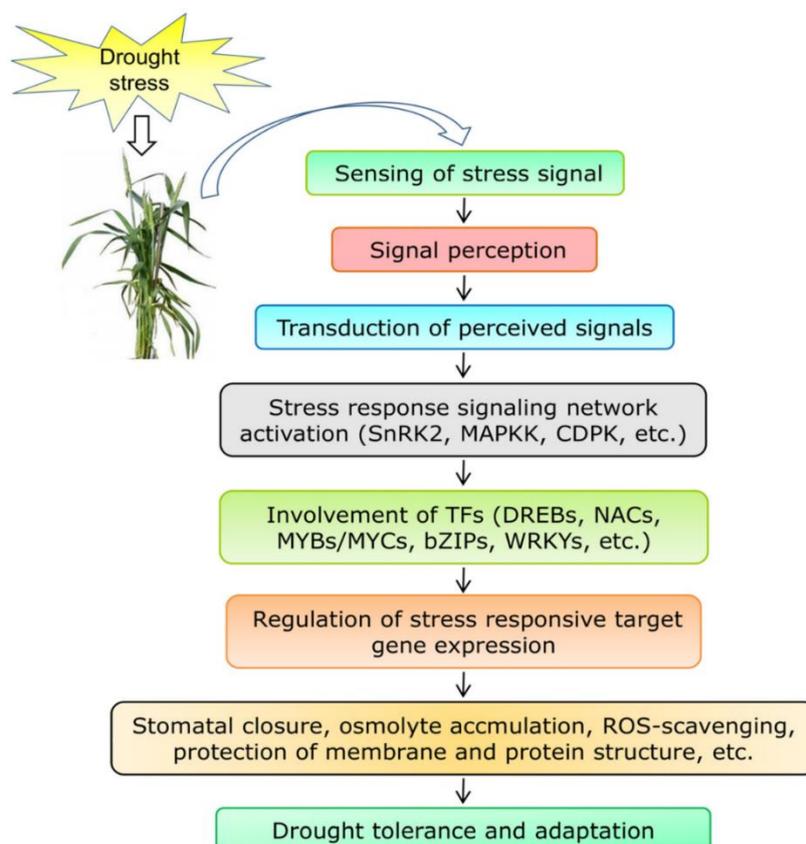


Figure 3. The perception of drought stress is the first step in the process that leads to the expression of drought tolerance, and it is followed by signal transduction by transcription factors and the activation of genes involved in adaptation [114].

VII. Classical breeding as a solution to overcome drought

To attain stress tolerance, various approaches were occasionally modified. These techniques include both traditional ones like selection and hybridization as well as more recent ones like mutation breeding, polyploidy breeding, genetic engineering, etc. The limitations of standard breeding techniques include the requirement for a significant amount of labor and energy [115]. The aforementioned limits of the strategies that are now in use make it necessary to come up with an alternate strategy to give plants resistance to a variety of challenges. The alternate approach would be more palatable if it is straightforward, affordable, and easy for farmers to embrace. It should also be successful in demonstrating tolerance [116]. Since this period is so important to agricultural productivity, several experiments have been done to reduce it.

VIII. Endophytes as PGPMs (plant growth-promoting micro-organisms)

Endophytes, or fungi without symptoms, are becoming more and more popular. They don't appear to cause any illnesses and spend all or part of their life cycle exclusively inside plant tissues. They may develop in plant or host tissue senescence, emerging to sporulate from roots, stems, and/or leaves [117]. Mycorrhizal fungi, pathogens, epiphytes, and saprotrophs are some of the organisms that infiltrate plant tissues, as are fungal endophytes. Endophytes can influence how plants develop and react to infections, herbivores, and environmental changes; some also create secondary compounds that are advantageous or fascinating [118]. Based on their preferred method of nutrition endophytic fungi can be divided into two major groups: obligatory endophytes, which are dependent on living plant cells, and facultative endophytes, which can devour both living and dead organic matter. Some endophytic fungi change to an obligatory habit, although the reasons why and how they do so are yet unknown [119]. Endophytic microorganisms can also be divided into two groups based on their capacity to build external structures from the host plant: those that cannot and those that can, such as nodules of N₂-fixing bacteria and mycorrhizal fungi [120]. Two or more coexisting microbial communities make comprise a microbial consortium. There is a chance for exosymbiotic or endosymbiotic consortiums. A potential substitute for chemical fertilizers in sustainable agriculture is a combination of various Plant growth-promoting (PGP) endophytic fungi. It is known that endophytic fungi cause plants to respond to stressors [121].

Numerous studies have been done on the development of microbial consortiums and microbes with various PGP characteristics, such as fungi, bacteria, or archaea. These relationships could be rhizosphere-based, endophytic, or epiphytic, [122]. Since endophytic fungi usually develop in sparse populations and restricted locations inside plants, it can be difficult to pinpoint the exact connection between them and their host plant. Care must be made to prevent contamination by undesirable epiphytic fungi while separating fungal endophytes [123]. Every plant in the universe is home to at least one or more endophytic fungi. Fungi dwell inside the living plant tissue of their hosts and do not manifest symptoms. These fungi have undergone in-depth investigation over a wide range of geographic and climatic zones [124].

IX. Identification of endophytes using morphological and molecular markers

According to [125] there are numerous more methods for classifying mushrooms, including color, spore size, colony diameter, texture, form, growth rate, hyphae morphology, and conidia morphology. A compound microscope was used to investigate the shapes that spore positioning in fungus morphology produced. Molecular identification, in contrast to morphological and biochemical tests employed in laboratory diagnosis of fungi, is swift, sufficient, reproducible, and capable of providing high specificity in identifying fungi species and subspecies [126]. Endophytes were identified utilizing molecular techniques using the Fungi Genomic DNA Extraction to obtain DNA. The universal primers ITS1 (5'-TCCGTAGGTGAACCTGCGG-3') and ITS4 (5'-TCCTCCGC TTATTGATATGC-3'), which were previously described, were used to amplify the nuclear ribosomal DNA internal transcribed spacer (ITS ITS1 + 5.8S + ITS2)[127]. Modern molecular biological methods like targeted gene sequencing, ITS gene amplification, and genomic DNA extraction may be utilized to detect fungal endophytes. Phylogeny and taxonomic affinity were determined using DNA that has been amplified by the polymerase chain reaction (PCR). To determine the potential of endophytic fungi for enhancing plant development and other agricultural and biotechnological purposes, internal transcribed spacer (ITS) genes are sequenced and compared with sequences in the NCBI database using MEGA software [128].

According to [129] a variety of fungal isolates can be determined and identified down to the species level using molecular identification techniques based on complete fungal DNA extraction. For mycologists researching fungus taxonomy, molecular evolution, population genetics, and fungus-plant interactions, this barcode has developed into a vital tool. Fungi can be recognized using molecular techniques through the use of universal primers and the sequencing of PCR-amplified 18S rRNA genes.

X. Different types of priming and the role of Biopriming in drought Stress Resilience

Abiotic stress can have a negative impact on plants; however, endophytes can help. There is limited evidence for endophyte-associated drought resistance in food crops, despite grasses having a large body of research supporting it. Endophytes may improve biomass production in drought-stressed plants and decrease stomatal conductance in these plants. They may also serve as a deterrent to microbial disease competitors and predators. Several grass species showed improved vegetative development when their fungus symbionts were present [130]. According to recent studies, endophytic fungi in the rhizosphere may emit plant growth-promoting secondary metabolites (gibberellins, auxins, and cytokinin) that stimulate plant growth [131]. Endophytes reduce stress in the host by triggering the host's stress response mechanisms and producing anti-stress chemicals such as phytohormones that encourage the growth of root hairs and increase total root area, facilitating nutrient uptake, as well as by boosting the activity of 1-aminocyclopropane-1-carboxylate deaminase (ACC), which lowers the level of ethylene and osmolytes [132]. Due to the importance of endophytes and their contribution to reducing abiotic stress, the priming strategy was proposed. Auxins, kinetin gibberellins, polyamines, ethylene, and salicylic acid are widely used to control thermopriming [133]. The pre-sowing of seeds at varying temperatures is known as thermopriming. Although some species have used thermopriming at high temperatures, the best results are frequently found at low temperatures. This might lead to better germination, especially for plants used in warm climates. [134]. The phrase "chemo priming" refers to seed treatment that uses a variety of chemical solutions as priming agents. The first step in this process is priming the surface with a number of both natural and artificial compounds, including hydrogen peroxide, sodium nitroprusside, urea, thiourea, mannose, selenium, chitosan, fungicide, and antioxidants (ascorbic acid, glutathione, tocopherol, melatonin, and proline) [115]. Nutri-priming involves pretreating (priming) seeds in nutrient-rich solutions as opposed to just soaking them in water. More and more data points to the importance of plant mineral-nutrient status in boosting plant tolerance to environmental stressors [133]. Controlling seed imbibition during germination establishes the hydropriming period. During hydropriming, seeds are immersed in sterile, distilled water that is kept at the appropriate temperature (often in a range from 5 to 200 C). After soaking, the seeds must be dried because improperly dried seeds will not store well and will actually do more harm than good. After soaking, seeds were undercover and forced to air-dry until they reached their initial weight [134]. The term "bio-priming" refers to a biological seed treatment procedure that combines seed hydration with microbe inoculation. By improving seed viability, germination, vigor indices, plant growth, and subsequent disease protection, it raises crop productivity. The method often recommended for biopriming is to immerse the seeds in water for 12 hours. In order to preserve seeds and control seed hydration for the management of abiotic and

biotic stress, a biological seed treatment technique known as biological priming (bio-priming) is used [135]. This supports the idea that farmers should use seed bio-priming techniques as they will not only ensure the health of seeds and crops but also help to ensure ecological sustainability. Contrarily, seed bio-priming can enhance the nutritional and physiological characteristics of seeds, resulting in better germination and adaptation under various soil conditions. Additionally, when combined with beneficial microbial agents connected to plant roots, seed bio-priming can increase plant productivity and immunity [136]. Pre-soaked seeds receive 10 g of the microorganism's specially prepared product per kilogram of seed before being thoroughly mixed in. Soaking seeds in water for 12 hours is the procedure that is frequently advised for biopriming. At a rate of 10 g/kg of seed, a chosen prepared product of the microorganism is added and thoroughly mixed with the pre-soaked seeds [133],[137], revealed that *Fusarium oxysporum* development is stimulated by p-hydroxybenzoic acid, which is decreased by inoculation with *P. chrysosporium*, thereby greatly reducing the wilt disease in *Chrysanthemum morifolium* plants. As a result, the soil's microbial and fungi community structure was altered, and the physiological condition of *C. morifolium* plants was improved. *P. chrysosporium* is a unique source for the quick generation of auxin and extracellular antioxidants, according to studies [138].[139], Studied Increases in total phenolics were generated by *Trichoderma* colonization, while reductions in proline, malondialdehyde (MDA), and hydrogen peroxide (H₂O₂) were caused by drought stress, which occurred when water was withheld for 4 to 13 days. Seed biopriming could lessen the harm caused by the buildup of harmful reactive oxygen species (ROS), a prevalent element that adversely impacts plants under drought-stress circumstances. It reduces the effects of drought stress by triggering physiological defenses against oxidative damage in plants because of improved ROS scavenging abilities.

[140], his study analyzed the makeup of fungal communities in three *Triticum aestivum* plants' root endosphere and rhizosphere, using culture-dependent fungal community profiling. Results showed that the mycobiome composition was influenced by the type of soil preparation and the section of the root.

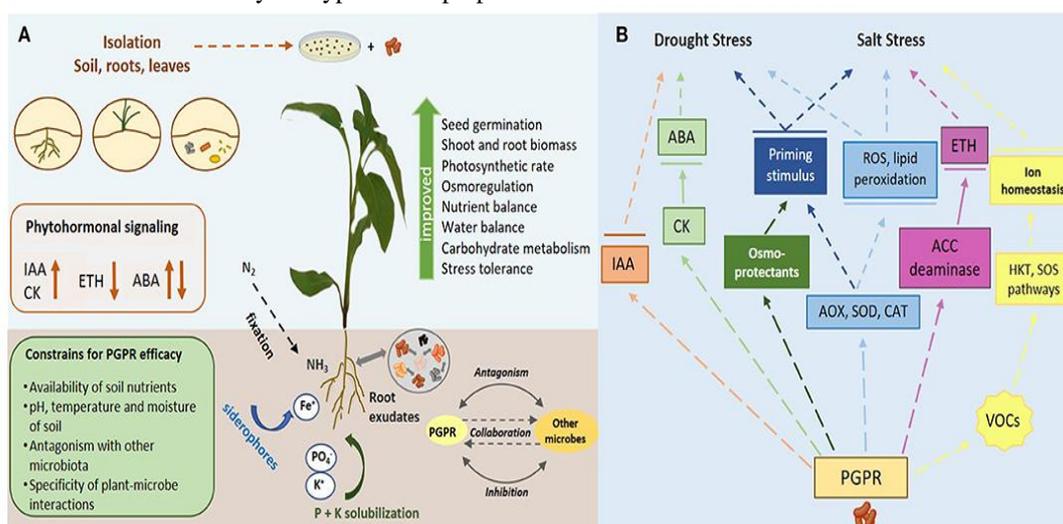


Figure 4. A description of PGPM's role in reducing the consequences of abiotic stress caused by salinity or drought. depending on [141].

There are two approaches to applying biopriming: either subject the investigated plant to stress and segregate endophytes from those that withstand stress, then identify them using morphological and molecular methods, and then apply biopriming. For wheat, earlier studies looked at a few isolates as PGP characteristics of endophytic fungus. *Trichoderma atroviride*, *Trichoderma hamatum*, *Septoriatritici*, *Setosphaeria rostrata*, *Stemphylium*, *Stemphylium botryosum*, *Talaromyces flavus*, and *Rhodotorula rubra* are a few of the endophytic fungi that affect wheat. [142,128].

Fungal endophyte	Host
<i>Cochliobolus sp.</i>	Wheat
<i>Curvularia sp.</i>	Wheat
<i>Drechslera sp.</i>	Wheat
<i>Glomus intraradices, BEG72</i>	Wheat
<i>Glomus mosseae</i>	Wheat
<i>Ophiostoma sp.</i>	Wheat
<i>Penicillium bilaiae, RS7B-SD1</i>	Wheat

<i>Setosphaeria rostrata</i>	Wheat
<i>Talaromyces flavus</i>	Wheat
<i>Trichoderma atroviride</i>	Wheat

Table (1): Multifunctional PGP attributes of endophytic fungi [143,144]. This research investigated whether biopriming wheat grains with endophytic fungal isolate can alleviate drought stress by analyzing the growth features, metabolic pathways, and gene expression in response to drought stress.

Conclusion and recommendation

Agriculture is currently being adversely affected by massive climate change and global warming. Because meeting the rising need for presence resources is not accessible in today's world, high-yielding stress-tolerant crops are urgently needed to preserve the balance between food production and rising human demand. Drought has a deleterious impact on wheat productivity and grain quality, necessitating the development of drought-tolerant wheat varieties. Wheat varieties are being bred for drought tolerance and to fulfill the demands of an ever-increasing global population using a variety of breeding procedures. Owing to the reduced content of total chlorophyll, total carotenoids, catalase activity, peroxidase activity, superoxide dismutase activity, antioxidant activity, total protein activity, proline content activity, total phenolic compound activity, and total flavonoid compound activity. Microbial seed priming alleviated the drought stress inhibitory impact on the drought-sensitive wheat's growth and physiological processes. By regulating osmolytes, photosynthetic pigments, and antioxidant enzymes, bio-primed grains were better able to establish into seedlings under drought stress. Based on these findings, one can conclude that the current study paves the way for a new method of mitigating abiotic stress in wheat via seed bio-priming with *A. fumigatus*. In this regard, it is critical to investigate the effect of seed bio-priming with *A. fumigatus* on the change of genes associated with stress and seed yield. Another conclusion is that Sids-1 and Gemmiza-7 are the most drought-resistant varieties that resist drought without effort when compared to others.

REFERENCES

1. Lesk, Corey, Pedram Rowhani, and Navin Ramankutty. "Influence of extreme weather disasters on global crop production." *Nature* 529.7584 (2016): 84-87.
2. Kingsbury, Noel. *Hybrid: the history and science of plant breeding*. University of Chicago Press, 2011.
3. Razzaq, Abdul, et al. "Physiological responses and drought resistance index of nine wheat (*Triticum aestivum* L.) cultivars under different moisture conditions." *Pak. J. Bot* 45.S1 (2013): 151-155.
4. FAO (2018a). *Crop Prospects and Food Situation. Quarterly Global Report*. Rome: Food and Agriculture Organization of the United Nations.
5. FAO (2018b). *Food Outlook: Biannual Report on Global Food Markets*. Rome: Food and Agriculture Organization of the United Nations.
6. FAO (2018c). *The State of Food Security and Nutrition in The World*. Rome: Food and Agriculture Organization of the United Nations.
7. Mohammad, Ayman A., et al. "Quinoa as non-wheat flour source and its utilization in sponge cake production: cultivation, nutritional and technological assessment Ayman A. Mohammad1, Heba M. Amer2, Fathy M. Mehaya1, and Mohamed S. Hussein2." *Sciences* 9.2 (2019): 332-340.
8. Cappelli, Alessio, and Enrico Cini. "Challenges and opportunities in wheat flour, pasta, bread, and bakery product production chains: A systematic review of innovations and improvement strategies to increase sustainability, productivity, and product quality." *Sustainability* 13.5 (2021): 2608.
9. Goncharov, Nikolay P. "Genus *Triticum* L. taxonomy: the present and the future." *Plant Systematics and Evolution* 295 (2011): 1-11.
10. Shewry, Peter R., and Sandra J. Hey. "The contribution of wheat to human diet and health." *Food and energy security* 4.3 (2015): 178-202.
11. Gowayed, Salah. *Egyptian wheat*. Cuvillier Verlag, 2009.
12. Elasaag, Yahia Hamid Amin. *Economics of Wheat in Egypt*. Diss. Agronomos, 2015.
13. Lambers, Hans, Francis Stuart Chapin, and Thijs Leendert Pons. *Plant physiological ecology*. Vol. 2. New York: Springer, 2008.
14. Naeem, Muhammad Kashif, et al. "Physiological responses of wheat (*Triticum aestivum* L.) to drought stress." *International Journal of Plant and Soil Science* 6.1 (2015): 1-9.
15. Mishra, Vimal, Keith A. Cherkauer, and Shraddhanand Shukla. "Assessment of drought due to historic climate variability and projected future climate change in the midwestern United States." *Journal of Hydrometeorology* 11.1 (2010): 46-68.
16. Liu, Caiyun, Zhiyuan Yang, and Yin-Gang Hu. "Drought resistance of wheat alien chromosome addition lines evaluated by membership function value based on multiple traits and drought resistance index of grain yield." *Field Crops Research* 179 (2015): 103-112.

17. **Li, Xinrong, et al.** "Divergent responses of moss-and lichen-dominated biocrusts to warming and increased drought in arid desert regions." *Agricultural and Forest Meteorology* 303 (2021): 108387.
18. **Wang, Wen, et al.** "Propagation of drought: from meteorological drought to agricultural and hydrological drought." *Advances in Meteorology* (2016).
19. **Anjum, S. A., et al.** "Gas exchange and chlorophyll synthesis of maize cultivars are enhanced by exogenously-applied glycinebetaine under drought conditions." *Plant, Soil and Environment* 57.7 (2011): 326-331.
20. **Dietz, K-J., Christian Zörb, and C-M. Geilfus.** "Drought and crop yield." *Plant Biology* 23.6 (2021): 881-893.
21. **Ali, Fawad, et al.** "Phenotypic stability of Zea mays grain yield and its attributing traits under drought stress." *Frontiers in plant science* 8 (2017): 1397.
22. **Dhakal, A.** "Effect of drought stress and management in wheat—A review." *Food Agribus. Manag* 2.2 (2021): 62-66.
23. **Fang, Yujie, and Lizhong Xiong.** "General mechanisms of drought response and their application in drought resistance improvement in plants." *Cellular and molecular life sciences* 72 (2015): 673-689.
24. **Ma, Jun, et al.** "Transcriptomics analyses reveal wheat responses to drought stress during reproductive stages under field conditions." *Frontiers in Plant Science* 8 (2017): 592.
25. **Jamali, Ali, et al.** "Morphological and yield responses of 20 genotypes of bread wheat to drought stress." *Archives of Biological Sciences* 72.1 (2020): 71-79.
26. **Farnia, A., and A. Tork.** "Changes in yield and yield components of wheat cultivars under water stress condition." *International Journal of Life Sciences* 9.5 (2015): 103-107.
27. **Das, Rupa, and Saikat Biswas.** "Influence of Abiotic Stresses on Seed Production and Quality." *Seed Biology Updates*. IntechOpen, 2022.
28. **Ahmad, I., et al.** "Morphological and physiological criteria for drought tolerance at seedling stage in wheat." *JAPS: Journal of Animal & Plant Sciences* 25.4 (2015).
29. **KIZILGEÇİ, Ferhat, et al.** "The drought effect on seed germination and seedling growth in bread wheat (*Triticum aestivum* L.)." *International Journal of Agriculture Environment and Food Sciences* 1.1 (2017): 33-37.
30. **Thapa, Sushil, et al.** "Soil water extraction and use by winter wheat cultivars under limited irrigation in a semi-arid environment." *Journal of Arid Environments* 174 (2020): 104046.
31. **Sidhu, Jagdeep Singh, et al.** "Genome-wide association study uncovers novel genomic regions associated with coleoptile length in hard winter wheat." *Frontiers in Genetics* 10 (2020): 1345.
32. **Tao, Ye, et al.** "Lower global warming potential and higher yield of wet direct-seeded rice in Central China." *Agronomy for Sustainable Development* 36 (2016): 1-9.
33. **Jaleel, Cheruth Abdul, et al.** "Drought stress in plants: a review on morphological characteristics and pigments composition." *Int. J. Agric. Biol* 11.1 (2009): 100-105.
34. **Leport, L., et al.** "Variation in pod production and abortion among chickpea cultivars under terminal drought." *European Journal of Agronomy* 24.3 (2006): 236-246.
35. **Anjum, Shakeel Ahmad, et al.** "Effect of progressive drought stress on growth, leaf gas exchange, and antioxidant production in two maize cultivars." *Environmental Science and Pollution Research* 23 (2016): 17132-17141.
36. **Bakht, S., et al.** "The response of major food crops to drought stress: Physiological and biochemical responses." *Agronomic Crops: Volume 3: Stress Responses and Tolerance* (2020): 93-115.
37. **Juenger, Thomas E., and Paul E. Verslues.** "Time for a drought experiment: Do you know your plants' water status?" *The Plant Cell* 35.1 (2023): 10-23.
38. **Mubarik, Muhammad Salman, et al.** "A manipulative interplay between positive and negative regulators of phytohormones: A way forward for improving drought tolerance in plants." *Physiologia Plantarum* 172.2 (2021): 1269-1290.
39. **Seleiman, Mahmoud F., et al.** "Drought stress impacts on plants and different approaches to alleviate its adverse effects." *Plants* 10.2 (2021): 259.
40. **Anjum, Shakeel Ahmad, et al.** "Growth and development responses of crop plants under drought stress: a review." *Zemdirbyste* 104.3 (2017): 267-276.
41. **Rahman, M., et al.** "Study on morpho-physiological traits in spring wheat (*Triticum aestivum* L.) Under rainfed condition." *Bangladesh Journal of Agricultural Research* 41.2 (2016): 235-250.
42. **Lou, Lili, et al.** "Photosynthetic and ascorbate-glutathione metabolism in the flag leaves as compared to spikes under drought stress of winter wheat (*Triticum aestivum* L.)." *PLoS One* 13.3 (2018): e0194625.
43. **Tian, Yonghang, et al.** "Genetic mapping of a QTL controlling leaf width and grain number in rice." *Euphytica* 202 (2015): 1-11.
44. **Zhao, Huan, et al.** "A drought rarity and evapotranspiration-based index as a suitable agricultural drought indicator." *Ecological Indicators* 82 (2017): 530-538.
45. **Fu, Jinmin, and Bingru Huang.** "Involvement of antioxidants and lipid peroxidation in the adaptation of two cool-season grasses to localized drought stress." *Environmental and Experimental Botany* 45.2 (2001): 105-114.

46. **Sharma, Davinder, et al.** "Wheat responses and tolerance to terminal heat stress: a review." *Wheat production in changing environments: responses, adaptation and tolerance* (2019): 149-173.
47. **Tan, Yanxiao, et al.** "Overexpression of MpCYS4, a phytocystatin gene from *Malus prunifolia* (Willd.) Borkh., enhances stomatal closure to confer drought tolerance in transgenic *Arabidopsis* and apple." *Frontiers in Plant Science* 8 (2017): 33.
48. **Sourour, Ayed, et al.** "A review: morphological, physiological, biochemical and molecular plant responses to water deficit stress." *Int J Eng Sci* 6.1 (2017): 1-4.
49. **Fang, Linchuan, et al.** "Expression of *Vitis amurensis* NAC26 in *Arabidopsis* enhances drought tolerance by modulating jasmonic acid synthesis." *Journal of experimental botany* 67.9 (2016): 2829-2845.
50. **Barnawal, Deepti, et al.** "Plant growth-promoting rhizobacteria enhance wheat salt and drought stress tolerance by altering endogenous phytohormone levels and TaCTR1/TaDREB2 expression." *Physiologia plantarum* 161.4 (2017): 502-514.
51. **Fahad, Shah, et al.** "Crop production under drought and heat stress: plant responses and management options." *Frontiers in plant science* (2017): 1147.
52. **Blum, Abraham.** "Osmotic adjustment is a prime drought stress adaptive engine in support of plant production." *Plant, cell & environment* 40.1 (2017): 4-10.
53. **Doneva, Dilyana, et al.** "The effects of putrescine pre-treatment on osmotic stress responses in drought-tolerant and drought-sensitive wheat seedlings." *Physiologia plantarum* 171.2 (2021): 200-216.
54. **Dziki, Dariusz, et al.** "Current trends in the enhancement of antioxidant activity of wheat bread by the addition of plant materials rich in phenolic compounds." *Trends in Food Science & Technology* 40.1 (2014): 48-61.
55. **Batool, Tahira, et al.** "Plant growth promoting rhizobacteria alleviates drought stress in potato in response to suppressive oxidative stress and antioxidant enzymes activities." *Scientific Reports* 10.1 (2020): 16975.
56. **Khan, Mudassar Nawaz, and Setsuko Komatsu.** "Proteomic analysis of soybean root including hypocotyl during recovery from drought stress." *Journal of proteomics* 144 (2016): 39-50.
57. **Hasanuzzaman, Mirza, et al.** "Regulation of ascorbate-glutathione pathway in mitigating oxidative damage in plants under abiotic stress." *Antioxidants* 8.9 (2019): 384.
58. **Gul, Zarmina, et al.** "An insight into abiotic stress and influx tolerance mechanisms in plants to cope in saline environments." *Biology* 11.4 (2022): 597.
59. **Nikolaeva, M. K., et al.** "Effect of drought on chlorophyll content and antioxidant enzyme activities in leaves of three wheat cultivars varying in productivity." *Russian Journal of Plant Physiology* 57 (2010): 87-95.
60. **Kaushal, Manoj, and Suhas P. Wani.** "**Rhizobacterial-plant interactions**: strategies ensuring plant growth promotion under drought and salinity stress." *Agriculture, Ecosystems & Environment* 231 (2016): 68-78.
61. **Huseynova, Irada M., et al.** "Drought-induced changes in photosynthetic apparatus and antioxidant components of wheat (*Triticum durum* Desf.) varieties." *Photosynthesis Research* 130 (2016): 215-223.
62. **Sharma, Anket, et al.** "Photosynthetic response of plants under different abiotic stresses: a review." *Journal of Plant Growth Regulation* 39 (2020): 509-531.
63. **Zivcak, Marek, et al.** "Photosynthetic electron transport and specific photoprotective responses in wheat leaves under drought stress." *Photosynthesis research* 117 (2013): 529-546.
64. **Lisar, S. Y., et al.** "Causes, effects and responses." *Water stress* 25.1 (2012): 33.
65. **Yeshi, Karma, et al.** "Plant secondary metabolites produced in response to abiotic stresses has potential application in pharmaceutical product development." *Molecules* 27.1 (2022): 313.
66. **Şirin, Seda, and Belma Aslım.** "Determination of antioxidant capacity, phenolic acid composition and antiproliferative effect associated with phenylalanine ammonia lyase (PAL) activity in some plants naturally growing under salt stress." *Medicinal Chemistry Research* 28 (2019): 229-238.
67. **Ceccaroni, Dayana, et al.** "Effect of the time and temperature of germination on the phenolic compounds of *Triticum aestivum*, L. and *Panicum miliaceum*, L." *Lwt* 127 (2020): 109396.
68. **Stagnari, Fabio, et al.** "Effects of sprouting and salt stress on polyphenol composition and antiradical activity of einkorn, emmer and durum wheat." *Italian Journal of Agronomy* 12.4 (2017).
69. **Zargar, Sajad Majeed, et al.** "Impact of drought on photosynthesis: Molecular perspective." *Plant gene* 11 (2017): 154-159.
70. **Dutta, Subhajit, et al.** "Oxidative and genotoxic damages in plants in response to heavy metal stress and maintenance of genome stability." *Plant signaling & behavior* 13.8 (2018): e1460048.
71. **Maluszynska, Jolanta, and Jolanta Juchimiuk.** "Plant genotoxicity: a molecular cytogenetic approach in plant bioassays." *Arh Hig Rada Toksikol* 56.2 (2005): 177-184.
72. **Chinnusamy, Viswanathan, and Jian-Kang Zhu.** "Epigenetic regulation of stress responses in plants." *Current opinion in plant biology* 12.2 (2009): 133-139.
73. **Kaur, A., A. Grewal, and P. Sharma.** "Comparative analysis of DNA methylation changes in two contrasting wheat genotypes under water deficit." *Biologia plantarum* 62 (2018): 471-478.

74. **Upreti, K. K., and Maryada Sharma.** "Role of plant growth regulators in abiotic stress tolerance." *Abiotic stress physiology of horticultural crops* (2016): 19-46.
75. **Mishra, Gyan P., et al.** "Epigenetics of Abiotic Stress Tolerance in Legumes." *Legumes: Physiology and Molecular Biology of Abiotic Stress Tolerance*. Singapore: Springer Nature Singapore, 2023. 89-114.
76. **Khaled, A. G. A., M. H. Motawea, and A. A. Said.** "Identification of ISSR and RAPD markers linked to yield traits in bread wheat under normal and drought conditions." *Journal of Genetic Engineering and Biotechnology* 13.2 (2015): 243-252.
77. **Shi, Rui, et al.** "Utilization of transcriptome, small RNA, and degradome sequencing to provide insights into drought stress and rewatering treatment in *Medicago ruthenica*." *Frontiers in Plant Science* 12 (2021): 675903.
78. **Wei, Liting, et al.** "Abscisic acid enhances tolerance of wheat seedlings to drought and regulates transcript levels of genes encoding ascorbate-glutathione biosynthesis." *Frontiers in plant science* 6 (2015): 458.
79. **Gaponenko, A. K., et al.** "Perspectives of use of transcription factors for improving resistance of wheat productive varieties to abiotic stresses by transgenic technologies." *Russian journal of genetics* 54 (2018): 27-35.
80. **Agarwal, Pradeep K., et al.** "Role of DREB transcription factors in abiotic and biotic stress tolerance in plants." *Plant cell reports* 25 (2006): 1263-1274.
81. **Strader, Lucia, Dolf Weijers, and Doris Wagner.** "Plant transcription factors—Being in the right place with the right company." *Current Opinion in Plant Biology* 65 (2022): 102136.
82. **Zhang, Hong Ying, et al.** "Characterization of genomic sequence of a drought-resistant gene TaSnRK2. 7 in wheat species." *Journal of genetics* 94 (2015): 299-304.
83. **NIU, CAN-FANG, et al.** "Wheat WRKY genes TaWRKY2 and TaWRKY19 regulate abiotic stress tolerance in transgenic *Arabidopsis* plants." *Plant, cell & environment* 35.6 (2012): 1156-1170.
84. **Dong, Baodi, et al.** "Effects of drought stress on pollen sterility, grain yield, abscisic acid and protective enzymes in two winter wheat cultivars." *Frontiers in Plant Science* 8 (2017): 1008.
85. **Petrov, P., et al.** "Relationships between leaf morpho-anatomy, water status and cell membrane stability in leaves of wheat seedlings subjected to severe soil drought." *Journal of Agronomy and Crop Science* 204.3 (2018): 219-227.
86. **Khoudi, Habib.** "SHINE clade of ERF transcription factors: A significant player in abiotic and biotic stress tolerance in plants." *Plant Physiology and Biochemistry* (2022).
87. **Nezhadahmadi, Arash, Zakaria Hossain Prodhan, and Golam Faruq.** "Drought tolerance in wheat." *The Scientific World Journal* 2013 (2013).
88. **Sheoran, S., et al.** "Genetic and molecular dissection of drought tolerance in wheat and barley." *J Wheat Res* 7 (2016): 1-13.
89. **LI, Xiao-lan, et al.** "Biotic and abiotic stress-responsive genes are stimulated to resist drought stress in purple wheat." *Journal of Integrative Agriculture* 19.1 (2020): 33-50.
90. **Juszczak, Iłona, and Dorothea Bartels.** "LEA gene expression, RNA stability and pigment accumulation in three closely related Linderniaceae species differing in desiccation tolerance." *Plant Science* 255 (2017): 59-71.
91. **Bücker-Neto, Lauro, et al.** "Interactions between plant hormones and heavy metals responses." *Genetics and molecular biology* 40 (2017): 373-386.
92. **Grzesiak, Stanislaw, et al.** "Variation among wheat (*Triticum easativum* L.) genotypes in response to the drought stress: I–selection approaches." *Journal of Plant Interactions* 14.1 (2019): 30-44.
93. **Chowdhury, J. A., et al.** "Effect of drought stress on gas exchange characteristics of four soybean genotypes." *Bangladesh Journal of Agricultural Research* 41.2 (2016): 195-205.
94. **Fathi, Amin, and Davood Barari Tari.** "Effect of drought stress and its mechanism in plants." *International Journal of Life Sciences* 10.1 (2016): 1-6.
95. **Guo, W. W., et al.** "Regeneration and molecular characterisation of two interspecific somatic hybrids of *Citrus* for potential rootstock improvement." *The Journal of Horticultural Science and Biotechnology* 83.4 (2008): 407-410.
96. **Mitra, Gyanendranath.** "Molecular approaches to nutrient uptake and cellular homeostasis in plants under abiotic stress." *Plant nutrients and abiotic stress tolerance* (2018): 525-590.
97. **Hossain, Akbar, et al.** "Strigolactones: a novel carotenoid-derived phytohormone–biosynthesis, transporters, signalling, and mechanisms in abiotic stress." *Plant Growth Regulators: Signalling Under Stress Conditions* (2021): 275-303.
98. **Khater, M. A., et al.** "Enhancement the performance of cowpea plants grown under drought conditions via trehalose application." *Middle East J* 7.3 (2018): 782-800.
99. **Vilela, Romel Duarte, et al.** "Antioxidant system is essential to increase drought tolerance of sugarcane." *Annals of Applied Biology* 171.3 (2017): 451-463.
100. **Shinde, Suhas, et al.** "Proline coordination with fatty acid synthesis and redox metabolism of chloroplast and mitochondria." *Plant Physiology* 172.2 (2016): 1074-1088.

101. **Ibrahim, Hemmat A., and Yasmin MR Abdellatif.** "Effect of maltose and trehalose on growth, yield and some biochemical components of wheat plant under water stress." *Annals of Agricultural Sciences* 61.2 (2016): 267-274.
102. **Munjal, Renu, and Satyavir Singh Dhanda.** "Assessment of drought resistance in Indian wheat cultivars for morpho-physiological traits." *Ekin Journal of Crop Breeding and Genetics* 2.1 (2016): 74-81.
103. **Fahad, Shah, et al.** "Crop production under drought and heat stress: plant responses and management options." *Frontiers in plant science* (2017): 1147.
104. **Lim, Chae Woo, et al.** "Function of ABA in stomatal defense against biotic and drought stresses." *International journal of molecular sciences* 16.7 (2015): 15251-15270.
105. **Bielach, Agnieszka, Monika Hrtyan, and Vanesa B. Tognetti.** "Plants under stress: involvement of auxin and cytokinin." *International journal of molecular sciences* 18.7 (2017): 1427.
106. **Sallam, Ahmed, et al.** "Drought stress tolerance in wheat and barley: advances in physiology, breeding and genetics research." *International journal of molecular sciences* 20.13 (2019): 3137.
107. **Sheoran, S., et al.** "Genetic and molecular dissection of drought tolerance in wheat and barley." *J Wheat Res* 7 (2016): 1-13.
108. **Gahlaut, Vijay, et al.** "Transcription factors involved in drought tolerance and their possible role in developing drought tolerant cultivars with emphasis on wheat (*Triticum aestivum* L.)." *Theoretical and Applied Genetics* 129 (2016): 2019-2042.
109. **Yang, Yunfei, et al.** "Transcriptional network involved in drought response and adaptation in cereals." *Abiotic and Biotic Stress in Plants-Recent Advances and Future Perspectives* (2016): 3-29.
110. **Li, Yaqing, et al.** "MYB-CC transcription factor, TaMYBsm3, cloned from wheat is involved in drought tolerance." *BMC Plant Biology* 19.1 (2019): 1-11.
111. **Tomar, Ram Sewak Singh, et al.** "Molecular and morpho-agronomical characterization of root architecture at seedling and reproductive stages for drought tolerance in wheat." *PloS one* 11.6 (2016): e0156528.
112. **Faheem, Muhammad, et al.** "Assessment of D-genome based genetic diversity in drought tolerant wheat germplasm." *International Journal of Agriculture and Biology* 17.4 (2015).
113. **Kulkarni, Manoj, et al.** "Drought response in wheat: key genes and regulatory mechanisms controlling root system architecture and transpiration efficiency." *Frontiers in chemistry* 5 (2017): 106.
114. **Gupta, Pushpendra Kumar, Harindra Singh Balyan, and Vijay Gahlaut.** "QTL analysis for drought tolerance in wheat: present status and future possibilities." *Agronomy* 7.1 (2017): 5.
115. **Jisha, K. C., K. Vijayakumari, and Jos T. Puthur.** "Seed priming for abiotic stress tolerance: an overview." *Acta Physiologiae Plantarum* 35 (2013): 1381-1396.
116. **Paris, Thelma R.** Guide to participatory varietal selection for submergence-tolerant rice. IRRI, 2011.
117. **Maheshwari, Dinesh K., et al.** "Nutrient availability and management in the rhizosphere by microorganisms." *Bacteria in agrobiolgy: Stress management* (2012): 301-326.
118. **Porrás-Alfaro, Andrea, and Paul Bayman.** "Hidden fungi, emergent properties: endophytes and microbiomes." *Annual review of phytopathology* 49 (2011): 291-315.
119. **Hallmann, Johannes, and Richard A. Sikora.** "Endophytic fungi." *Biological control of plant-parasitic nematodes: building coherence between microbial ecology and molecular mechanisms* (2011): 227-258.
120. **Pandey, Pragati, and Tulika Mishra.** "SEED PRIMING: AN EFFECTIVE TECHNIQUE FOR SEED GERMINATION." (2022).
121. **Shahzad, Raheem, et al.** "Inoculation of abscisic acid-producing endophytic bacteria enhances salinity stress tolerance in *Oryza sativa*." *Environmental and Experimental Botany* 136 (2017): 68-77.
122. **Verma, Priyanka, et al.** "Beneficial plant-microbes interactions: biodiversity of microbes from diverse extreme environments and its impact for crop improvement." *Plant-microbe interactions in agro-ecological perspectives: volume 2: microbial interactions and agro-ecological impacts* (2017): 543-580.
123. **Singh, Ram N., et al.** "First high quality draft genome sequence of a plant growth promoting and cold active enzyme producing psychrotrophic *Arthrobacter agilis* strain L77." *Standards in genomic sciences* 11 (2016): 1-9.
124. **Dos Reis, Jefferson Brendon Almeida, Adriana Sturion Lorenzi, and Helson Mario Martins do Vale.** "Methods used for the study of endophytic fungi: a review on methodologies and challenges, and associated tips." *Archives of Microbiology* 204.11 (2022): 675.
125. **Alsohaili, Sohail A., and Bayan M. Bani-Hasan.** "Morphological and molecular identification of fungi isolated from different environmental sources in the Northern Eastern desert of Jordan." *Jordan Journal of Biological Sciences* 11.3 (2018).
126. **Ikechi-Nwogu, G. C., et al.** "Isolation and Identification of Fungi Associated with Habanero Pepper (*Capsicum chinense* jacq) Using Basic Molecular Techniques." *Journal of Applied Sciences and Environmental Management* 25.7 (2021): 1121-1125.

127. **Ortiz, J., et al.** "Alleviation of metal stress by *Pseudomonas orientalis* and *Chaetomium cupreum* strains and their effects on *Eucalyptus globulus* growth promotion." *Plant and Soil* 436 (2019): 449-461.
128. **Yadav, Ajar Nath, et al.** "New and future developments in microbial biotechnology and bioengineering." (2018): 3-18.
129. **Anderson, Ian C., and John WG Cairney.** "Diversity and ecology of soil fungal communities: increased understanding through the application of molecular techniques." *Environmental microbiology* 6.8 (2004): 769-779.
130. **Soni, Ruchi, Sarita K. Yadav, and Ajay Singh Rajput.** "ACC-deaminase producing rhizobacteria: prospects and application as stress busters for stressed agriculture." *Microorganisms for Green Revolution: Volume 2: Microbes for Sustainable Agro-ecosystem* (2018): 161-175.
131. **Drogue, Benoît, et al.** "Control of the cooperation between plant growth-promoting rhizobacteria and crops by rhizosphere signals." *Molecular microbial ecology of the rhizosphere* 1 (2013): 279-293.
132. **El-Sayed, A. S., and A. A. Shindia.** "Characterization and immobilization of purified *Aspergillus flavipes* l-methioninase: continuous production of methanethiol." *Journal of Applied Microbiology* 111.1 (2011): 54-69.
133. **Lutts, Stanley, et al.** "Seed priming: new comprehensive approaches for an old empirical technique." *New challenges in seed biology-basic and translational research driving seed technology* 46 (2016).
134. **Paparella, S., et al.** "Seed priming: state of the art and new perspectives." *Plant cell reports* 34 (2015): 1281-1293.
135. **Bisen, Kartikay, et al.** "Unrealized potential of seed biopriming for versatile agriculture." *Nutrient use efficiency: from basics to advances* (2015): 193-206.
136. **De Zelicourt, Axel, Mohamed Al-Yousif, and Heribert Hirt.** "Rhizosphere microbes as essential partners for plant stress tolerance." *Molecular plant* 6.2 (2013): 242-245.
137. **Li, Ping, et al.** "Possible mechanisms of control of *Fusarium* wilt of cut chrysanthemum by *Phanerochaete chrysosporium* in continuous cropping fields: A case study." *Scientific reports* 7.1 (2017): 15994.
138. **Devi, Rube, et al.** "Beneficial fungal communities from different habitats and their roles in plant growth promotion and soil health." *Microbial Biosystems* 5.1 (2020): 21-47.
139. **Shukla, N., et al.** "Seed biopriming with drought tolerant isolates of *Trichoderma harzianum* promote growth and drought tolerance in *Triticum aestivum*." *Annals of applied Biology* 166.2 (2015): 171-182.
140. **Salamon, Sylwia, et al.** "Changes in root-associated fungal communities in *Triticum aestivum* ssp. *spelta* L. and *Triticum aestivum* ssp. *vulgare* L. under drought stress and in various soil processing." *Plos one* 15.10 (2020): e0240037.
141. **Mellidou, Ifigeneia, and Katerina Karamanoli.** "Unlocking PGPR-mediated abiotic stress tolerance: what lies beneath." *Frontiers in Sustainable Food Systems* 6 (2022).
142. **Saxena, A. K., et al.** "Microbial diversity of extreme regions: an unseen heritage and wealth." *Indian Journal of Plant Genetic Resources* 29.3 (2016): 246-248.
143. **Spagnoletti, Federico Nicolás, et al.** "Dark septate endophytes present different potential to solubilize calcium, iron and aluminum phosphates." *Applied Soil Ecology* 111 (2017): 25-32.
144. **Colla, Giuseppe, et al.** "Coating seeds with endophytic fungi enhances growth, nutrient uptake, yield and grain quality of winter wheat." *Int. J. Plant Prod* 9.2 (2015): 171-190.