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Effects of Heat and Drought Stress on Sustainable Agriculture and Future Food Security in Türkiye

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ABSTRACT

This review investigates the effects of heat and drought stress on future food security of Turkish agriculture. Temperature average is expected to rise to 3.2°C at the end of the current century while annual precipitation will decline more than 10% in the west and south and rise by 20% in the north of Türkiye, implying that climate change will affect ecosystem sustainability. It is therefore crucial to develop strategies to mitigate and adapt to climate change such as adjusting the planting schedule, reduced tillage, fertiliser microdosing, pre-sowing seed treatment, and the application of growth promoting bacteria to improve tolerance to stress by comprehending how plants respond physiologically and biochemically under these stress conditions. Long-term heat stress may hinder photosynthetic electron transport, decreasing the plant's ability to make use of energy for photosynthesis. The immediate response of plants under drought stress involves closing stomatal openings to reduce water loss through stomatal conductance. Combined heat and drought stress have a greater adverse effect on plant development and production than their effects in isolation. Plant phenotyping can play a major role in "climate-proofing" Turkish agriculture through the identification and development of crop varities with improved prouctivity, climate resilience and input requirements. Digital agriculture will also improve the efficiency of Turkish agricultural systems as the adapt to a hotter drier climate. To ensure future food security and the viability of the agro-economic system in Türkiye steps must be taken to make Turkish agriculture more robust in preparation for the impacts of climate change.

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Introduction

Türkiye, situated in the eastern Mediterranean Basin, is identified as one of the regions most susceptible to climate change according to the Intergovernmental Panel on Climate Change (IPCC). The country grapples with notable challenges in agriculture and various sectors due to these environmental shifts (Ağaçayak and Keyman, 2018). Despite being the second-largest sector in the Turkish economy, agriculture has witnessed a decline in land area from 26.3 million hectares in 2001 to 23.7 million hectares in 2016 (Ağaçayak and Keyman, 2018). Türkiye experiences an average precipitation of about 643 mm/yr, totaling 501 billion m3/yr precipitation. However, with only approximately 112 billion m3 of accessible water, Türkiye confronts water stress, particularly aggravated by excessive groundwater utilization in agricultural areas such as Konya province, where more than 600 sinkholes have emerged, endangering agricultural endeavors (ERF policy).

Climate change, recognized as a global concern, significantly impacts food security and agriculture. Defined as alterations to the global atmosphere's composition attributed directly or indirectly to human activity, climate change poses hazards like increased climate variability, more frequent extreme weather events, and temperature fluctuations that jeopardize agriculture (Bozoglu et al., 2019). These alterations can affect various aspects of agriculture, including crop production, markets, food prices, and supply chain infrastructure, among others (Bozoglu et al., 2019).

The Mediterranean Basin, encompassing Türkiye, is projected to be among the most affected regions, contending with severe heat waves, rising temperatures, diminished precipitation, reduced soil moisture, and escalating sea levels (Dellal and Unuvar, 2019). These shifts are expected to result in heightened occurrences of intense extreme weather events such as floods and droughts, notably impacting semi-arid and arid regions within the Mediterranean (Dellal and Unuvar, 2019). Despite possessing 24 million hectares of agricultural land, only approximately 20% are irrigated, with the remaining 80% reliant on rainfall. However, over 70% of Türkiye's total water resources are utilized for agricultural irrigation (Dellal and Unuvar, 2019; Ahmed et al., 2022). This excessive water consumption, coupled with elevated temperatures and drought conditions, exacerbates the situation. Illegal groundwater drilling compounds the issue, as highlighted by a survey conducted by the Turkish Industry and Business Association (TÜSİAD), reporting a 97% decrease in harvests and yields among farmers due to climate change-related impacts (TÜSİAD).

The two main abiotic restrictions to plant growth in every future climate change scenario are drought and heat stress. Whenever these circumstances get even more extreme, either separately or in combination, agricultural productivity and food security would be drastically reduced. Negative environmental factors that affect agriculture and lower crop productivity include unfavorable temperatures (hot or low), drought stress, and salt stress (Bashir et al., 2019). Althought they hinder the rate which crops are produced at all phases of plant growth, the severity of injury during the phase related to reproduction, particularly the filling stage of seeds which determines the seed quality, is crucial and results in significant decrease in crop yield. Both drought and heat stress have a considerable effect on the seedling rate by diminishing either seed number or seed size, ultimately having an impact on the marketing trait of seeds and their quality. More consideration is required since these stresses, when combined, have an adverse effect on seed quality (Sehgal et al., 2018). There is a decrease in agricultural yield and increase in crop losses as a result of the drop in precipitation and rise in temperatures. To develop techniques to increase stress tolerance, it is essential to comprehend the systems referring to related genes, physiology or biochemistry that control the multiple seed filling activities under harsh environmental conditions (Sehgal et al., 2018). Abiotic factors distinctly influence the reproductive growth phase of numerous crops, and have been demonstrated to cause a reduction in crop yields, therefore affecting food security in a negative way. Plants have a number of adaptative and avoidance strategies to lessen the negative impacts of drought and heat stress (Kumari et al., 2021; Kamal et al., 2019). When both of these stresses are present, they tend to have more detrimental impacts on plant growth and yield as comparison to their effects when they occur alone (Kumari et al., 2021).

The great bulk of food we consume are obtained from crops cultivated in the field; thus, global food security is seriously threatened by the interaction of drought and heat stress (Cohen et al., 2021; Killi et al., 2017). Biochemical and morpho-physiological changes could be generalised to encompass a wide spectrum of plant responses to various challenges (Fahad et al., 2017). It is crucial to comprehend how crops react physiologically and biochemically to any unfavourable situation to create strategies and mechanisms for plant tolerance. Kavas et al., (2013) carried out research to explore drought resilience in melon cultivars. Drought tolerance in the studied melon cultivars was directly connected to an increase in enzyme activity brought on by antioxidants. Leaf rolling was a key adaptation observed in the most tolerant cultivar to protect photosynthesis, thereby reducing yield loss (Saglam et al., 2014). Stress alters the physiology of plants which impairs different growth stages including vegetative or reproductive organ production (Kumari et al., 2021; Sehgal et al., 2018). If stress occurs throughout the reproductive growth stage, it is more detrimental to crop production since initial termination of flower development an irreversible process that reduces grain size and weight resulting in spikelet sterility (Govindaraj et al., 2018; Cohen et al., 2021; Khan et al., 2021). Crops survive drought conditions by maturing more rapidly, before the impact of prolonged drought stress becomes excessive (Govindaraj et al., 2018; Cohen et al., 2021). Photosynthetic diffusional constraints affect yield in drought stressed rice cultivars during flowering (Lauteri et al., 2014). Developing tolerance to both drought and heat stresses has been a top target for biotech firms and breeders (Cohen et al., 2021). Practical agronomic techniques include adjusting the planting schedule, reduced tillage, microdosing of fertilizers, pre-sowing seed treatment, and the use of plant growth promoting bacteria may aid to some extent in minimising the deleterious effect of combined stress of heat and drought (Kumari et al., 2021). Under varying climates, these technologies can lower the possible risks, increase soil fertility and productivity (Dar et al., 2013). Beneficial bacteria in the plant's rhizosphere create plant growth-promoting (PGP) substances, which protect plants from living or non-living things and support their normal functional activities (Ojuederie et al., 2019).

Physiological changes in plants subjected to drought stress, heat stress or both of these stresses have been observed. Compared to either drought or heat stresses, interaction of both of them caused a discernible drop in total chlorophyll content (Alhaithloul, 2019). Both drought and heat stresses significantly inhibited various growth traits (see Table 1) such as the number of leaves, plant height, fresh / dry shoot weight, and the reproductive efficiency of plants (Hussain et al., 2019; Bhardwaj et al., 2021). More harm was caused by drought stress in terms of lowering stomatal conductance (Alhaithloul, 2019), while in terms of physiological variables including chlorophyll content, plant height and photosynthesis, heat stress had a greater influence than drought (Alhaithloul, 2019). Furthermore, respiration linked to the tricarboxylic acid cycle pathway in corn is downregulated during heat and drought stress (Alhaithloul, 2019).

Table 1 summarizes the effects of heat stress, drought stress, and combined stress on various physiological parameters in plants, including inhibition of seed production, reduction in plant height, chlorophyll content, stomatal conductance, induction of hydrogen peroxide concentration, lipid peroxidation, electrolyte leakage, and other morpho-physiological changes (Fahad et al., 2017; Alhaithloul, 2019; Bhardwaj et al., 2021; Giordano et al., 2021; Hassan et al., 2021; Kumari et al., 2018; He et al., 2018; Hadebe et al., 2017; Calanca et al., 2017; Killi et al., 2020; Awasthi et al., 2017; Rajendran et al., 2020; Zhou et al., 2019; Hussain et al., 2019; Sehgal et al., 2017; Wang et al., 2015; Balota et al., 2008; Cohen et al., 2021; Perdomo et al., 2017; Sattar et al., 2020; Zinta et al., 2014; Sehgal et al., 2019; Conde et al., 2011; Rizhsky et al., 2002; Zandalinas et al., 2018; Raja et al., 2020; Machado and Paulsen, 2001).

Table 1. Effects of heat, drought, and combined stress

Heat Stress (H)	Drought Stress (D)	Combined Stress (H + D)
• -Inhibition of seed production (Fahad et al., 2017; Alhaithloul, 2019). • -Reduction in plant height (Alhaithloul, 2019). • -More significant decline in total chlorophyll content (Bhardwaj et al., 2021). • -Stomatal conductance decrease not that severe (Bhardwaj et al., 2021; Giordano et al., 2021). • -Induction of Hydrogen peroxide concentration (Alhaithloul, 2019; Hassan et al., 2021). • -Increased electrolyte leakage into the water and lipid peroxidation (Kumari et al., 2018; Alhaithloul, 2019). • -Soil water loss (He et al., 2018; Alhaithloul, 2019).	• -Less significant decline in total chlorophyll (Hadebe et al., 2017; Alhaithloul, 2019). • -Severe decrease stomatal conductance (Calanca et al., 2017; Killi et al., 2020; Bhardwaj et al., 2021). • • -Induction of Hydrogen peroxide concentration (Alhaithloul, 2019). • -Lipid peroxidation and leaf electrolyte leakage induction (Alhaithloul, 2019). • -Accumulation of phenols more conspicuously than heat stress (Alhaithloul, 2019).	• -Plant height (Awasthi et al., 2017; Rajendran et al., 2020), • -Leaf area (Zhou et al., 2019), • -Number of branches, root development (Hussain et al., 2019), • -Total flowers (Sehgal et al., 2017), • -Total pods (Sehgal et al., 2017), • -Biomass (Awasthi et al., 2017), • -Water content in crops (Wang et al., 2015), • -Stomatal conductance (Balota et al., 2008; Cohen et al., 2021), • -Chlorophyll content (Perdomo et al., 2017; Sattar et al., 2020), • -Photosynthesis (Zinta et al., 2014) decreases in stressed crops. • -Stomatal density (Sehgal et al., 2019), • -Electrolyte leakage (Conde et al., 2011), • -Respiration (Rizhsky et al., 2002), • -ROS production (Zandalinas et al., 2018), --Lipid peroxidation, antioxidant production (Raja et al., 2020), stress proteins, leaf chlorosis and senescence increases (Machado and Paulsen 2001).

The Effect of Heat and Drought Stress on Plant Carbon and Water Balance

As temperatures rise to excessive levels, rates of photosynthesis decline and photorespiration increases (Berry and Björkman 1980). This is caused by the affinity of the enzyme ribulose-1,5-bisphosphate carboxylase / oxygenase for carbon dioxide decreasing at high temperatures (Crafts-Brandner and Salvucci 2000). Prolonged exposure to heat stress can impair photosynthetic electron transport, reducing the capacity of the plant to utilise energy for photosynthesis, commonly termed photochemical energy usage (Feller et al., 1998; Sharkey 2005). The initial response of plants to a reduction in soil water availability is to close stomata and reduce stomatal conductance as a result of a series of hormonal and hydraulic signals of soil drying (Davies and Zhang 1991; Tardieu and Davies 1992). This reduction in stomatal conductance not only reduces transpirative water loss, but also the entry of carbon dioxide into the leaf for photosynthesis. The increase in diffusive resistance to carbon dioxide transport to the location of carboxylation results in a decrease in rates of photosynthesis (Flexas et al., 2002; Killi and Haworth 2017). Longer-term exposure to heat stress (Killi et al., 2017) and drought (Haworth et al., 2019) can also affect the biochemical efficiency of photosynthesis. Specifically, both stresses result in an increase in the generation of reactive oxygen species as intercepted light energy cannot be used for photosynthesis or dissipated safely (Killi et al., 2020). If this oxidative stress overwhelms protective antioxidant systems, this can result in photooxidative stress and damage to photosynthetic apparatus such as the chloroplast thylakoid membranes where photosystem II electron transport occurs (Heckathorn et al. 1998; Crafts-Brandner and Salvucci 2002). More detailed reviews of the physiological effects of heat and drought stress can be found in Killi et al. (2017) and Zandalinas et al. (2018).

Plant physiological status underlies the response of individuals to the diffusive and biochemical constraints imposed by heat and drought stress. Variation in photosynthetic physiology, leaf gas exchange capabilities and protective physiology may be exploited to develop more climate tolerant crops suited to a hotter drier future. Figure 1 shows the response of stomatal conductance to progressive soil drying in drought tolerant and sensitive varieties of sunflower. The drought sensitive variety of sunflower exhibits an earlier drop in stomatal conductance than its drought tolerant counterpart. Furthermore, when grown at a higher temperature, the more climate resilient drought tolerant variety exhibits higher rates of leaf gas exchange than the sensitive variety. This illustrates the potential utility of physiological analysis in identifying climate resilient varieties through plant phenotyping programs (Haworth et al., 2023).

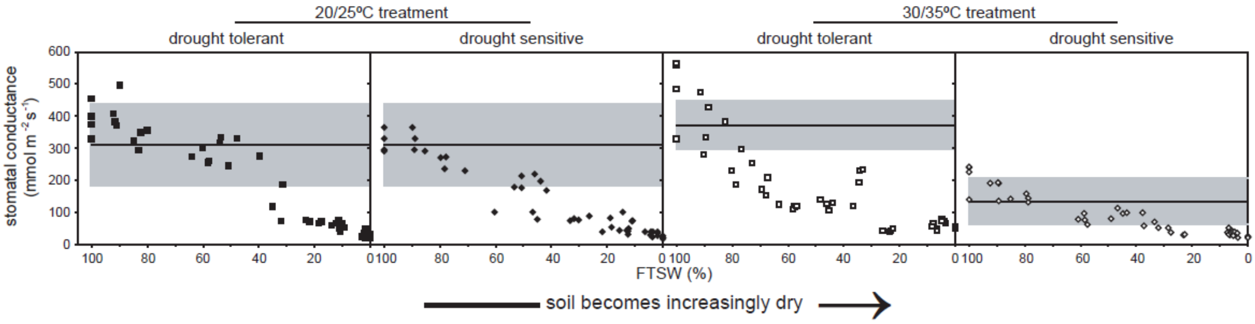

Figure 1. Stomatal conductance response of tolerant and sensitive sunflower varieties

The absence of a centralised plant phenotyping platform in Türkiye is a profound impediment to climate-proofing Turkish agriculture through adaptation to climate change and land degradation (Costa et al., 2019).

Figure 1: stomatal conductance response of drought tolerant (square symbols) and drought sensitive (diamond symbols) sunflower to progressive soil drying (indicated by the Fraction of Transpirable Soil Water – FTSW) at a night/day temperature regime of 20/25°C (black fill) and 30/35°C (white fill). Black horizontal line indicates the mean stomatal conductance values of control plants, grey shading either side indicates +/- one standard error of the mean. Re-drawn from Killi et al. (2017).

Plant Phenotyping as a Tool to Develop Food Security in Türkiye

Food access and stability of production are crucial to guarantee reliable access to food in the future. If collective attempts to revive and conserve food are not initiated in the near future, the resources required to produce new varieties that can cope with harsh environmental conditions while offering superior nutrition would be depleted (Zsögön et al., 2017). We may shift our focus away from the traditional agricultural model and onto less-popular native crops with bright prospects for easing world hunger and maintaining food security. Scientists are becoming interested in the utilisation of traditional food plants, therefore comprehending their genetic basis for further enhancement is critical. Recent breakthroughs in high throughput omics technologies enable the dissection of the chemical and hereditary basis of phenotypes related to stress tolerance and nutrition. (Fukushima et al., 2009). Omics approaches are vital for finding the genes that control a certain attribute of interest in plants. The combination of computational bioinformatics instruments with low-cost sequencing technologies and the use of automated equipment via high-throughput phenotyping technology may improve the discovery of genes governing essential agricultural aspects related to food quality (Steinwand and Ronald, 2020).

Effects of Heat and Drought on Soil Health

The organisation of primary and secondary particles in a soil mass that regulates how much air and water in the soil is referred to as the soil structure. Soil health has been defined as an essential component of sustainable agriculture. Soils perform important ecological functions such as infiltration capacity, organic carbon accumulation, water flow and storage, and root and microbial community activity (Patil and Lamnganbi, 2018). Maintaining soil quality becomes critical for an ecosystem to thrive. Drought and heat have an impact on all parts of our communities and environment (Sharma and Gobi, 2016).

Soil Organic Carbon (SOC) has an enormous effect on soil health quality, and functionality. Yearly greenhouse effect caused by fossil C is calculated to be 8.9 giga tonnes C (8.9×10^{15} g), and soil C upto 2 m of soil depth of 2400 giga tonnes (2400×10^{15} g). As a result, elevating SOC has been put forward as an approach to reducing climate change. The carbon emissions caused by human activity over total soil organic carbon stock ratio (8.9/2400), equals to 0.4% (4 per mile). It has been proposed that one strategy to reduce the effects of global warming is to boost soil organic carbon content by improving soil structure and health (Minasny et al., 2017). Soil Organic Carbon (SOC) above the critical level is required for soil aggregation, which regulates soil aeration and water retention, which also regulates tolerance to heat, drought and abrupt climate change; rhizospheric processes, and gaseous emissions (e.g., CO_2, CH_4, N_2O), which regulate atmospheric chemistry (Lal, 2016). Soil health is additionally related to animal, human, and environmental health in the surrounding area. Soil health improvements, together with increased availability of water and nutrients, boost soil resilience to extreme events associated with climate change (Lal, 2016).

Drought degrades land, which negatively impacts resource-dependent rural populations (Hermans and McLeman, 2021). The loss of soil fertility decreases the soil capacity for storing soil carbon and this land degradation may exacerbate global warming through increasing the level of carbon dioxide in the atmosphere. Severe environmental conditions especially heat and drought degrade areas used for feeding livestock and diminish crop production, resulting in higher animal deaths and decreased revenue from animal selling, which leads to food insecurity (Hermans and McLeman, 2021). The biggest field crops farmed in Türkiye are wheat, barley, maize, sunflower, and cotton, which account for more than 72% of the total harvested area. The majority of climate change scenarios expect that temperature will reach 3°C, yearly precipitation will generally fall by 30% in the west and south and rise by 20% in the north of Türkiye. Heat and drought stress are therefore major concerns for Turkish agriculture (Tatar, 2016). According to Dogan and Kan, 2019, even 1% rise in temperature results in a reduction in wheat yield of 0.84%, 0.48%, and 0.43% in slight, severe or moderate drought zones, respectively. Both the vegetation and the wildlife of the environment suffer from drought. Drought effects can either be temporary or long-term. The two most significant effects of drought are the loss of soil biodiversity and soil erosion. Long-term deterioration of nutrient availability and soil structure may result from a pattern of persistent drought, which may also cause an associated decrease in organic matter and a loss of aggregate stability. The negative consequences of drought can considerably disrupt the process related to biological breakdown by reducing the water that is accessible in the soil (Sharma and Gobi, 2016). Many microorganisms are unable to endure acute drought and heat stress due to a lack of potential survival strategies. According to Geng et al. (2015), the optimum mass water content of soil for carbon contained within the organism of soil organic matter such as fungi and bacteria was 19.5%, and the threshold of biomass carbon to drought was 14.3%, which may potentially show that soil ecosystem changes and crop irrigation is required. We can conclude from this that the bulk moisture level of soil needs to be maintained above 10% to keep the entire soil form intact.

Another significant factor that varies over the long and short term is soil temperature, which is determined by the proportion of energy received relative to the energy released from the soil. The temperature of the soil has an impact on the pace of breakdown of different organic substances. Organic material from remains of organisms is reduced by higher soil temperatures, and soil cation exchange capacity is also reduced by smaller clay particles (Onwuka and Mang, 2018). Increased temperature will hasten soil erosion and organic matter decomposition, leading to higher carbon dioxide generation in the soil and disturbance of the carbon to nitrogen ratio (C:N) (Patil and Lamnganbi, 2018). Soil water retention, transportation and availability to plants undergo shifts associated with the temperature of the soil. Dark-coloured-soil is generally higher in organic material, which also improves the soil's capacity to hold water (Onwuka and Mang, 2018). Under extreme drought conditions, elevated soil temperature causes water to be removed from living cells. This desiccation causes catastrophic damage to cellular components, causing them to spill out, and killing the microorganisms (Sharma and Gobi, 2016).

Ensuring Food Security in Turkish Agriculture by Using Digital Agriculture

Agriculture is undoubtedly vital for meeting the nutritional needs of a population. Precision agriculture not only introduces cutting-edge technologies, but also its use results in more accurate and better farm management systems. Improved product quality, higher sustainability, decreased risk in the management system, safeguarding the environment, better food safety through product traceability of products, and rural development are all advantages of digital agriculture (Talebpour and Yegül, 2015). Digital agriculture is defined as highly efficient, intelligent-water-saving, non-polluting agriculture and high-quality that uses computer technology to enhance profitability and sustainability. By lowering transaction costs, providing data to support management decisions, lowering losses, and assuring efficient and sustainable resource use, digital agriculture is the most practical and essential method for increasing efficiency, optimizing outputs and maximizing economic returns on investment (Ozdogan et al., 2017). Despite Türkiye's limited involvment in smart farming or digital agricultural uses, initiatives are being attempted to promote the development of these technologies.

Türkiye's agriculture industry has been unable to develop financially in recent years, owing to issues such as low productivity and inefficiency. Furthermore, to accelerate the required digital conversion, efforts to develop the higher education curriculum must be made to boost the competence and knowledge of farmers, especially younger farmers, to accommodate the use of digital agricultural apps that are going to become more prevalent within the coming years (Ozdogan et al., 2017). To promote digital farming in Türkiye, government support for strategic goals is also required. On this point, the concomitant development of digital agricultural activity and the encouragement of related procedures with laws and projects in Türkiye will be necessary. University research institutions will be capable of developing projects using scientific research and build an ecosystem centered on digital agriculture (Ozdogan et al., 2017). Doktar, located in the Technopolis of Ege University, and Tarla.io two systems related to digital farming, are outstanding businesses in this area.

Various methods are used today to promote food accessibility, including genetically modified foods in North America, plant breeding and in vitro planting. Besides these strategies, utilizing advanced innovations have been proposed as ways to attain future nutritional security (Talebpour and Yegül, 2015). Early warning and detection systems for drought frequently use data collecting and monitoring techniques that rely on spacecraft and sensors to gather information on several drought signals (Hermans and McLeman, 2021). The living component of soil organic matter is a crucial indicator of soil health. Monitoring of soil organic matter can be valuable in maintaining soil sustainability towards food security (Geng et al., 2015).

Details on Plant Growth Promoting Bacteria (PGPB) to Improve Soil Structure and Climate Resilience of Plants

Interactions between soil microorganisms and vegetation are the subject of extensive research worldwide. Plant growth-promoting bacteria (PGPB) are bacteria that reside in plant root zone and are directly involved in crop development by immobilizing minerals or acting as a protective controller (Kumari et al., 2019). Plant growth promoting bacteria are an effective option to encourage plant growth, lessen pathogenic organisms, and enhance soil nutrients to achieve of ecologically viable farming (Gupta et al., 2015). The application of PGPB in farming has gradually grown in recent years because it provides an opportunity to switch from the usage of synthetic pesticides and fertilizers, for the development of growth in crops through a number of strategies that encompass the building of soil structure, the degradation of organic substances, the recovery of essential compounds, the manufacturing of multiple growth regulators for crops, the encouragement of root development, and many other processes (Bhattacharyya and Jha, 2012; Gupta et al., 2015). Plant growth promoting bacteria affect the entire microorganism in the root system niche by the synthesis of different chemicals. Plant growth promoting bacteria often stimulate crop development directly by altering crop hormonal activity or through their capacity to provide nutrients, particularly primary macronutrients or lowering indirectly the restricting effect of the biological control agents (BCAs), plant–bacteria interactions, and ecological defenders (Gupta et al., 2015). Rhizospheric bacteria which are involved in this root-plant interaction have a positive impact on plant growth via direct or indirect mechanisms such as nitrogen fixation (Kumari et al., 2019). Plant growth promoting bacteria may indirectly promote crop development by eliminating diseases or by activating crop protection mechanisms (Kumari et al., 2019). Bacteria involved in plant-root interactions are known to impact soil sustainability and quality, seed germination under drought stress, and cleanup strategies. It was demonstrated that a typical PGPB (Bacillus subtilis UD1022) may improve the preservation of soil water. This influence is probably due to the PGPB's propensity to generate extracellular compounds having a great ability to hold water (Zheng et al., 2018). As a result of PGPB, the common bean, wheat (Timmusk et al., 2015), and maize (Naseem & Bano, 2014) plants have all demonstrated enhanced tolerance to water deficit. A study conducted by Yavuz et al. (2023) investigated the role of 35 PGPRs obtained from diverse plant-rhizosphere soil samples in semi-arid regions in enhancing the resilience of specifically watermelon to water stress. The conclusive data were some PGPRs such as B7, B22, B26 and B28 supported carotenoid synthesis and antioxidant defense system, and B31, B32, and B35 isolates exhibited significant growth-promoting effects and also B13 and B15 isolates demonstrated the activation of antioxidant defense mechanisms to promote growth and alleviate severe water stress in watermelon plants.

Phenotyping Technologies and Development of High Throughput Plant Phenotyping (HTPP) In Türkiye

It is necessary to choose crop types that are more resilient to harsh climatic conditions and suited to future climatic circumstances. One of the key components of agricultural technology and crop monitoring for enhancing the sustainability of agricultural output is High Throughput Plant Phenotyping (HTPP), where a wide range of plant characteristics such as plant growth, canopy structure, physiology, resistance to diseases and pests, and productivity are measured (Table 2) (Yalcin, 2018; Uyaner et al., 2020). In this context, HTPP is crucial to the accomplishment of reproduction attempts made up of thousands of parcels by cutting down on the time needed to swiftly identify plants with genetic differences under field conditions and to determine which gene is responsible for the phenotypic variation (Xiang and Tian, 2011, Haghighattalab et al., 2016). Despite the tremendous advancements in HTPP, several economic, practical, and governmental obstacles also exist that prevent the successful use of HTPP techniques in the field and under controlled circumstances throughout the Mediterranean. Long droughts or sudden rainstorms and floods are common in the Mediterranean area, which have a detrimental effect on agricultural productivity in addition to the soil and water supplies that are accessible. Additionally, the high cost of HTPP infrastructures and the lack of competent labour may be a significant barrier in Mediterranean countries (Haworth et al., 2023).

In Türkiye, phenotyping is often carried out by agricultural research organizations supported by public and commercial funding sources to choose breeding stock. Türkiye has a tremendous potential to contribute to the creation of crops that are resistant to biotic or abiotic stress because of its wide diversity of wild species and indigenous of agricultural crops (Costa et al., 2019). The chance to set up HTPP facilities was offered by the primary financing organization in Türkiye, the Scientific and Technological Research Council of Türkiye (TUBITAK), to encourage the choice of novel breeding resources and the creation of novel phenotypes for a variety of agricultural crops. A hurdle for the application of HTPP in Türkiye, meanwhile, is a lack of human resources, particularly those with training in computing technology to interpret large genomic and phenomic datasets. Therefore, the government, academic institutions, and private sector must establish strategies and plans to produce enough skilled employees (Costa et al., 2019).

Table 2. Phenotyping technologies and their properties (Deery et al. 2014)

Phenotyping Sensors	Properties
RGB Cams	Conventional, the most prominent device and gives details about the canopy material, no spectral calibration
LiDAR Sensors	provide 3D structural information, fast measurement and used for rapid leaf area index mapping
Spectral Sensing	Supplying details about spectral reflectance from the canopy and soil. Provides information on chlorophyll content, photosynthetic status, energy dissipation, and water status. Fast measurement but sensor calibration is required
Fluorescence	Selective, fast-response for passive fluorescence measurement, and sun-induced chlorophyll fluorescence is widely used for field based phenotyping.
Thermal Sensors	Infra-red thermography can be used to track rates of stomatal conductance due to the influence of transpirative cooling. The correlation between canopy temperature and stomatal conductance can be used to phenotype stomatal behaviour and used of irrigation scheduling in digital agriculture applications.

Heat and Drought Stress Effects on Turkish Agriculture

According to the World Bank (2022), the agricultural sector accounted for 6.5% of the Turkish economy. A potential increase in the frequency and severity of combined heat wave and drought events would have pronounced negative implications for the economic viability and sustainability of agricultural production in Türkiye. Agricultural production in Türkiye is highly diversified ranging from intensive lowland cereal, foliage, and biomass crops to high value fruit and nut tree crops and less productive marginal upland tree crops. Due to the highly heterogeneous nature of Turkish agriculture the effects of heat and drought stress will likely depend upon the type of crop and the characteristics of the specific region. Crops such as cereals generally require large volumes of water and are particularly sensitive to heat stress for example wheat: (Spiertz et al., 2006). Cereals may therefore suffer severe reductions in yield as their carbon and water balances are adversely affected (Chen et al., 2016; Qaseem et al., 2019). However, given the annual nature of these crops there is greater scope to select climate resilient genotypes through phenotyping (for example see Figure 1) (Haworth et al., 2023), or switch to alternative hardier crops such as quinoa (Killi and Haworth 2017). Longer-lived tree crops generally have a greater capacity to tolerate abiotic stress (possibly due to greater investment in photosynthetic tissue: Poorter et al., 2009) but have less capacity for adaptation through the selection of new varieties. In these cases, mitigation and adaptation strategies may be required. For example, olives are a characteristic Mediterranean crop, and of significant agro-economic value to the Turkish economy (~€782 million with 228 000 tons in 2023 as table olives, olive oil and food/cosmetic derivatives such as soaps) (TÜİK, 2023). Olives are generally tolerant of heat and water deficit (Marino et al. 2014). However, heat waves can severely impair photosynthesis and exacerbate pre-existing drought stress in olives (Fig 2) (Haworth et al., 2018). Adaptations such as the use of deficit irrigation shade netting and application of kaolin to leaves (to reduce the absorbance and increase the reflectance of light) may be required to maintain olive production in regions where pronounced increases in heat and drought stress occur. Given the diversity of Turkish agriculture between regions it may be necessary to develop infrastructure to coordinate the required development of climate resilience to maintain food security and the long-term viability of this culturally, economically, and environmentally important sector. Efforts should be focused on the establishment of a national phenotyping facility and the development of digital agriculture applications to enhance productivity, optimise climate adaptation, and minimise agricultural inputs (water, nutrients, pesticides, and herbicides) (Costa et al., 2019). The predicted increase in heat wave and drought events poses a formidable challenge to Turkish agriculture that requires a robust strategy to ensure continued productivity as our climate becomes hotter and drier.

The Effects of Heat and Drought Stress on Sustainable Agriculture and Future Food Security in Türkiye

Türkiye's agriculture industry, which makes a substantial economic contribution, is confronted with a number of difficulties due to an increase in high temperatures and droughts (Şekercioğlu et al., 2011; Bozoglu et al., 2019).

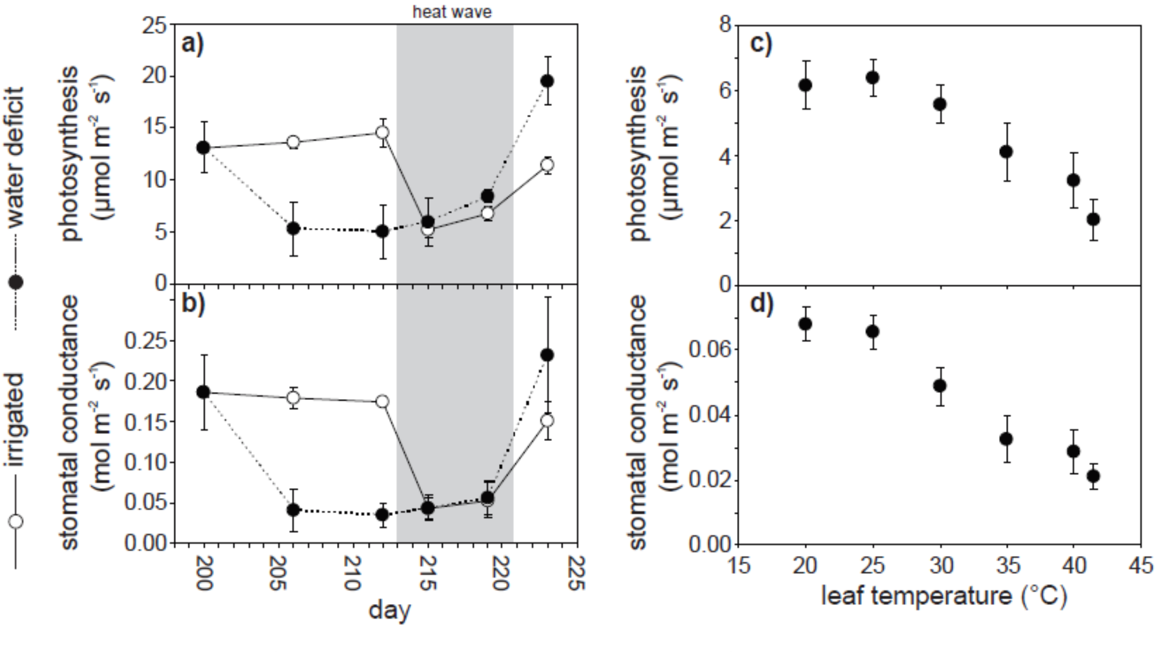

Figure 2. The response of phosynthesis and stomatal conductance of water deficit and irrigated olive plants

The response of photosynthesis (a) and stomatal conductance (b) of fully irrigated (white fill) and water deficit (black fill) olive plants to a heat wave (light grey shading marks the beginning and end of period where midday temperatures exceeded 40°C). The photosynthetic (c) and stomatal conductance (d) gas exchange responses of olives to a controlled increase in temperature under controlled conditions of constant light, [CO_2], temperature, and vapour pressure deficit. redrawn from Haworth et al. (2018).

Certain crops, such as cereals and olives, are more sensitive to heat stress than others; wheat yields can be severely reduced, while olives need to be adapted by using deficit irrigation (Jacobsen et al., 2012; Haworth et al., 2018; Fraga et al., 2020). Digital agriculture offers viable alternatives for increasing production and reducing inputs, while phenotyping tools have the ability to choose crop types that are adaptable to climate change (Costa et al., 2019; Araus et al., 2022). In order to guarantee long-term agricultural profitability and hasten the implementation of digital farming methods, government backing is essential. In order to maintain productivity and food security in the face of changing climate conditions, it is necessary to expand infrastructure, implement climate resilience methods, and widely use digital technologies in order to manage the effects of heat and drought stress on Turkish agriculture (Ozdogan et al., 2017).

Discussion

Türkiye, situated in the eastern Mediterranean Basin, is identified as one of the regions most susceptible to climate change according to the Intergovernmental Panel on Climate Change (IPCC). The country grapples with notable challenges in agriculture and various sectors due to these environmental shifts (Ağaçayak and Keyman, 2018). Despite being the second-largest sector in the Turkish economy, agriculture has witnessed a decline in land area from 26.3 million hectares in 2001 to 23.7 million hectares in 2016 (Ağaçayak and Keyman, 2018). Türkiye experiences an average precipitation of about 643 mm/yr, totaling 501 billion m3/yr precipitation. However, with only approximately 112 billion m3 of accessible water, Türkiye confronts water stress, particularly aggravated by excessive groundwater utilization in agricultural areas such as Konya province, where more than 600 sinkholes have emerged, endangering agricultural endeavors (Yüksel et al., 2021).

Climate change, recognized as a global concern, significantly impacts food security and agriculture. Defined as alterations to the global atmosphere's composition attributed directly or indirectly to human activity, climate change poses hazards like increased climate variability, more frequent extreme weather events, and temperature fluctuations that jeopardize agriculture (Bozoglu et al., 2019). These alterations can affect various aspects of agriculture, including crop production, markets, food prices, and supply chain infrastructure, among others (Bozoglu et al., 2019).

The Mediterranean Basin, encompassing Türkiye, is projected to be among the most affected regions, contending with severe heat waves, rising temperatures, diminished precipitation, reduced soil moisture, and escalating sea levels (Dellal and Unuvar, 2019). These shifts are expected to result in heightened occurrences of intense extreme weather events such as floods and droughts, notably impacting semi-arid and arid regions within the Mediterranean (Dellal and Unuvar, 2019). Despite possessing 24 million hectares of agricultural land, only approximately 20% are irrigated, with the remaining 80% reliant on rainfall. However, over 70% of Türkiye's total water resources are utilized for agricultural irrigation (Dellal and Unuvar, 2019; Ahmed et al., 2022). This excessive water consumption, coupled with elevated temperatures and drought conditions, exacerbates the situation. Illegal groundwater drilling compounds the issue, as highlighted by a survey conducted by the Turkish Industry and Business Association (TÜSİAD), reporting a 97% decrease in harvests and yields among farmers due to climate change-related impacts (TÜSİAD).

In light of Türkiye's vulnerability to climate change and its profound impact on agriculture, this complation aims to investigate the physiological responses of plants to the drought, heat or combined effect of heat and drought. Türkiye which is identified as one of the regions most susceptible to climate change by IPCC, the observed challenges in agriculture, including declining land area and water stress, underscore the urgent need to understand the effects of these stressors on plant physiology. Climate change-induced alterations, such as extreme weather events, and rising temperatures, are projected to exacerbate existing challenges in Türkiye (Ağaçayak and Keyman, 2018; Bozoglu et al., 2019; Dellal and Unuvar, 2019). By elucidating the effects of climate change, we aim to contribute to the development of strategies to enhance plant tolerance and resilience, ultimately promoting sustainable agricultural practices and future food security (Alhaithloul, 2019; Hussain et al., 2019; Bhardwaj et al., 2021

Conclusion

Climate change is an enormous issue in Türkiye, and the country has begun to observe its effects on agriculture, which is heavily reliant on its weather for maximum yield. Temperature rises and the associated serious consequences would jeopardise the future food security of Türkiye. Since Turkish agriculture is relatively variable, the impacts of drought and high temperatures would probably rely on the type of plant and the features of the particular area of the country. Wheat, barley, maize, sunflower, and cotton make up the vast majority of the Turkish food supply, encompassing over 72 percent of the entire cultivated land. The overwhelming part of climate change predictions indicate that temperatures would rise by upto 5°C in some regions, that yearly rainfall would fall by 30% in the West and South of Türkiye and rise by 20% in the North. Therefore, heat and drought stress will pose a significant threat for Turkish agriculture.

Stress shifts plant physiology, limiting several growth phases such as vegetative or reproductive phases, and it is most destructive during the reproductive stage. If high temperatures keep rising or rainfall continues to fall in Türkiye, the availability of extensively consumed foods is going to decline. The agricultural area in Türkiye is anticipated to shrink by 10% because of climate change, as temperatures rise and rainfall falls. This review shows that temperature and precipitation are key determinants in farming industry. Agriculture is crucial in sustaining a population’s food demands. Digital agriculture is characterised as high-quality, highly profitable, water conservation farming that uses electronic devices to increase financial viability and sustainability. The applying of PGPB in agriculture has been growing since it allows farmers to avoid using chemical pesticides and fertilisers, and some bacteria in the plant's root zone produce plant growth-promoting (PGP) compounds that shield crops from biotic or abiotic stress conditions and enable their growth. High

Throughput Plant Phenotyping (HTPP) is an essential part of farming technology and tracking crops for boosting food production reliability. High Throughput Plant Phenotyping is essential for a successful conclusion of efforts relating to reproduction required to quickly recognise crops with distinct genes in the field and understand which gene is accountable for the phenotypic difference. The Scientific and Technological Research Council of Türkiye (TUBITAK), Türkiye's principal funding organisation, granted the opportunity to establish HTPP centres to support the selection of innovative breeding materials and the generation of unique phenotypes for various kinds of agricultural products. To anticipate future climate change, crop endurance must be strengthened to shield them against abiotic and biotic challenges. Soil bacteria studies, for instance, provides options to enhance plant against these challenges. Finally, it is critical to focus attention on the influence of climate change for farming efficiency and future food security in Türkiye since climate change is predicted to pose severe risks to the country.

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