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EDITORS

Prof. Dr. Selahattin ÇINAR

Assoc. Prof. Dr. Seyithan SEYDOŞOĞLU

PHYSIOLOGICAL RESPONSES OF STRAWBERRY PLANTS TO DROUGHT STRESS

Arş. Gör. Betül Ayça DÖNMEZ,
Çukurova Üniversitesi, Biyoteknoloji Ana Bilim Dalı, ADANA
Kırşehir Ahi Evran Üniversitesi, Tarımsal Biyoteknoloji Bölümü, KIRŞEHİR
betul.donmez@ahievran.edu.tr
ORCID NO: 0000-0002-7631-7384

Prof. Dr. Salih KAFKAS
Çukurova Üniversitesi, Ziraat Fakültesi, Bahçe Bitkileri, ADANA
skafkas@cu.edu.tr
ORCID NO: 0000-0002-9037-4764

Prof. Dr. N. Ebru KAFKAS
Çukurova Üniversitesi, Ziraat Fakültesi, Bahçe Bitkileri, ADANA
ebru@cu.edu.tr
ORCID NO: 0000-0003-3412-597

ABSTRACT

Drought is a global threat that results in increasingly destructive consequences due to global warming, possessing all living organisms. It leads to losses in water sources and in especially agricultural production. Due to its location in Mediterranean climate zone and varying climatic conditions across the region, Türkiye is one of the most dramatically impacted countries by drought stress. Strawberry is the most commercially produced and consumed berry in *Rosaceae* family owing to its rich nutrient value and high adaptation ability to grow various regions. Besides fresh fruit, it can be consumed by humans as processed products such as jam, jelly, beverage, yogurt. It has a significant market value in terms of imports and exports. Also, our country ranks 5th among strawberry producer countries in the world. But, strawberries are excessively sensitive to water deficit conditions on account of some morphological characteristics such as root system, leaf area, fruit texture etc. Depending on plant developmental stages, duration time and severity of stress, water deficiency could significantly reduce strawberry production and fruit quality and lead to even plant death. Even though there are some solutions such as efficient management of water sources, changing cultural practices etc., it is needed to find effectual solutions such as determination of drought tolerance existing cultivars and enhancement of new drought tolerant strawberry cultivars. For this purpose, it is requisite to understand the impact of drought stress on plants and plant responses to drought such as physiological response. In this review, various physiological responses of strawberries on water deficit condition will be discussed. Understanding those plant responses could provide valuable sights for drought tolerant strawberry cultivar enhancement. This study is supported by Çukurova University BAP Coordination Office within the scope of project number FDK-2023-15809.

Keywords: Strawberry, Drought, Stress, Physiological responses

ÇİLEK BİTKİLERİNİN KURAKLIK STRESİNE KARŞI FİZYOLOJİK TEPKİLERİ

ÖZET

Kuraklık, küresel ısınma nedeniyle giderek daha yıkıcı sonuçlara yol açan, tüm canlı organizmaları etkileyen küresel bir tehdittir. Su kaynaklarında ve özellikle tarımsal üretimde kayıplara yol açar. Türkiye, Akdeniz iklim kuşağında yer alması ve bölge genelinde iklim koşullarının değişmesi sebebiyle kuraklık stresinden en çok etkilenen ülkelerden biridir. Çilek, zengin besin değeri ve yüksek adaptasyon yeteneği nedeniyle Gülgiller familyasında en çok üretilen ve tüketilen meyvedir. Taze meyvenin yanı sıra reçel, jöle, içecek, yoğurt gibi işlenmiş ürünler olarak da insanlar tarafından tüketilebilir. İthalat ve ihracat açısından önemli bir pazar değerine sahiptir. Ayrıca, ülkemiz Dünyada çilek üreticisi ülkeler arasında 5. sırada yer almaktadır. Ancak çileğin kök sistemi, yaprak alanı, meyve dokusu vb. bazı morfolojik özellikleri nedeniyle su eksikliği koşullarında aşırı duyarlı olduğu belirlenmiştir. Bitkinin gelişim evrelerine, stresin süresine ve şiddetine bağlı olarak su eksikliği çilek üretimini ve meyve kalitesini önemli ölçüde azaltmakta ve hatta bitki ölümü bile neden olabilmektedir. Su kaynaklarının etkin yönetimi, kültürel uygulamaların değiştirilmesi vb. bazı çözümler olsa da, mevcut çeşitlerin kuraklığa dayanıklılığının belirlenmesi ve yeni kuraklığa toleranslı çilek çeşitlerinin geliştirilmesi gibi etkili çözümler bulmak gereklidir. Bu amaçla, kuraklık stresinin bitkiler üzerindeki etkisini ve bitkilerin kuraklığa karşı fizyolojik tepkilerini anlamak gerekir. Bu derlemede, çileklerin su eksikliği durumundaki çeşitli fizyolojik tepkileri tartışılacaktır. Bu bitki tepkilerinin anlaşılması, kuraklığa dayanıklı çilek çeşidinin geliştirilmesi için değerli bakış açıları sağlayabilir. Bu çalışma, Çukurova Üniversitesi BAP Koordinatörlüğü FDK-2023-15809 nolu proje kapsamında desteklenmektedir.

Anahtar Kelimeler: Çilek, Kuraklık, Stres, Fizyolojik tepkiler

1. INTRODUCTION

Global climate change is among the most critical global issues impacting all organisms in the world due to its increasingly severe impact. As for, drought is one of the most devastating consequences of global climate change, which has restrictive impacts on the environment, agriculture, economic, social, and humanitarian. Rapid depletion of water sources restricts agricultural productivity and livestock activities, leading to crop yield and economic losses. Also, it limits biodiversity and species in flora and fauna. Regarding humankind, water deficiency directly is limiting access to food and to clean water, forcing people to migrate. In addition, it is expected that the world population will exceed 12 billion to 2100, which will make difficult to feed their growing populations for counties (Dockterman, 2014). To overcome these problems, all countries need to consider the impacts and future risks of climate change, adaptation and mitigation options.

The cultivated strawberry knows as *Fragaria* × *ananassa* Duch. is one of the most commercially produced berries, having a unique taste, flavor and attractive color. It has high essential nutrient value, such as vitamin C and Calcium (Ca), and is rich in phenolic compounds beneficial to human health. Besides fresh fruit, it can be consumed as processed products such as jam, jelly, beverage, and yogurt (Kafkas, 2016). Due to its high nutrient content and high market value, it is the most commercially produced and consumed berry, accounting for approximately 10.5 M tons from more than 400 ha area in the world (FAO, 2023). China, United States of America, Mexico, Spain and Türkiye are main strawberry producers, respectively. In our country, strawberry production is possible at altitudes from sea level up to 2000 m which providing us advantage both in terms of import and export activities (Aslantaş and Karakurt, 2007). Mediterranean, Aegean and Marmara regions are prominent strawberry producing regions.

Rising the severity of drought in recent years has negatively affected the regions where strawberry production is intensive worldwide (Figure 1.1) (Ariza et al.,2021). Türkiye possesses a wide range of different climatic zones and microclimate areas in terms of its geographical location and climate characteristics which provides cultivation of different agricultural products (Kapluhan, 2013). However, factors such as environmental and soil pollution, excessive use of groundwater, insufficient management of water resources, and excessive application of fertilizers and pesticides are among the main factors that accelerate drought and desertification processes in our country. Some experts state that alteration of climate structure and precipitation regime are results of global climate change, combined with these incorrect practices and behaviors mentioned, will bring about serious restrictions on agricultural production and economic losses in future (Özüpekçe, 2021).

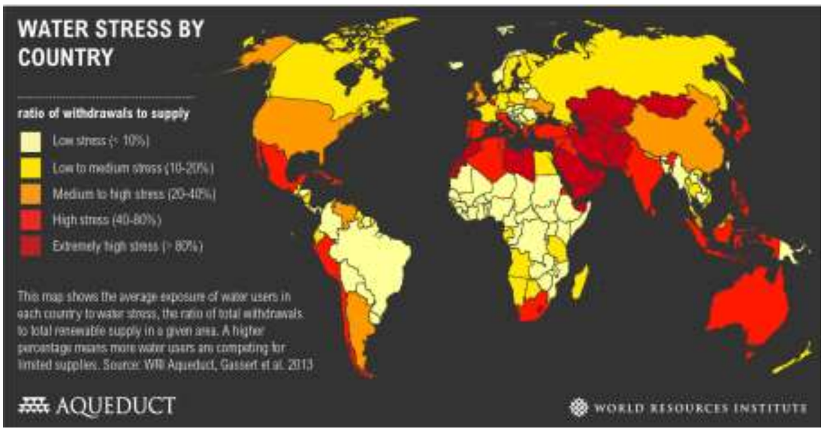

Figure 1. 1. World water stress map (Source: World Resources Institute)

As known, plants have been under pressure from some stress factors that negatively affect their growth and development. Drought is one of the most important abiotic stress factors affecting the growth, development and survival of plants caused by global climate change and cause ecological and economic losses (Akbaş, 2014). According to United Nations Convention to Combat Desertification (UNCCD, 1997), drought is termed as a natural event that causes land and water resources to be adversely affected and the hydrological balance to be disrupted due to precipitation falling significantly below normal levels. As agricultural drought is the consequence of the synergistic effect of meteorological, hydrological, and agricultural factors and defined as the lack of sufficient water in the soil to meet plant requirements. Cultivated strawberries are extremely sensitive to water deficit conditions since their wide leaf area, superficial root systems, and juicy fruit texture. It has been established that water deficiency could cause a decline in plant growth, fruit/crop quality and yield up to 70%, and eventually plant death (Boyer, 1982; Wandel et al., 2016). Depending on plant species, their growth stages, severity and duration of stress, exposure time and combination with other stress factors, it injures plants at various stages of development and undermines cellular activities (Du et al., 2020). It is known that water deficiency during especially flowering and fruit ripening stages in strawberry have limited its fruit size, quality and yield (GinÃ© Bordonaba and Terry, 2008).

Drought stress brings about a range of changes on plants such morphological, physiological, biochemical, and molecular changes. Leaves are the main indicator of drought stress. Insufficient water content inhibits plant growth and development such as decreases the leaf area, number and shoot length (Zhang et al., 2024). Water deficiency initially perceives from roots which triggers them extension deeper since decrease in turgor pressure in plants cells (Seleiman et al., 2021). This stress causes ABA (abscisic acid) synthesis in roots and ABA transportation to aerial parts of plants via xylem to protect plants against water losses. ABA accumulation in guard cells leads to stomatal closure (Brunetti et al., 2019). Hampering gas influx-exflux for plants due to closure reduces plant transpiration and photosynthesis. Low CO_2 and high O_2 levels in plant cells increases photorespiration (Mozafari et al., 2019) and enzyme activity which disrupts the light and dark reactions. Drought stress also stimulation extensive production and accumulation of reactive oxygen species (ROS).

Their accumulation leads to losses in fruit production, its quality and yield losses and eventually plant death (Hossain et al., 2015; Dar et al., 2017; Gholami and Zahedi, 2019). Plants also synthesize some osmolytes and osmo-protectants which are secondary indicators of drought stress such as glycine betaine and proline. It is also inevitable that some gene expressions are responsible for drought stress such as transcription factors, some proteins (Heat shock (HSPs) proteins etc. (Yang et al., 2021).

Drought stress is one of the most detrimental abiotic stress factors affecting strawberry production, which is still to be well-characterized. It is requisite to determine the effect of drought stress on strawberries at blooming and fruit ripening stages and their responses. This review could be beneficial to understand the physiological responses of strawberries against water deficiency and to improve and enhance new drought tolerant strawberry cultivars in breeding studies.

1.1. Plant Drought Strategies

Drought stress disturbs plant structural and metabolic activities, delays plant growth and development, damages photosynthetic activity, disturbs protein synthesis and even plant death. However, plants show some response mechanisms to cope with stress factors (Figure 1.2). Their responses to drought stress depend on duration and severity of stress, genetic background of plants to be exposed to stress and their developmental stages. In strawberry, flowering and fruit ripening stages are critical stages in terms of exposing drought stress. However, stress factors could trigger the plant to adapt to adverse conditions. It is stated that severe stress causes irreversible distribution on plant physiology and even plant death while mild stress induces the defense mechanism of plants such as root extension deeper into soils, stomatal closure, accumulation of osmo-protectant etc. (Bandurska, 2022). Plants evolutionary have enhanced three basic strategies against drought stress: escape, avoidance and tolerance.

Escaping strategy from the drought stress allows the plant to adjust and shorten its life cycle to the appropriate time. Early flowering is a common escaping strategy for plants which inhibits plant growing period and but leads to production losses (Vassileva et al., 2023). Drought avoidance strategy is a plant adaptation that enhances water use efficiency (WUE) under dry conditions. This strategy can be focused on two main mechanisms: maximizing water uptake by the plant root system (water spender) and minimizing water loss from the shoot parts (water saver) (Basu et al., 2016; Delfin et al., 2021). But WUE depends on plant species and the duration and severity of drought. It is stated that plants having higher WUE is generally related to increased yields under water deficit condition (Hatfield and Dold, 2019). Water saver plants tend to limit water loss via maintaining metabolic activity at low stages such as stomatal closure, decreasing transpiration and photosynthesis rates or via morphological adjustments such as developing thicker cuticles, increased wax deposition, decreasing leaf area, radiation absorption and curling the leaf (Kim et al., 2007). In contrast, water spenders plants tend to increase root proliferation at depth especially deeper tap root to maintain water uptake and enhance hydraulic conductance (Mori et al., 2011; Caine et al., 2019). Although drought avoidance strategies could be effective for plant water saving, it may lead to limited vegetative growth which reduces crop productivity. Drought tolerance is another mechanism that allows plants to produce and reproduce their economic product with minimum loss under water deficit environment. During this process, plants protect their cells by synthesizing protective substances such as osmolyte or osmo-protectants and overexpression of some drought-responsive genes and elements, transcription factors and some proteins against osmotic and ionic stress (Yang et al., 2021). Those plants also repair the damage that occurs when the stress ends.

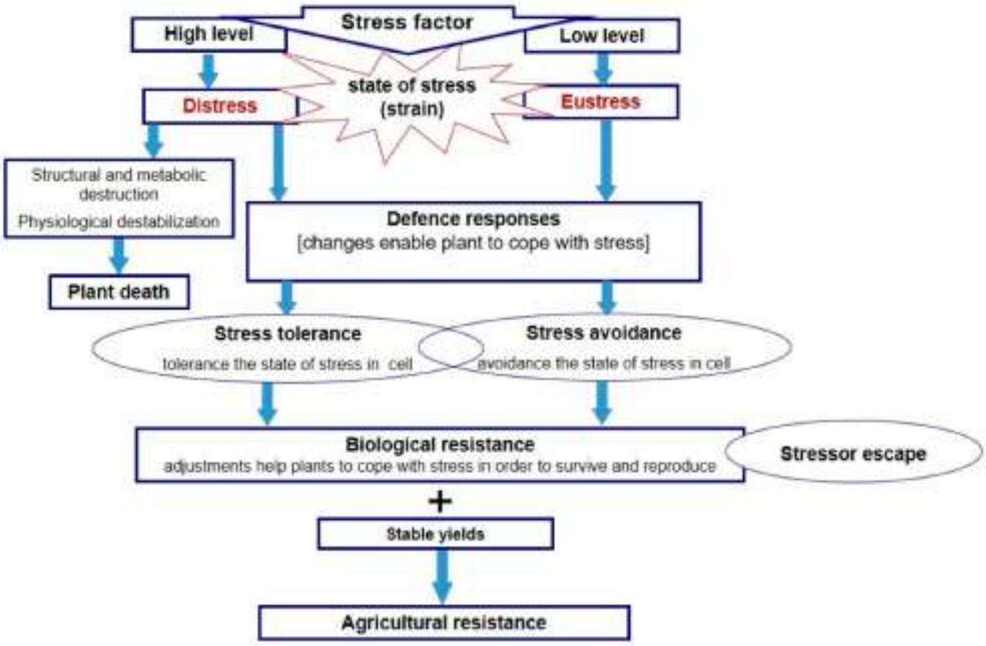

Figure 1.2. Plant responses mechanism to drought stress, escape, avoidance and tolerance (Bandurska, 2022).

1.2. Physiological Responses of Strawberry Plants Against Drought Stress

Drought stress is a multifaceted stress factor inhibits plant physiology and metabolic activity and further fruit quality and yield (Bhargava and Sawant, 2013). Strawberries are vulnerable to drought stress due to their morphological characteristics. Water deficiency is one of the main factors limiting growth, stomatal conductance and net photosynthesis in strawberry plants (Dehghanipoodeh et al., 2018). Limiting gas exchange between the plant and the environment due to stomatal closure cause stomatal conductivity, net photosynthesis and respiration to decrease in strawberry cultivars “Earlibrite, California and Sweet Charlie” (Ibrahim et al., 2022). High O_2 levels in the chloroplast promotes Rubisco oxygenase activity, increasing photorespiration. This energy-consuming process reduces photosynthetic efficiency and leads to carbon loss, further affecting plant growth.

Several studies showed that decline in relative water content (RWC), leaf water potential and osmotic potential are the main key indicators of drought stress. Ibrahim et al. (2022) determined that decrease in plant growth, transpiration rate, net photosynthesis, stomatal conductance and relative water content depending on different strawberry cultivars under water deficit condition. It is also stated that total chlorophyll content and leaf water potential decreased when limited irrigation regime for strawberry cultivar "Camarosa" (Ödemiş et al., 2020). Accumulation of ABA induces higher amount of ROS production which causes oxidative stress in plant cell. Their accumulation disrupts cell membrane stability due to lipid peroxidation which enhances the electrolyte leakage (Zahedi et al., 2023). Quantum efficiency of photochemistry (Fv/Fm) is one of the most frequently used methods to measure amount of light absorbed by the chlorophyll which allows to accurate prediction on severity of stress via measuring the maximum photosystem II (PSII) quantum efficiency value (Arief et al., 2023). Conversely, it is considered that the increase in leaf canopy temperature of strawberries under drought stress due to stomatal closure thereby limiting gas exchange (Ödemiş et al., 2020). As mentioned above, plants also possess the drought stress tolerance mechanisms allowing them to produce their economic product with minimum loss. Several studies on strawberries have proved that tolerant cultivars have developed mechanisms to increase their water use efficiency (WUE) (Klamkowski and Treder, 2008; Ghaderi and Siosemardeh, 2011; Zahedi et al., 2020).

2. CONCLUSION

Drought stress is one of the most important stress factors that inhibit agricultural production and cause dramatic losses. Depending on plant species and their developmental stages, stress duration time and severity, drought stress limits vegetative growth, disrupts plant physiological and metabolic activities. Impact of drought stress on plant is like cascade containing the series of changes on plant starting with perceiving water deficiency by root ending up tolerance to stress or plant death. Even though efficient water sources management and better cultural practices is effective for agricultural production under water deficit conditions, determination of drought tolerant cultivars among current ones and enhancement of new tolerant ones could give better and accurate solutions. Integration of marker assistant selection (MAS), Quantitative trait locus (QTL) analysis, genetic engineering, genome editing technologies into traditional breeding to determine drought tolerant plants or their improvement would be beneficial for future of humankind against food scarcity and sustainable for agricultural production against global climate change.

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