Available online at www.agrifarming.org

DOI: http://dx.doi.org/10.18782/2582-7146.243

ISSN: 2582 – 7146

Current Research in Agriculture and Farming

Curr. Rese. Agri. Far. (2024) *5*(6), 60-67

Review Article

Peer-Reviewed, Refereed, Open Access Journal

Decoding Drought: Physiological Disruptions and Plant Survival Strategies under Water Scarcity

Muhammad Bilal[1*], Rameen Nawaz[2], Muhammad Sharjeel[3], Muhammad Ahmad[4], Kaynat Tariq[5], Usman Shahid[2,6]

[1,3,5]Institute of soil and Environmental Sciences, University of Agriculture Faisalabad 38040, Pakistan

[2,6] Center of Agriculture Biochemistry and Biotechnology (CABB), University of Agriculture Faisalabad 38040, Pakistan

[4]Department of Agronomy, University of Agriculture, Faisalabad 38040, Pakistan

*Corresponding Author E-mail: bilalch7132@gmail.com

Received: 8.10.2024 | Revised: 23.11.2024 | Accepted: 6.12.2024

ABSTRACT

Drought is a major abiotic stressor threatening global food security by adversely affecting plant physiology and crop productivity. As water availability diminishes due to climate change and anthropogenic activities, drought stress impairs various physiological, biochemical, and molecular functions in plants. This review explores the multifaceted effects of drought stress, including its impact on plant growth, water relations, photosynthesis, enzyme function, mineral uptake, and metabolic regulation. It also discusses the role of global warming, rainfall anomalies, and salinity in exacerbating drought stress. By highlighting how plants respond and adapt to drought through tolerance mechanisms, the review underscores the urgency of developing drought-resilient crop varieties and sustainable water management strategies to ensure agricultural sustainability in a changing climate.

Keywords: *Drought Stress, Plant Physiology, Photosynthesis Inhibition, Osmotic Adjustment, Climate Change Adaptation*

INTRODUCTION

A lack of water resources has made drought the single biggest danger to the world's food security. The major famines of history were sparked by it. (De Marsily & Abarca-del-Rio, 2016) Since the water in the world the current food supply is running low, and the pressures of an ever-growing population will probably make the effects of the drought worse in the future. (Farooq et al., 2009a). It is often acknowledged that droughts are the deadliest natural disasters in terms of human casualties, damage to agriculture, and economic effects. (Humphries & Baldwin, 2003). Plant growth and development are negatively impacted by drought, which also significantly lowers crop growth rates and biomass buildup.

Cite this article: Bilal, M., Nawaz, R., Sharjeel, M., Ahmad, M., Tariq, K., & Shahid, U. (2024). Decoding Drought: Physiological Disruptions and Plant Survival Strategies under Water Scarcity, *Curr. Rese. Agri. Far. 5*(6), 60-67. doi: http://dx.doi.org/10.18782/2582-7146.243

(Ahluwalia et al., 2021) Reduced rates of cell division and expansion, leaf growth, stem elongation, root proliferation, disrupted stomatal oscillations, plant water and nutrient connections with decreased crop output, and water use efficiency (WUE) are the principal effects of drought on crop plants. (Farooq et al., 2012). Consequently, one of the most common environmental stresses that stunts growth and reduces productivity is drought stress. (Salehi-Lisar & Bakhshayeshan-Agdam, 2016) It causes a variety of physiological, biochemical, and molecular reactions in plants, enabling them to build tolerance mechanisms that allow them to adapt to harsh environments. (Kalefetoğlu & Ekmekci, 2005).

CAUSES OF DROUGHT STRESS IN PLANTS:

Future air temperature increases and atmospheric CO_2 levels are predicted to cause global climate change to accelerate, which will eventually modify the distribution and patterns of rainfall. (Hughes, 2003) Drought stress conditions are often prevalent over large areas on a worldwide scale because to climate change. In addition to drought, salt stress is thought to be a major contributor to plant water shortage. (Seleiman et al., 2021).

GLOBAL WARMING:

A few of the effects of climate change may be advantageous for the output of agriculture. Because increased CO2 has been shown to promote higher rates of photosynthesis, for instance, its presence in the atmosphere at elevated quantities may one day increase grain yields . (MANISANKAR) But most of the time, climate change has negative effects on agricultural and natural habitats. (Olesen & Bindi, 2002) Elevations in atmospheric temperature have the potential to cause glaciers to melt and inundate low-lying or null-slope agricultural areas. (Seleiman et al., 2021)

Rainfall Anomalies:

More stress is expected in locations where agricultural output depends solely on rainfall as opposed to those that are irrigated by rivers, canals, and the water channel. (Bhumbla, 1981)Thus, in regions that receive rain, the distribution of rainfall throughout the year and the occurrence of drought periods are highly connected, with certain years seeing high levels of water stress throughout a specific time frame. (Edwards & McKee, 1997) The main human activities that impact rainfall patterns and, consequently, plant water availability through their impact on climate change are industrialization, deforestation, and urbanization. (Seleiman et al., 2021)

EFFECTS OF DROUGHT STRESS ON PLANTS.

Plant growth and productivity:

For maximum production to be harvested, an early and ideal crop stand must be established. (McDonald & Copeland, 2012) Low grain yield, however, is mostly caused by a suboptimal plant population if the crop is subjected to an early drought that hinders germination. (Wojtyla et al., 2016)Early-season drought significantly lowers stand establishment and germination, mostly because of decreased energy supply, decreased water intake during the imbibition phase of germination, and decreased enzyme activity. (Farooq et al., 2012)

Metabolic Effect:

Due to the fact that water serves as a transport medium, a solvent for biological processes, and occupies the majority of a cell's volume, when it is lost from a cell, regulation is no longer present in the cell and metabolism is disturbed, among other cellular reactions and functions. (Ball, 2008) Degradation of nucleic acids, such as RNA and DNA, is another component contributing to metabolic damage during drought stress. (Kalefetoğlu & Ekmekci, 2005).

Mineral Uptake and Assimilation:

The internal cycling of reserve materials provides the majority of the nutrients needed for plant development and biomass production. (Ovington, 1965) These materials need water for solubilization and translocation. Interactions at the soil–root interface, such as (1) root morphology and development rate, (2) the roots' kinetics of nutrient absorption, and (3) the availability of nutrients in the soil, control nutrient absorption. Reduced soil water availability has an impact on the pace at which numerous plant nutrients diffuse, which in turn has an impact on the concentration and composition of soil solution. (Farooq et al., 2012).

Water relations:

Plant water relations are influenced by a number of significant factors, including relative water content, leaf water potential, stomatal resistance, rate of transpiration, leaf temperature, and canopy temperature. (Sinclair, 1983) Wheat leaves had a larger relative water content at first during leaf development, but as the leaves matured and dry matter accumulated, this amount dropped. (Kobata et al., 1992) It is evident that the relative water content of water-stressed versus non-stressed wheat and rice plants was lower. (Izanloo et al., 2008) These plants' leaf water potential, relative water content, and transpiration rate all significantly dropped when they were subjected to drought stress, and their leaf temperatures also increased as a result. (Farooq et al., 2009a).

Photosynthesis:

Reduced photosynthesis is one of the main effects of drought, and it results from reduced leaf expansion, compromised photosynthetic machinery, early leaf senescence, and consequently lower food production. In comparison to non-stomatal constraints on photosynthesis, stomatal constraints might be relatively minor. (Kapoor et al., 2020) This suggests that the harm is not limited to CO2 uptake pathways. Stomatal closure brought on by dryness plays a critical function in limiting the amount of CO2 that leaves can absorb. (Farooq et al., 2009a).As a result, less CO2 enters the leaves, freeing up more electrons for the synthesis of active oxygen species. (Fryer et al., 1998).The quantity of heat that can be dispersed rises as transpiration rate falls. (Hagishima et al., 2007)

Photosynthetic enzymes:

A reduction in Rubisco activity causes extremely severe drought conditions to impede photosynthesis. (Parry et al., 2002) The availability of CO2 in the chloroplast and changes in photosystem II during drought circumstances are two factors that closely regulate the activity of the photosynthetic electron transport chain. (Roupsard et al., 1996) .Cell shrinkage brought on by dehydration causes a decrease in cellular volume. The contents of cells get thicker as a result. (Moreira et al., 2010).Consequently, they aggregate and denaturate when the likelihood of protein-protein interaction increases. (Farooq et al., 2009a)

Respiration:

The phenomena of drought tolerance is expensive since it requires a significant amount of energy to manage. (Salehi-Lisar & Bakhshayeshan-Agdam, 2016).The percentage of carbohydrates lost during respiration is what defines the plant's total metabolic efficiency. (Yamaguchi, 1978). The carbon fixed during photosynthesis is largely consumed by the root, which uses it for dry matter formation, growth, and maintenance. (Friend et al., 1994) The amount of this percentage is influenced by environmental factors, plant growth, and developmental processes (i.e. employed in respiration). (Farooq et al., 2009a).

However, when soil water supply is decreased, plant development is frequently constrained by the rate of photosynthesis. Reduced photosynthetic capacity during droughts may result in a negative carbon balance unless growth and carbon consumption are simultaneously and proportionately reduced. (Bhattacharya & Bhattacharya, 2021)

Source-sink Relationship:

The byproduct of photosynthesis, carbohydrates, serves as a growth and maintenance substrate for tissues that do not participate in photosynthesis. (Bräutigam & Weber, 2011) Plants require sugar transporters for cell sugar partitioning and long-distance carbohydrate allocation. (Daie, 1985) Plant development is mostly influenced by the practical movement of sugars through the phloem across plant organs. (Savage et al., 2016) Source, sink, and the path between them all have an impact on sugar transport via the phloem, which in turn affects the source-sink interaction. (Griffiths et al., 2016) Assimilate export from source to sink is influenced by the rate of photosynthesis and the quantity of sucrose in leaves. (Foyer & Paul, 2001) Dry weather slows the flow of water because it decreases sugar content and photosynthesis. (Quick et al., 1992) Additionally, a drought makes it more difficult for the sink to efficiently use assimilates. (Bijalwan et al., 2022).

Leaf Relative Water Content (RWC):

A key regulator of plant physiological processes is leaf RWC. The first sign of the drought stress response is a drop in RWC. (Rampino et al., 2006) There is a substantial contemporaneous correlation between the rate of transpiration and the relative water content of leaves. (Lake & Woodward, 2008) Reduced RWC causes stomata to close as it lowers leaf water potential. (Bennett et al., 1987) The main process that determines leaf temperature is transpiration; raising stomatal resistance in rice leaves reduces transpiration rate because of ABA content and raises leaf temperature. (Wahab et al., 2022).

Chlorophyll contents:

One of the primary components of chloroplasts used in photosynthesis is chlorophyll, and the rate of photosynthetic activity is positively correlated with the percentage chlorophyll content. (Kong et al., 2016) It has been suggested that a typical sign of oxidative stress under drought stress is a decrease in chlorophyll content, which can be caused by pigment photo-oxidation and chlorophyll degradation. (Ansari et al., 2019) Plants need photosynthetic pigments primarily for light absorption and the synthesis of reducing agents. Chlorophyll A and B are both susceptible to soil drying out. (Hendry et al., 1987) Depending on the length and intensity of the drought, numerous species have been observed to exhibit decreased or unchanged chlorophyll levels during this stressful time. (Anjum et al., 2011)

Drought effects on osmotic regulators accumulation:

Osmotic adjustment and stomatal closure are the first physiological responses of plants to drought stress. (Zivcak et al., 2016) These mechanisms are employed to preserve the moisture content of the tissue while also absorbing water from the surrounding environment. (Lewicki, 1998) This ultimately keeps the cells' normal physiological and biochemical processes going. Research on the effects of drought stress has revealed that plants store Pro, SS, and SP. (Zia et al., 2021) These three osmotic adjustment chemicals have varying contents according to our investigation. Under conditions of drought stress, the Pro content increased significantly and impressively. (Forlani et al., 2019) A. amurensis had the largest Pro accumulation, which may be connected to its greater tolerance to drought. (Xu et al., 2020) By safeguarding the redox balance and promoting cell homeostasis, pro has antioxidant activity that lowers lipid peroxidation (Gao et al., 2020).

RESPONSES TO DROUGHT STRESS:

Depending on the species and genotypes, the duration and degree of water loss, the age and developmental stage, the organ and cell type, and the cellular compartment (such as the cell wall and cell membrane), plants respond differently to water deficits. (Lovisolo et al., 2010) Responses to drought stress can manifest as changes in gene expression or as quick as a few seconds (e.g., a change in a protein's phosphorylation status) (Farooq et al., 2009b) And as long as minutes or hours. "Early-response genes" and "delayed-response genes" are two categories of stress-responsive genes:

1. Early-Response Genes: These are frequently momentarily expressed and induced extremely quickly (within minutes). (Chechik & Koller, 2009)

New protein synthesis is not necessary for their stimulation because all necessary signaling components are present. (Proud, 2007)

2. Genes with a delayed response are those whose expression is frequently maintained and whose activation is triggered by stress more gradually—within hours. They make up the great bulk of genes that react to stress. (Costa-Mattioli & Walter, 2020)

Typically, transcription factors encoded by early-response genes activate downstream delayed-response genes. (Brenner et al., 2005).

CONCLUSION

Drought stress profoundly affects plant physiological processes, limiting growth, reducing productivity, and threatening food security worldwide. From impairing photosynthesis and enzymatic activity to altering water relations and mineral uptake, drought imposes complex challenges on crop systems. Climate change and human-induced environmental changes further intensify the frequency and severity of droughts, necessitating urgent attention. Understanding plant responses at the physiological and molecular levels is essential for breeding and engineering drought-tolerant crops. Future agricultural strategies must prioritize integrated water management, climate-smart farming practices, and resilient crop development to mitigate the detrimental impacts of drought and sustain global food production.

Acknowledgement:

I would like to sincerely thank my co-authors for their support and kind gesture to complete this manuscript in time.

Funding Information: No funding was received for this study.

Disclosure Statement: The author reports no conflicts of interest.

Author Contribution: All authors have participated in the critical revision of the entire manuscript and approval of the final manuscript

REFERENCES

Ahluwalia, O., Singh, P. C., & Bhatia, R. (2021). A review on drought stress in plants: Implications, mitigation and the role of plant growth promoting rhizobacteria. *Resources, Environment and Sustainability*, *5*, 100032.

Anjum, S. A., Xie, X., Wang, L. C., Saleem, M. F., Man, C., & Lei, W. (2011). Morphological, physiological and biochemical responses of plants to drought stress. *African journal of agricultural research*, *6*(9), 2026-2032.

Ansari, W. A., Atri, N., Pandey, M., Singh, A. K., Singh, B., & Pandey, S. (2019). Influence of drought stress on morphological, physiological and biochemical attributes of plants: A review. *Biosciences Biotechnology Research Asia*, *16*(4), 697-709.

Ball, P. (2008). Water as an active constituent in cell biology. *Chemical reviews*, *108*(1), 74-108.

Bennett, J., Sinclair, T., Muchow, R., & Costello, S. (1987). Dependence of Stomatal Conductance on leaf Water Potential, Turgor Potential, and Relative Water Content in Field-Grown Soybean and Maize 1. *Crop science*, *27*(5), 984-990.

Bhattacharya, A., & Bhattacharya, A. (2021). Effects of Soil Water Deficit on Carbon Metabolism of Plants: A Review. *Soil Water Deficit and Physiological Issues in Plants*, 99-192.

Bhumbla, D. (1981). Land and water management and agricultural production in India. *Journal of the Indian Society of Soil Science*, *29*(4), 403-418.

Bijalwan, P., Sharma, M., & Kaushik, P. (2022). Review of the effects of drought stress on plants: A systematic approach.

Bräutigam, A., & Weber, A. P. (2011). Do metabolite transport processes limit photosynthesis? *Plant physiology*, *155*(1), 43-48.

Brenner, W. G., Romanov, G. A., Köllmer, I., Bürkle, L., & Schmülling, T. (2005). Immediate-early and delayed cytokinin response genes of Arabidopsis thaliana identified by genome-wide expression profiling reveal novel cytokinin-sensitive processes and suggest cytokinin action through transcriptional cascades. *The Plant Journal*, *44*(2), 314-333.

Chechik, G., & Koller, D. (2009). Timing of gene expression responses to environmental changes. *Journal of Computational Biology*, *16*(2), 279-290.

Costa-Mattioli, M., & Walter, P. (2020). The integrated stress response: From mechanism to disease. *Science*, *368*(6489), eaat5314.

Daie, J. (1985). Carbohydrate partitioning and metabolism in crops. *Horticultural Reviews*, 69-108.

De Marsily, G., & Abarca-del-Rio, R. (2016). Water and food in the twenty-first century. *Remote sensing and water resources*, 313-337.

Edwards, D. C., & McKee, T. B. (1997). Characteristics of 20th century drought in the United States at multiple time scales.

Farooq, M., Hussain, M., Wahid, A., & Siddique, K. (2012). Drought stress in plants: an overview. *Plant responses to drought stress: From morphological to molecular features*, 1-33.

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. (2009a). Plant drought stress: effects, mechanisms and management. *Sustainable agriculture*, 153-188.

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. (2009b). Plant drought stress: effects, mechanisms and management. *Sustainable agriculture*, 153-188.

Forlani, G., Trovato, M., Funck, D., & Signorelli, S. (2019). Regulation of proline accumulation and its molecular and physiological functions in stress defence. *Osmoprotectant-mediated abiotic stress tolerance in plants: recent advances and future perspectives*, 73-97.

Foyer, C. H., & Paul, M. J. (2001). Source–sink relationships. *e LS*.

Friend, A. L., Coleman, M. D., & Isebrands, J. (1994). Carbon allocation to root and shoot systems of woody plants. *Biology of adventitious root formation*, 245-273.

Fryer, M. J., Andrews, J. R., Oxborough, K., Blowers, D. A., & Baker, N. R. (1998). Relationship between CO2 assimilation, photosynthetic electron transport, and active O2 metabolism in leaves of maize in the field during periods of low temperature. *Plant physiology*, *116*(2), 571-580.

Gao, S., Wang, Y., Yu, S., Huang, Y., Liu, H., Chen, W., & He, X. (2020). Effects of drought stress on growth, physiology and secondary metabolites of Two Adonis species in Northeast China. *Scientia Horticulturae*, *259*, 108795.

Griffiths, C. A., Paul, M. J., & Foyer, C. H. (2016). Metabolite transport and associated sugar signalling systems underpinning source/sink interactions. *Biochimica et Biophysica Acta (BBA)-Bioenergetics*, *1857*(10), 1715-1725.

Hagishima, A., Narita, K. i., & Tanimoto, J. (2007). Field experiment on transpiration from isolated urban plants. *Hydrological Processes: An International Journal*, *21*(9), 1217-1222.

Hendry, G. A., Houghton, J. D., & Brown, S. B. (1987). Tansley Review No. 11. The degradation of chlorophyll-A biological enigma. *New Phytologist*, 255-302.

Hughes, L. (2003). Climate change and Australia: trends, projections and impacts. *Austral Ecology*, *28*(4), 423-443.

Humphries, P., & Baldwin, D. S. (2003). Drought and aquatic ecosystems: an introduction. *Freshwater biology*, *48*(7), 1141-1146.

Izanloo, A., Condon, A. G., Langridge, P., Tester, M., & Schnurbusch, T. (2008). Different mechanisms of adaptation to cyclic water stress in two South Australian bread wheat cultivars. *Journal of Experimental Botany*, *59*(12), 3327-3346.

Kalefetoğlu, T., & Ekmekci, Y. (2005). The effects of drought on plants and tolerance mechanisms. *Gazi University Journal of Science*, *18*(4), 723-740.

Kapoor, D., Bhardwaj, S., Landi, M., Sharma, A., Ramakrishnan, M., & Sharma, A. (2020). The impact of drought in plant metabolism: How to exploit tolerance mechanisms to increase crop production. *Applied Sciences*, *10*(16), 5692.

Kobata, T., Palta, J. A., & Turner, N. C. (1992). Rate of development of postanthesis water deficits and grain filling of spring wheat. *Crop science*, *32*(5), 1238-1242.

Kong, D.-X., Li, Y.-Q., Wang, M.-L., Bai, M., Zou, R., Tang, H., & Wu, H. (2016). Effects of light intensity on leaf photosynthetic characteristics, chloroplast structure, and alkaloid content of Mahonia bodinieri (Gagnep.) Laferr. *Acta Physiologiae Plantarum*, *38*, 1-15.

Lake, J., & Woodward, F. (2008). Response of stomatal numbers to CO2 and humidity: control by transpiration rate and abscisic acid. *New Phytologist*, *179*(2), 397-404.

Lewicki, P. P. (1998). Effect of pre-drying treatment, drying and rehydration on plant tissue properties: A review. *International Journal of Food Properties*, *1*(1), 1-22.

Lovisolo, C., Perrone, I., Carra, A., Ferrandino, A., Flexas, J., Medrano, H., & Schubert, A. (2010). Drought-induced changes in development and function of grapevine (Vitis spp.) organs and in their hydraulic and non-hydraulic interactions at the whole-plant level: a physiological and molecular update. *Functional plant biology*, *37*(2), 98-116.

MANISANKAR, G. AGR 691-MASTER'S SEMINAR (0+ 1).

McDonald, M. F., & Copeland, L. O. (2012). *Seed production: principles and practices*. Springer Science & Business Media.

Moreira, R., Chenlo, F., Chaguri, L., & Mayor, L. (2010). Analysis of chestnut cellular tissue during osmotic dehydration, air drying, and rehydration processes. *Drying Technology*, *29*(1), 10-18.

Olesen, J. E., & Bindi, M. (2002). Consequences of climate change for European agricultural productivity, land use and policy. *European journal of agronomy*, *16*(4), 239-262.

Ovington, J. (1965). Organic production, turnover and mineral cycling in woodlands. *Biological reviews*, *40*(3), 295-336.

Parry, M. A., Andralojc, P. J., Khan, S., Lea, P. J., & Keys, A. J. (2002). Rubisco activity: effects of drought stress. *Annals of botany*, *89*(7), 833-839.

Proud, C. G. (2007). Signalling to translation: how signal transduction pathways control the protein synthetic machinery. *Biochemical Journal*, *403*(2), 217-234.

Quick, W., Chaves, M., Wendler, R., David, M., Rodrigues, M., Passaharinho, J., Pereira, J., Adcock, M., Leegood, R., & Stitt, M. (1992). The effect of water stress on photosynthetic carbon metabolism in four species grown under field conditions. *Plant, Cell & Environment*, *15*(1), 25-35.

Rampino, P., Pataleo, S., Gerardi, C., Mita, G., & Perrotta, C. (2006). Drought stress response in wheat: physiological and molecular analysis of resistant and sensitive genotypes. *Plant, Cell & Environment*, *29*(12), 2143-2152.

Roupsard, O., Gross, P., & Dreyer, E. (1996). Limitation of photosynthetic activity by CO2 availability in the chloroplasts of oak leaves from different species and during drought. Annales des sciences Forestières,

Salehi-Lisar, S. Y., & Bakhshayeshan-Agdam, H. (2016). Drought stress in plants: causes, consequences, and tolerance. *Drought stress tolerance in plants, Vol 1: physiology and biochemistry*, 1-16.

Savage, J. A., Clearwater, M. J., Haines, D. F., Klein, T., Mencuccini, M., Sevanto, S., Turgeon, R., & Zhang, C. (2016). Allocation, stress tolerance and carbon transport in plants: how does phloem physiology affect plant ecology? *Plant, Cell & Environment*, *39*(4), 709-725.

Seleiman, M. F., Al-Suhaibani, N., Ali, N., Akmal, M., Alotaibi, M., Refay, Y., Dindaroglu, T., Abdul-Wajid, H. H., & Battaglia, M. L. (2021). Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants*, *10*(2), 259.

Sinclair, R. (1983). Water relations of tropical epiphytes: I. Relationships between stomatal resistance, relative water content and the components of water potential. *Journal of Experimental Botany*, *34*(12), 1652-1663.

Wahab, A., Abdi, G., Saleem, M. H., Ali, B., Ullah, S., Shah, W., Mumtaz, S., Yasin, G., Muresan, C. C., & Marc, R. A. (2022). Plants' physio-biochemical and phyto-hormonal responses to alleviate the adverse effects of drought stress: A comprehensive review. *Plants*, *11*(13), 1620.

Wojtyla, Ł., Lechowska, K., Kubala, S., & Garnczarska, M. (2016). Molecular processes induced in primed seeds—increasing the potential to stabilize crop yields under drought conditions. *Journal of plant physiology*, *203*, 116-126.

Xu, W., Shen, W., Ma, J., Ya, R., Zheng, Q., Wu, N., Yu, Q., Yao, W., Zhang, N., & Zhang, J. (2020). Role of an Amur grape CBL-interacting protein kinase VaCIPK02 in drought tolerance by modulating ABA signaling and ROS production. *Environmental and Experimental Botany*, *172*, 103999.

Yamaguchi, J. (1978). Respiration and the growth efficiency in relation to crop productivity. *Journal of the Faculty of Agriculture, Hokkaido University*, *59*(1), 59-129.

Zia, R., Nawaz, M. S., Siddique, M. J., Hakim, S., & Imran, A. (2021). Plant survival under drought stress: Implications, adaptive responses, and integrated rhizosphere management strategy for stress mitigation. *Microbiological research*, *242*, 126626.

Zivcak, M., Brestic, M., & Sytar, O. (2016). Osmotic adjustment and plant adaptation to drought stress. *Drought stress tolerance in plants, Vol 1: physiology and biochemistry*, 105-143.