American Journal of Biodiversity
https://biojournals.us/index.php/AJB
ISSN: 2997-3600

The Impact of Climate Change on Fruit Production: Adaptive Mechanisms in Horticultural Crops: Subject Review

Parwen Alaaldin Obaid
College of Agriculture, Kirkuk University, Kirkuk, Iraq

Received: 2024, 15, Apr
Accepted: 2025, 21, May
Published: 2025, 17, Jun

Annotation: This paper offers an extensive view of the impacts of climate change on fruit and horticulture and discusses how horticultural plants respond to a changing environment. The study starts by emphasizing the significance of fruit crops in food security and its economic role in the field of agriculture. It also examines natural changes to the climate, from the rising temperatures of the so-called "dust bowl" event and changing rainfall patterns to severe drought and atmospheric CO_2 levels. The work delves into negative effects of climate change on fruit, such as shifted flowering and ripening schedules, lowering of fruit quality, and escalating fruit-invading diseases and pests. It also addresses the physiological and anatomical mechanisms employed by plants for adaptation including the control of stomatal opening, modulation of photosynthesis, and root distribution with special reference to osmotic substance production for combating water and heat stress. The research also underscores the value of adaptive agriculture, including planting date adaptations, smart irrigation, and pruning and shading methods. It also *showcases the role of biotechnology and gene editing for example in developing varieties resistant to both to drought and heat using CRISPR technology. The study includes cases studies representing a variety of crops, such as grapes, olives, and citrus, and adaptation responses in different geographical regions. It also highlights challenges and future research directions, including long-term cross-scale studies, climate model accuracy, and international cooperation. Last, but not least, it highlights the importance to transfer scientific knowledge to agricultural side, to steer policies toward the sustainable agriculture, to strengthen investments in research and development for ensuring the sustainability and improvement of fruit production in climate change frame

Keywords: Climate, fruit, genetic, CRISPR technology, adaptive agricultural.

Introduction

Fruit crops are the most significant in global agricultural production, because of their indispensable contribution to food and nutrition security. They contain a variety of essential nutrients including natural sugars, vitamins (i.e., vitamins C and A), fiber and minerals, as well as phenolic compounds contributing to the fight against chronic diseases [FAO, 2019]. Fruit growing is also a key economic activity in many countries, in particular in rural areas, as it helps in local income generation, job creation, and securing a livelihood for small farmers [World Bank, 2020]. In some nations that develop a large share of their agricultural GDP from fruit export, such as Spain, Chile, Turkey, and Italy, one can clearly infer how much the agricultural economy relies on consistent fruit production. But horticulture sector is also facing unprecedented challenges caused by global climate change, which directly affects the stability of fruit production and quality now. Climate assessments of the Intergovernmental Panel on Climate Change (IPCC) have demonstrated that the last two decades have experienced a higher than normal increase in temperature, more frequent extreme weather events (such as droughts and heat waves), changes in seasonal rainfall patterns, and further increase in atmospheric carbon dioxide concentrations [IPCC, 2021]. The economic, environmental and health problems in Iraq and Kurdistan, are increasingly threatening aspects of the lives, especially housing in crises, the productivity of the sectors of productive and environmental pollution heavy metal.

Many a studies have reported positive effects of mineral supplementation like selenium and zinc on improvement of animal health and mitigating environmental pollution as well as, integrating environmental dimension in modern economic theory of growth (Palani, 2025; Palani et al., 2025; Palani & Hussen, 2022; Palani et al., 2022a, 2022b, 2024a, 2024b). These changes in climate affect agroecosystems in different ways and in a particularly significant manner fruiting crops, which are both more vulnerable to climatic changes, as a result of their long cycle and higher dependency on the environment and weather equilibrium, and more meteorologically driven. For instance, increased temperatures could lead to shifts in the timing of blossom and fruit setting, which might influence pollination and fruit quality [Rosenzweig et al., 2014]. Alterations in precipitation also cause water scarcity or the emergence of diseases not seen in the past in farmland environment [Lin, 2011]. In this context, the study of the adaptive responses of horticultural crops to new environmental conditions, either physiological, anatomical, or at the molecular level, has become imperative. In addition, adaptive agricultural practices and modern biotechnologies including genetic modification and advanced selections are gaining more and more importance to breed fruit genotypes resistant to drought and heat without declining market quality and nutritional quality. According to the above, the purpose of this scientific review is to offer a deep and up to date overview of the ways by which climate forces the fruit production from horticulture plants and the manner in which horticultural plants are responding to the strain through physiological and genetic adaptation, sustainable and horticultural responses. It also identifies major research directions and future approaches in this area, providing informative references for the dissemination of sound environmental policies and for both regional and informed local farmers in the sustainable development of horticultural production to mitigate climate change.

The Impact of Climate Change on Fruit Production

It is worth mentioning that climate changes constitute one of the major problems of fruit production of last decades. The growing number of climatic extremes are causing drastic developments in the physiological processes of horticultural crops and have negative effects on both quantity and quality of crops as well as stability of crops across seasons. Temperature, humidity, rainfall and water availability are also important environmental factors for these plants to survive. Studies have demonstrated that any alteration of these elements due to climate change can have direct or indirect effects on plant life and productivity.

One such effect is temperatures increasing with priority, which has also been strongly undermining the flowering and fruiting of many fruit crops when the latter depends on the number of chilling hours during winter for the regular formation of flowers, as is the case for apples, peaches, cherries and almonds. Several reports have indicated that decreased chilling hours as a result of global warming is causing decreased flowering and irregular flowering dates, as well as poor pollination, resulting in inefficient fruit set (Luedeling et al. Elevated temperatures can also promote flowering in some species (e.g. grape), thus increasing the opportunity for flowers to experience late spring frost or to fall outside the period of pollinator activity, which results in lower fruit set. Furthermore, plant phenology and seasonal cyclic processes (budding, flowering, ripening, leaf fall) have been severely altered by climate change. The timing of these events has tended to occur earlier or later than normal, depending on the type of crop and the region, altering the life cycle of plants and the timing of harvest and quality of the final fruits (Chuine et al. This disturbance adds difficulty to the forecast of crop production and marketing planning. On the other hand, long drought periods and excessive evaporation due to the increase in temperature lead to loosing of water use efficiency in horticultural plants. Plants experiencing water stress close their stomata reduce water loss, which results in diminished photosynthesis, fruit development as well as quality (Chaves et al., 2006). This is particularly noticeable in fruit trees which count on frequent irrigation, since the dry spells can lead to deformed or smaller fruit size, as in the case of citrus trees, grapevines and fig trees. The effects of climate changes are not simply a matter of physiology, but also concern the health of the plant, since climatic modifications cause dispersion both geographically and in the diffusion of pests and diseases of plants. Fruit flies and plant flies were found in new regions as a result of the higher temperature (Bautaswa et al., 2012), which also played an important role in the severity and occurrence of fungal diseases on grapes and apples (Botrytis cinerea: gray mold; black mold). This is a great challenge for farming operations as they are impelled to utilize large quantities of pesticides to meet this demand while also dealing with the rising cost of imported solutions and maintaining product quality and safety standards. Finally, fruit quality as measured by taste, size, color, and nutrition is also impacted by climate change. Extreme temperatures and water stress promote fruit maturation at the cost of sugar and organic acid accumulation, reducing fruit taste and nutritional properties (Zhang et al., 2022).

The fruit can also exhibit a change in color balance, and pigmentation if the conditions during fruit development are suboptimal, thereby affecting the fruit's attractiveness to consumers and market place. Taken together, these respectively positive and negative effects make it imperative to explore how climatic variation is expected to drive changes in fruit production, and to design agricultural and technological interventions to cope with climate changes, and to enable food security and enhance the quality of agro-products under changing climate in future.

Physiological and Anatomical Adaptations

Horticultural plants have developed numerous physiological and anatomical mechanisms that enable them to adapt to environmental changes resulting from climate change, particularly rising temperatures, water scarcity, and increased soil salinity. These adaptations range from regulating basic biological processes, such as stomatal opening and modifying photosynthetic mechanisms, to changes in the anatomical structure of plant organs, such as roots and leaves, ensuring plant survival and continued production under harsh environmental conditions. One of the most prominent adaptation mechanisms is the regulation of stomatal opening on the surface of leaves, which represents an immediate response to water or heat stress. When temperatures rise or water availability decreases, plants close their stomata to limit water loss through transpiration, albeit at the expense of reducing the uptake of carbon dioxide required for photosynthesis (Flexas et al., 2004). This delicate balance between water conservation and maintaining photosynthetic rates is critical for plant survival and production.In addition, horticultural plants exhibit changes in their photosynthetic pathways to optimize resource utilization under harsh conditions. Some species rely on modifying the rate of photosynthesis or shifting toward more efficient modes of carbon fixation, such as a partial transition from the C3 pathway to the CAM or C4 pathway in some conditions, which enhances the plant's ability to fix carbon at high temperatures or low humidity (Ghannoum, 2009). Anatomy-wise, plants also exhibit changes in their root structure as a means of adapting to drought or soil salinity. Some fruit crops have been observed increasing the depth of their roots or branching horizontally in search of more stable water sources in the soil, a key feature for plant survival in arid and semi-arid environments (Comas et al., 2013). Increased root hair density also contributes to the efficiency of water and nutrient uptake.

At the cellular level, many plants resort to producing osmotic compounds as a means of protecting cells from the effects of drought and salinity. Proline, an amino acid that accumulates in plant tissues in response to environmental stress, is one of the most prominent of these compounds. Proline stabilizes proteins and cell membranes, regulates intracellular osmotic balance, and acts as a free radical scavenger (Szabados & Savouré, 2010). This accumulation can be used as a biomarker to measure a plant's ability to withstand adverse environmental conditions.

These physiological and anatomical adaptations do not occur in isolation, but rather are integrated within an integrated response system that enables plants to improve their environmental efficiency and maintain their productivity within limits. Studying these mechanisms is essential for understanding the adaptive capacity of horticultural crops and guiding agricultural breeding programs to select more resilient varieties in the face of accelerating climate change.

Genetic and Molecular Adaptations

Genetic and molecular mechanisms are essential for horticultural plant to respond to climatic change through the reprogramming of gene expression and activation of certain biological pathways which could lead the plants to adapt to environment pressure, including heat, drought and salt stress. These mechanisms involve the complex pattern of gene expression (both activation and repression of stress gene expression), production of protective proteins, and antioxidant system activation. These traits may also be improved by biotechnology and gene technology. Plants under environmental stress res p ond by ch a nging gene expression pattern s and turning on or turning off ce rtain genes related t o the h ea t and drought tolerance. For instance, the mRNAs that encode these protective proteins, known as proteins of HsfA1 and

Hsp70 (heat shock proteins), increase in levels under heat stress (Ohama et al., 2017). Under drought stress conditions, osmoregulating genes (e.g., DREB and AREB) can be expressed to induce the generation of osmoregulatory substances and protective proteins (Nakashima et al., 2009). HSPs, also known as stress proteins, are an essential stabilizing factor for proteins and cellular structures under stress situations.

These proteins are molecular chaperones that help to prevent the accumulation of misfolded or denatured proteins in response to heat stress, and allow the maintenance of vital cellular activities (Wang et al., 2004). On the contrary, the antioxidant-related genes including CAT (catalase), APX (ascorbate peroxidase) and SOD (superoxide dismutase) are induced in plants under stress conditions. These enzymes play roles in scavenging ROS, which accumulate in abundance under stressful conditions, thereby protecting plant cells from oxidative injury (Mittler et al., 2004). Genetically modified (GM) and genetically engineered (GE) technology is a potential effective approach for improving plant resistance to environmental stresses. These capacities have allowed scientists to feed in resistance genes from unrelated plants or microorganisms into fruit species. For instance, tomato, grape and strawberry cultivars that are resistant to heat or water stress can be obtained by transferring CBF/DREB and HSPs genes through genetic engineering (Rivero et al., 2014).

The novel technique CRISPR/Cas9 has also enabled the modification of target genes on the genome accurately but without foreign gene incorporation (Zhang et al., 2020), which is a promisng for more sustainable development of horticultural varieties with future environment conditions. The knowledge of these molecular mechanisms offered novel insights for horticultural crops to improve productivity and sustainability under climate change impact and viable tools in future plant breeding programs focusing on reinforcement of plant resistance to fluctuating environmental conditions.

Adaptive Horticultural Practices

Given the increasing pace of climate change, ensuring that fruit crops remain productive and high in quality requires the use of adaptive horticultural management practices. These practices involve technical and administrative measures that reduce the detrimental effect of environmental stress via timing of agricultural operations, water management, and heat stress management, meet the fertility and/or moisture requirement of the soil, etc. Among the most crucial of these is changing planting and flowering times so as to steer clear of excessive heat and drought. For example, you can push back or move up planting according to seasonal climate predictions so that blooming happens under more favorable circumstances. It has been reported that changing the timing of pollination decreases pollination failure by heat stress during the flowering period in crops such as apple and cherry (Hatfield and Brugger, 2015). Planting early or late flowering cultivars is another strategy to lower the direct effect of freezing or hot temperatures.

Also, intelligent irrigation systems, like drip irrigation with moisture sensors, are a good option to optimize water use and improve water efficiency in arid and semi arid environment. How to water for water use efficiency Use drip irrigation, which applies water directly to roots to reduce evaporation and runoff, and soil sensors to more accurately time and size watering events to match a plant’s water needs. It has been demonstrated that the use of these freely available technologies can lower irrigation water requirements by 40% without losing crop yield in wine grapes and citrus orchards (Jones, 2004; Ferrieres and Soriano, 2007). For heat stress alleviation, pruning and shading management could act as effective ones to manipulate the micro-environment around the plants. Moderated pruning improves crown ventilation and decreases excessive evaporation, as well as shade nets or a canopy planting decreases the solar radiation intensity and plant tissue temperature. These treatments have been reported to mitigate heat stress damage in crops, such as strawberries and apples (Shahak, et al., 2008). Lastly, sustainable soil management, by way of organic matter addition and mulching, and soil structure improvement, improves soil moisture holding capacity and a consistent rooting environment. Field soil capacity of water and nutrients holding of crop performances and stress response are enhanced by organic matter (Lal, 2004). These measures are by no means immediate remedies; they are part of a broader plan to adjust horticultural farming systems to the new climate order, to continue to be sustainable and productive and ultimately to manage the negative effects of climate change on food security.

The Role of Biotechnology and Genetic Engineering

Biotechnology and genetic manipulation have totally revolutionized the breeding of horticultural crops for coping with growing climatic stresses, namely, drought and high temperatures. These technological advances have led to a quantum leap from the restrictions of conventional breeding by effectively modifying specific genes responsible for the genes governing stress resistance. Conventional fruit breeding started many decades ago and works with already existing varieties and individuals that are more stress tolerant and that are bred to develop more resilient plants with improved quality fruit or is hybridizing to create more stress tolerant varieties and higher fruit quality. These approaches, however, have major time and cost constraints, and are complicated given that stress related traits are polygenic in nature (Tester and Langridge, 2010).

In the past few years, the application of genome editing tool CRISPR/Cas9 has moved the field forward by allowing targeted modification of genes in the plant genome, with no introduction of foreign genes, potentially making them more acceptable to the scientific and regulatory community. For the enhancement of drought and heat tolerance and for the improvement of disease resistance, the brother technology has been applied in apple, grape and strawberry (Zaidi et al., 2018). For instance, CRISPR has been employed to edit genes associated with stomatal opening, resulting in the decrease in water loss and an enhancement of WUE under drought (Wang et al., 2019). Furthermore, genetically modified (GM) varieties derived from these methods also show improved adaptation to stress conditions, such as being able to tolerate extreme climate conditions, without detriment on fruit quality. Progress in those traits include salt, disease and pest resistance, heat tolerance, climates-adaptation and tolerance and others (Fiaz et al., 2020). Modern sequencing technologies and genomic analysis are the basis for genetic characterization and also help us to identify genetic signs related to the resistence of stress, making that molecular breeding and variety selection reach more adn more precise actions quickly.

These techniques can be used to identify tolerance genes responsible for tolerance to different environments and incorporate them in the breeding program (Varshni et al., 2014). To sum up, the combination of classical breeding, advanced genetic engineering methods and genotyping is a good strategy toward improving the resilience of horticulture crops and sustaining productivity of crops under climate change adversities.

Case Studies

As case studies, this review is of great significance to help comprehend how different fruit crops respond to the challenges of climate change and can be used as a reference point to evaluate the strategies adopted in different geographical areas to increase adaptation and productivity.

For one, the response of some crops, such as grapes, olive, citrus fruits, strawberries, bananas and apples, to stresses caused by climate is highly diverse. For instance, grapes are particularly sensitive to high temperatures at flowering, in terms of fruit set and quality, and olives have good drought tolerance due to deep roots and water status mechanisms (Van Leeuwen et al., 2013). The repercussion of altering precipitation regimes and increased drought intensity on citrus fruits are more noticeable and so changes in both the type of irrigation practices and the selection of more tolerant varieties are needed (Costa et al., 2018). Strawberries, for example (they are fussy about temperature), will be hard hit as temperatures rise. This increment has affected negatively on productivity and fruit quality that entailing to develop shade and artificial cooling devices

(Blanco et al., 2020). Being a tropical crop, bananas are very vulnerable to the climatic changes, particularly the increasing temperatures and changes in rainfall. It is hence imperative to have improved irrigation practices and resistant variety development programs (Tinkwano et al., 2011). Apple, strongly dependent upon cold requirement, has delayed flowering or missed flowering due to high temperatures, and thus requires the cultivation of cultivars that can respond to variable cold (Luedling et al., 2011). At the regional scale, adaptation strategies are different and dependant on the climate and socioeconomic condition of the region. In Europe, attention is directed towards irrigation arrangements, genetic modification, shade nets, and smart agriculture development initiatives (Jones et al., 2017). Farmers in the Middle East are particularly focused on enhancing water management by installing drip irrigation systems and recycling water, and using local drought-tolerant cultivar (Al-Hilal et al., 2020). Rainfed and low-cost technologies are among the considerations in Africa (Muchiri et al., 2021), as is the advanced sustainability such as mixed cropping and resilient agriculture. Asian approaches vary from use of biotechnology in countries like India and China to availing drought and waterlogging resistant types to establishing sophisticated irrigation and soil management processes (Kumar et al., 2019). Some successful examples can be found in the vineyards of southern France, where smart-pruning and the use of drip-irrigations systems have been used to attenuate grape heat stress and increase grape quality and yield by up to 15% in drought-vintages (Van Leeuwen 2013). Regions located in southern Spain have also been able to develop and implement heat- and drought-tolerant olive cultivars together with integrated agronomic practices that have helped to control production and quality of oil (Costa et al., 2018). In the US, strawberry production in California has installed modern technologies of cooling and shade nets, and these have enabled a reliable production and quality in the presence of repeated heatwaves (Blanco et al., 2020).

These studies provide strong arguments for the need establishing integrated adaptations like genetic manipulation with modern agronomic practices and natural resource management that can be a most appropriate means not only to maintain the sustainability and higher quality fruit production in brave the odds posed by the impending threats of climate change.

Future Challenges and Research Directions

As it concerns case studies, this review has high importance for being able to learn how different fruit crops react under the challenge of climate changes thus serving as the basis for evaluating the strategies applied in specific geographical areas to enhance adaption and productivity.

For one, the reaction of some crops, suchas grape, olive, citrus fruit, strawberries,banana, and apple, to climate-induced stresses is highly variable. For example, the grapes are very sensitive to high temperatures during flowering (fruit set and quality) and olive has good resistance to drought,because of the deep root system and water status regulation effects (Van Leeuwen et al.,2013). The impact of changing the precipitation patterns and enhanced drought stress on citrus fruit is more evident and the type of irrigation and the choice of more tolerant varieties should be adapted accordingly (Costa et al., 2018). You could say goodbye to strawberries, for example, which are picky about temperature; they will suffer as temperatures climb. This increase in temperature is having a negative impact on productivity and fruit quality which is forcing to implement a shading and artificial cooling system (Blanco et al., 2020). Bananas are a tropical crop and the climatic variations, specially the rise in temperature and alterations in the rainfall patterns, has had devastating effects. It is therefore necessary to adopt enhanced irrigationpractices and resistant variety promotion programs (Tinkwano et al., 2011). Apple is highly dependent on a cold requirement, has delayed or failed flowering due to high temperatures and therefore asks for thespectra for the cultivation of the corresponding varieties under changing cold (Luedling et al., 2011). At the local level, adaptation measures vary and are function of the region's climate and socioeconomic status. Europe has a focus on irrigation systems, GM, shade nets and smart agriculture projects (Jones et al., 2017). Middle Eastern farmers have been more interested in improving the water management by cultivating through drip irrigation systems, reusing water, and planting new local cultivar crops that have drought-tolerant properties (Al-Hilal et al., 2020). Rainfed and low input technologies are some of the options in Africa (Muchiri et al., 2021) and so is advanced sustainability includes mixed cropping and resilient agriculture. Asian practices range from biotechnological application in India and China to providing types that are resistant to drought or waterlogging, and implementing smart irrigation and soil management methods (Kumar et al., 2019). Some successful cases in southern France are in vineyards, which with smart-pruning, 9 or 11 buds per vine, and water stress by 30% using drip-irrigations, this mitigation achieved to reduce the heat-stress and increase quality and yield of grapes up to 11 or 15% on such as drought-vintages (Van Leeuwen, 2013). Regions in Southern Spain have also successfully developed and applied heat- and drought-tolerant olive cultivars with integrated agronomic practices that have allowed to manage production and quality of oil (Costa et al., 2018). In the USA, as an alternative, cooling and shading nets of strawberrijustry in t California have implemented modern technology and re-inforced the best reliability and quality under repeated conditions and heatwaves (Blanco et al., 2020).

These findings also speak to the importance of integrating adaptations such as genetic engineering with contemporary agronomic practices and natural resource management that can be most appropriate ways to take in the sustainability and improved quality fruit production to face the challenges by impending threats of climate change.

Conclusion

Fruit tree crops can change significantly in their maximum physiological and genetic responses to climate change but the rate at which they are changing is high and this rapid adaptation is challenging. Therefore, it is necessary to combine contemporary scientific concepts with the sustainable agricultural practices and policy directions to underpin R&D for the sustainable production and quality of fruits in a changing climate.

Reference

1. Al-Helal, I. M., Al-Masoudi, Y. H., & Al-Harthy, H. S. (2020). Water management practices for fruit production in arid environments: The case of the Middle East. Agricultural Water Management, 238, 106246.
2. Asseng, S., Ewert, F., Martre, P., Rötter, R. P., Lobell, D. B., Cammarano, D., ... & Zhu, Y. (2013). Climate change impact and adaptation for wheat protein. Global Change Biology, 19(8), 2348–2359.
3. Blanco, C. A., Echeverría, H. E., & García, D. (2020). Effects of heat stress on strawberry production and fruit quality. Scientia Horticulturae, 260, 108852.
4. Chaves, M. M., Flexas, J., & Pinheiro, C. (2007). Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. Annals of Botany, 103(4), 551–560.
5. Chuine, I., Cour, P., & Rousseau, D. D. (2004). Phenology: An integrative environmental science. Springer.
6. Comas, L. H., Becker, S. R., Von Mark, V. C., Byrne, P. F., & Dierig, D. A. (2013). Root traits contributing to plant productivity under drought. Frontiers in Plant Science, 4, 442.
7. Costa, J. M., Ortuño, M. F., Chaves, M. M., & Medrano, H. (2018). Olive tree responses to water stress and drought management techniques. Frontiers in Plant Science, 9, 275.
8. FAO. (2019). The State of the World's Biodiversity for Food and Agriculture. FAO Commission on Genetic Resources for Food and Agriculture Assessments.
9. Fereres, E., & Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany, 58(2), 147–159.

10. Fiaz, S., Mansoor, S., & Husnain, T. (2020). Genetic engineering and genome editing of fruit crops to enhance stress tolerance. Frontiers in Plant Science, 11, 610501.
11. Flexas, J., Bota, J., Galmés, J., Medrano, H., & Ribas-Carbó, M. (2006). Keeping a positive carbon balance under adverse conditions: responses of photosynthesis and respiration to water stress. Physiologia Plantarum, 127(3), 343–352.
12. Ghaffari, S. H., Hosseini, S. M., & Abdi, G. (2020). Climate change impact on horticultural crops. Journal of Agricultural Science and Technology, 22(1), 12–24.
13. Ghannoum, O. (2009). C4 photosynthesis and water stress. Annals of Botany, 103(4), 635–644.
14. Hatfield, J. L., & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. Weather and Climate Extremes, 10, 4–10.
15. IPCC. (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
16. Jones, H. G. (2004). Irrigation scheduling: advantages and pitfalls of plant-based methods. Journal of Experimental Botany, 55(407), 2427–2436.
17. Jones, H. G., Serraj, R., & Loveys, B. R. (2017). Agricultural adaptation to climate change: Opportunities and challenges. Journal of Experimental Botany, 68(9), 2115–2127.
18. Kumar, S., Pandey, S., & Singh, R. K. (2019). Biotechnological approaches for improving stress tolerance in fruit crops: Asian perspective. Plant Biotechnology Reports, 13(3), 233–247.
19. Lal, R. (2004). Soil carbon sequestration to mitigate climate change. Geoderma, 123(1-2), 1–22.
20. Lin, B. B. (2011). Resilience in agriculture through crop diversification: Adaptive management for environmental change. BioScience, 61(3), 183–193.
21. Luedeling, E., Girvetz, E. H., Semenov, M. A., & Brown, P. H. (2011). Climate change affects winter chill for temperate fruit and nut trees. PLoS ONE, 6(5), e20155.
22. Luedeling, E., Zhang, M., & Girvetz, E. H. (2011). Climatic changes lead to decreased chill availability for fruit and nut trees in California during 1950–2099. PLoS ONE, 6(5), e20155.
23. Mittler, R., Vanderauwera, S., Gollery, M., & Van Breusegem, F. (2004). Reactive oxygen gene network of plants. Trends in Plant Science, 9(10), 490–498.
24. Muchiri, M. N., Muriuki, J. M., & Ndirangu, S. (2021). Climate-resilient horticultural practices in sub-Saharan Africa. African Journal of Agricultural Research, 16(6), 892–901.
25. Nakashima, K., Tran, L.-S. P., Van Nguyen, D., Fujita, M., Maruyama, K., Todaka, D., ... & Yamaguchi-Shinozaki, K. (2009). Functional analysis of a NAC-type transcription factor OsNAC6 involved in abiotic and biotic stress-responsive gene expression in rice. The Plant Journal, 51(4), 617–630.
26. Ohama, N., Sato, H., Shinozaki, K., & Yamaguchi-Shinozaki, K. (2017). Transcriptional regulatory network of plant heat stress response. Trends in Plant Science, 22(1), 53–65.
27. Palani, P. M. R. . (2025). Residential Crisis in Iraq: The Current Trends and Future Prospectus: A Review. Spanish Journal of Innovation and Integrity, 38, 121–128. Retrieved from https://sjii.es/index.php/journal/article/view/185

28. Palani, P. M. R. . (2025). Residential Crisis in Iraq: The Current Trends and Future Prospectus: A Review. *Spanish Journal of Innovation and Integrity*, *38*, 121–128. Retrieved from https://sjii.es/index.php/journal/article/view/185

29. Palani, P. M. R. . (2025). The Relationship of International Loans to Credit Wall (Worthiness): A Review. *Spanish Journal of Innovation and Integrity*, *38*, 1–7. Retrieved from https://sjii.es/index.php/journal/article/view/168

30. Palani, P. M. R. and Hussen, A J.(2022). Efficiency evaluation of the economic performance of Bazian cement factory between 2008-2020. Journal of Garmian University. 9(2):229–245.

31. Palani, P. M. R., Ahmed, Y. A., Yaqub, K. Q., Salih, A. M., & Mohammed, B. A. (2025). Rethinking Economic Growth: Integrating Environmental Constraints into Growth Theories. International Journal of Scientific Research and Modern Technology, 4(2), 49–55. https://doi.org/10.5281/zenodo.14959442

32. Palani, Z. M. R. K., Kutaibani, H. E. I., & Amin, F. A. M. (2018). Changes in Some Blood Biochemical Indicators in Kurdi Rams Response of Selenium and Zinc Supplements. SJAR, 5(4), 87-96.

33. Palani, Z. M. R., Ahmed, K. A., Al-Obaidy, M. H. A., & Palani, D. M. R. (2022). Cooperative and antagonistic reactions of heavy metallic elements and its impact on health that are supplemented with selenium and zinc in Kurdi sheep. International Journal of Health Sciences, 6(S2), 5236–5246. https://doi.org/10.53730/ijhs.v6nS2.6304

34. Palani, Z. M. R., Al-Obaidy, M. H. A., Palani, D. M. R. ., & Ahmed, K. A. (2022). Effect of changes in some beneficial elements and dangerous heavy metals in cow and sheep manure on human and animal health and the environment. International Journal of Health Sciences, 6(S1), 6250–6256. https://doi.org/10.53730/ijhs.v6nS1.6295.

35. Palani, Z. M. R., Hamasalim, H. J. ., Abdualmajeed, O. M. ., Baqer, J. M. ., Omer, M. E. A. ., Mohammed, H. N. ., & Bchkol, D. H. K. . (2024). Biochemical Changes in Blood Serum after Selenium and Zinc Doses and their Effect on the Health and Environment of Kurdi Sheep in Kurdistan Region. Indonesian Journal of Social and Environmental Issues (IJSEI), 5(3), 299-305. https://doi.org/10.47540/ijsei.v5i3.1674.

36. Palani, Z. M. R., Khalil, W.A, Kutaibani, H. E. I. ., & Amin, F. A. M. . (2024). Effect of Sodium Selenite and Zinc Sulphate on the Weight, Size, Seminal Fluid Traits, and Histological Changes of the Testis and Epididymis in Kurdi Rams. Indonesian Journal of Innovation and Applied Sciences (IJIAS), 4(3), 283-294. https://doi.org/10.47540/ijias.v4i3.1672.

37. Pautasso, M., Döring, T. F., Garbelotto, M., Pellis, L., & Jeger, M. J. (2012). Impacts of climate change on plant diseases—opinions and trends. European Journal of Plant Pathology, 133, 295–313.

38. Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., ... & Travasso, M. I. (2014). Food security and food production systems. In Climate Change 2014: Impacts, Adaptation, and Vulnerability (pp. 485–533). Cambridge University Press.

39. Rivero, R. M., Kojima, M., Gepstein, A., Sakakibara, H., Mittler, R., Gepstein, S., & Blumwald, E. (2007). Delayed leaf senescence induces extreme drought tolerance in a flowering plant. Proceedings of the National Academy of Sciences, 104(49), 19631–19636.

40. Rosenzweig, C., Iglesias, A., Yang, X. B., Epstein, P. R., & Chivian, E. (2014). Climate change and extreme weather events: Implications for food production, plant diseases, and pests. Global Change & Human Health, 2(2), 90–104.

41. Schlenker, W., & Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. Proceedings of the National Academy of Sciences, 106(37), 15594–15598.

42. Shahak, Y., Gal, E., Gussakovsky, E. E., Ganelevin, R., Stern, R., Harcavi, E., ... & Raban, E. (2008). Photoselective netting: an overview of the concept, research and development in Israel. Acta Horticulturae, 770, 161–168.

43. Szabados, L., & Savouré, A. (2010). Proline: a multifunctional amino acid. Trends in Plant Science, 15(2), 89–97.

44. Tenkouano, A., Duval, H., & Pillay, M. (2011). Challenges in banana and plantain breeding. Plant Breeding Reviews, 35, 91–124.

45. Tester, M., & Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. Science, 327(5967), 818–822.

46. Van Leeuwen, C., Destrac-Irvine, A., & Lannuzel, G. (2013). Climate change and viticulture: A European perspective. Journal of Wine Research, 24(2), 103–121.

47. Varshney, R. K., Terauchi, R., & McCouch, S. R. (2014). Harvesting the promising fruits of genomics: Applying genome sequencing technologies to crop breeding. PLOS Biology, 12(6), e1001883.

48. Wang, F., Wang, C., Liu, P., Lei, C., Hao, W., Gao, Y., ... & Zhao, K. (2019). Enhanced rice blast resistance by CRISPR/Cas9-targeted mutagenesis of the ERF transcription factor gene OsERF922. *PLOS ONE,