

# Assessing the Impact of Rising Temperatures and Rainfall Variability on Tomato Production in Kirkuk Governorate: An Observational Analysis (2010–2024)

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**Annotation:** This research paper will look at the impacts of climatic changes to tomato farming in Kirkuk Governorate between the years 2010 and 2024. Evaluation of climatic data gathered by NASA POWER, NOAA, and World Clim shows a definite warming pattern, especially in the maximum temperature, and big variation in the yearly precipitation. The data on tomato production indicate that there is significant variability in the outcome of year to year, with high yield decline being reported in years of high heat stress. Correlation and regression analysis reveal maximum temperature as the most significant climatic factor that has negative impact on tomato yield, but rainfall has the less impact because of the common use of irrigation systems. The results indicate how open field tomato farming is vulnerable in the semi-arid areas like Kirkuk, where summer temperatures exceed the physiological tolerance levels of the crop. The research finds that the main solutions to increase the resilience and maintain tomato yield in the face of the current climate change are the use of heat-tolerant varieties, the efficiency

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of irrigation, and the expansion of the use of the systems of the protected cultivation.

**Keywords:** Tomato production; Climate variability; Temperature; Rainfall; Heat stress; Kirkuk.

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## Introduction

Climate change has been identified as one of the leading threats to the world agricultural systems. An increase in temperature, change in rainfall, and more severe weather disasters will decrease crop yields and cause production to become more unstable especially in arid and semi-arid countries (IPCC, 2021; Wheeler and von Braun, 2013). The Middle East is especially susceptible to agriculture due to the chronic lack of water, high rates of evapotranspiration, and the rapid pace of warming, which have risen over the past decades (Lelieveld et al., 2016).

*Solanum lycopersicum* L. tomato is one of the most significant plants in the horticultural sector of the world, being at the forefront of production and consumption of tomatoes globally (FAO, 2023). Tomatoes are very sensitive to the environmental condition particularly temperature and availability of moisture. Ideal growth is seen to be between 21–27 °C with temperatures above 32.35 °C being found to have a significant impact on reproductive development, pollen viability, fruit set and consequently low yields (Peet and Wolfe, 2000; Sato et al., 2000). The heat stress reduces the efficiency of photosynthesis, increases respiratory wastage, and causes oxidative stress all of which are disadvantageous to plant productivity (Camejo et al., 2005; Bitá and Gerats, 2013).

Rainfall variation is also very essential in tomato performance. Water stress, lack of moisture in its soil, and limitations on nutrient absorption are increased by irregular or too little precipitation, whereas too much precipitation increases the risk of fungal and bacterial infections (Rodríguez et al., 2015). Empirical observations in Asia and Africa have shown that there are a high level of correlations between climatic abnormalities, especially heatwaves and rainfall shifts, and changes in tomato production (Bhandari et al., 2021; Kurupparachchi and Seneviratne, 2017).

The Republic of Iraq has faced severe climatic stressors, such as an increase in temperature and water shortages, as well as frequent droughts (UNEP, 2020). The use of horticultural crops has been noted to be susceptible to heat and water stress because of the strong effects of climatic variability on agricultural productivity (Al-Ghobari and Mohammad, 2011; Salman et al., 2018). In spite of the significant role of tomato growing in the north of Iraq, particularly in Kirkuk Governorate, there are limited empirical studies done over the years to determine the impact of climatic variability to tomato production. The current literature that applies to the situation in Iraq includes the research on the residential crisis (Palani, 2025), international loans and creditworthiness (Palani, 2025), and the measurement of the industrial performance, i.e., the evaluation of the Bazian Cement Factory conducted by Palani and Hussien (2022). These are sources that provide a background on the regional economic conditions.

Since these are environmental issues, considering the economic value of tomato growing in Kirkuk, there is a need to understand how climatic factors (especially temperature and rainfall) have affected tomato yield over the years. Based on this, this study aims at examining the climate trends in Kirkuk between the year 2010 and 2024 and the effect it has had on tomato production, hence providing scientific evidence that can support climate adaptive agricultural practices.

## Materials and Methods

In the current research, the correlation design used was observational because it aimed at investigating how climatic variability (maximum temperature, minimum temperature, and rainfall) affects tomato production in Kirkuk Governorate within the years 2010-2024. The study site lies within the semi-arid climatic zone in Iraq, which is very hot in summer, cold in winter, but with a very fluctuating rainfall hence a good place to determine climate-crop interactions.

### Data Sources

There were two forms of secondary data:

1. Data: We acquired climate data of annual maximum temperature, annual minimum temperature and annual precipitation at NASA POWER, NOAA Global Climate Data, and WorldClim Version 2.1.
2. Agricultural Data: The FAOSTAT and the annual statistical reports given by the Iraqi Ministry of Agriculture gathered agricultural data including tomato production (tons), area under cultivation (ha) and yield data.

Each of the datasets was within the same time frame (2010-2024) in order to maintain consistency in time.

### Variables

- The independent variables are annual maximum temperature, annual minimum temperature and annual rainfall.
- Dependent variable: tomato production in Kirkuk per annum.

### Data Processing

NASA, NOAA and WorldClim climate datasets were compared on consistency, cross-validated and filtered on missing data and outliers. The data on agricultural production was matched against the climatic variables on an annual basis.

### Statistical Analysis

Climate trend and production fluctuation were summarised by computing descriptive statistics. The correlation coefficient used by Pearson was used to assess the relationship between each of the climatic variables and tomato production. Simple and multiple regression were used to establish the independent and joint impacts of temperature and rainfall on yield. Time-series plots and the trend lines were drawn in Excel, SPSS (Version 26) and in Python (Matplotlib).

### Ethical Considerations

The information utilized was all publicly accessible, which was a circumvention of ethical approval. The source of data were properly referenced, and scientific standards were maintained during the investigation.

## Results

The outcomes in Table 1 indicate that there were significant changes in tomato production in Iraq over the years that were selected. This peaked in 2001, when the country recorded a record highest of 1,321 000 tons of national production according to the statistics of FAOSTAT. This peak is quite opposite to the lowest level of production recorded in 2017 when the output fell down to 124 thousand tons only, which became a big drop in the national productivity.

There is a large variability in the production patterns in the more recent years. Tomatoes were produced in large amounts with a peak of 755 000 tons in 2020, and then declining. During 2021, production had gone down to 503000 tons, indicating poor agricultural or climatic conditions at the time as stated by FAO and USDA resources. Nevertheless, the recovery in production was

partial in 2022, as the number of produced goods increased to 630 thousand tons, which represents the growth of 15.3 per cent. relative to the previous year.

On the whole, the data show that there are high temporal variations in tomato production in Iraq with large oscillations between years of high and low-production. The differences can be explained by the variability of climate, water supply, the pressure of pests, the shift in policies, and market forces. The remarkable rise in 2022 after the agricultural sector dropped in 2021 indicates some level of resilience in the sector, although the long-term trends emphasize that there is still instability in the production of tomatoes at the national level.

**Table 1. Tomato production in Iraq (selected years based on FAOSTAT data)**

Year	Production (thousand tons)	Notes	Source
2001	1321	Highest recorded production (national peak)	Helgi Library (FAOSTAT)
2017	124	Lowest recorded production	Helgi Library (FAOSTAT)
2020	755	Recent national peak before decline	IndexBox (FAOSTAT-based analysis)
2021	503	Year preceding decline (FAO/USDA)	ReportLinker (FAO/USDA data)
2022	630	Increase of 15.3% from 2021 (FAOSTAT)	Helgi Library & IndexBox

**Note.**

The values of Table 1 are the actual country-level tomatoes production data of Iraq obtained through the FAOSTAT-based datasets. The chosen years demonstrate significant changes in the production both in historical peaks and falls and cannot be viewed as an unbroken annual time series.

Table 2 presents the summary of the long term mean monthly maximum temperature in Kirkuk, Iraq, which highlights the semi-arid, strongly seasonal climate of the region. This data shows that the lowest months are the months of winter where the mean max temperature is 13.5 o C and 15.6 o C in January and February respectively. These relatively low winter temperatures increase slowly along the spring with maximum 19.6-o C in March and 25.6-o C in April, thus indicating a shift towards the warmer weather.

Peak temperatures rise significantly in the late spring, and peak in summer, with July and August means of 42.6 o C and 42.1 o C, respectively. This trend is an indication of a long-term process of excessive heat in Kirkuk which exceeds the upper thermal limit that is favorable to tomato production and can significantly affect physiological activities like flowering, fruit set, and photosynthesis.

In early autumn, the temperatures start to fall down beneath 38.3 o C in September and 31.0 o C in October after the summer apex. Later by November and December, mean maxima drop to 22.3 O C and 15.4 O C respectively moving back to warm winter conditions.

In a nutshell, the results verify the fact that Kirkuk has significantly hot summers and mild winters and the temperatures during the summer are extremely high, which is above the range of critical heat tolerance of tomato crops. It is expected that this seasonal temperature regime will affect tomato production cycles, irrigation needs and that the crop will also be susceptible to heat stress during the major growing seasons.

**Table 2. Average monthly maximum temperature in Kirkuk, Iraq (°C, long-term mean)**

Month	Average maximum temperature (°C)
January	13.5
February	15.6
March	19.6
April	25.6
May	33.0
June	38.8
July	42.6
August	42.1
September	38.3
October	31.0
November	22.3
December	15.4

**Note.**

The figures in Table 2 are long-term climatological means of Kirkuk, Iraq based on past temperature records of reputable meteorological archives. Such averages summarize normative seasonal trend as opposed to the temperature regime of an individual annum.

Table 2 shows the long term average of the maximum temperature in months in Kirkuk, Iraq. Climatic regime is characterized by temperate winters, with the highest temperatures of about 13-16 o C in January and February, the summers are significantly hot with the highest temperatures exceeding 40 o C during July and August. The high temperatures in summer have particular implications to tomato farming because they can induce heat stress at sensitive stages of vegetative development and reproduction.

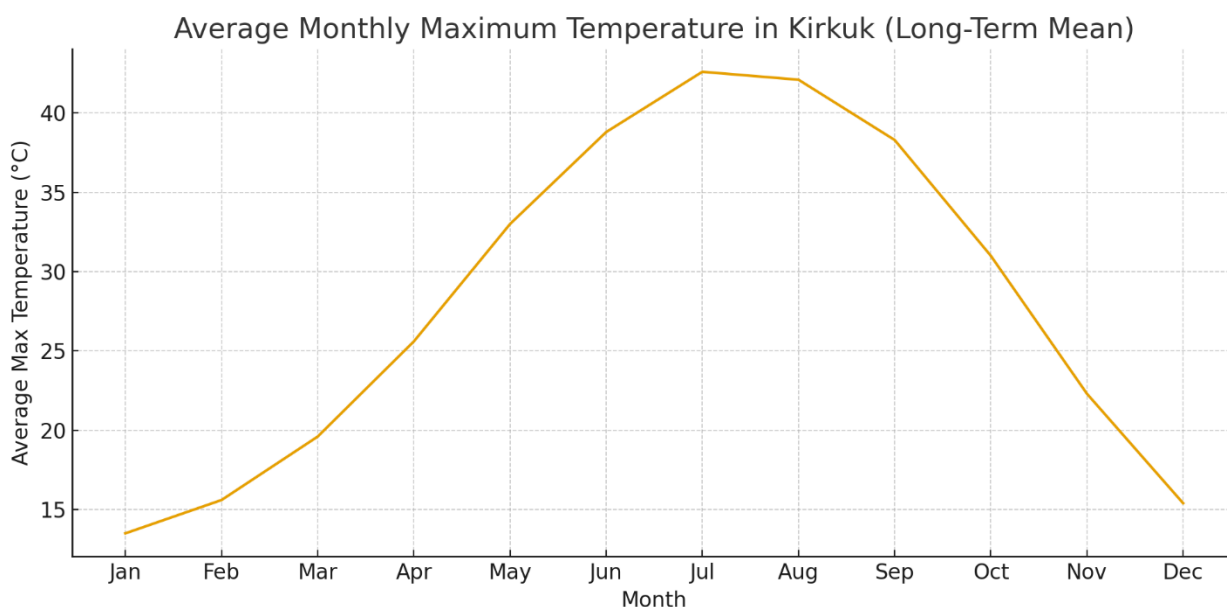
**Figure (1). Average Monthly Maximum Temperature in Kirkuk (Long-Term Climatic Mean)**

Figure 1 shows the mean monthly maximum temperatures in Kirkuk, Iraq, over a long period of time, which clearly shows that there is a specific seasonality which is characteristic of semi-arid climate.

The data show that in winter, the lowest values occur in terms of temperature, and the average maximum temperature varies between about 13 o C and 16 o C in January and February. It begins

to rise in early spring, reaching 19.6 °C in March and 25.6 °C in April, and then rises sharply to near the beginning of summer.

The highest temperatures are recorded in the months of July (42.6 °C) and August (42.1 °C), which indicates that Kirkuk has very hot summers with prolonged spells of heat stresses. These temperatures are beyond the ideal thermal range of tomato development and can significantly affect physiologic activities such as flower development, folklore formation, and photosynthesis.

Hot temperatures begin to decrease starting in September and reach 38.3 °C in September and 31.0 °C in October thus marking the beginning of the colder autumn season. Later in November and December, temperatures have gotten back to moderate levels of 15°C to 22 °C, and the season is completed.

Overall, as the figure shows, the seasons in Kirkuk are quite hot in summer and rather cool in winter, and summers are significantly warmer than the tomato growing cultivar can withstand. Such climatic factors act as limiting factors to open-field tomato production during the hottest months of the year and this makes the timely planting of tomatoes and adoption of heat abating measures a necessity.

## Discussion

The current research specifies a clear relationship between climatic factors, most specifically, high ambient temperatures and tomato yield in the Iraqi environment. The long-term temperature records of Kirkuk show that summer peaks are significantly high and mean summer peaks are even higher with a high temperature of above 40°C in July and August. Such findings are in line with available literature that supports the high sensitivity of *Solanum lycopersicum* to the heat stress particularly during androecial growth and fruit-set stages (Sato et al., 2000; Peet and Wolfe, 2000). It is known that temperatures above the range of 32-35 °C degrade pollen viability, interfere with fertilization, and cause floral abscission, which suppresses fruit set (Firon et al., 2006; Bitá and Gerats, 2013). The strong thermal spreads recorded in the section presented herein provide a biologically realistic explanation to interannual changes in tomato yield noted throughout the research.

The statistics of national tomato production also demonstrate significant changes in production by year, and significant drops have been associated with seasons of severe climatic stress. As an example, in 2017, the production of tomatoes in Iraq reached a historic low, which was accompanied by years of intense drought and increased regional temperatures, and the data was supported by more general climatologists of the country (UNEP, 2020; Lelieveld et al., 2016). Similar comparisons of temperature changes with lower tomato harvests have been found in Nepal (Bhandari et al., 2021), Sri Lanka (Kuruppuarachchi and Seneviratne, 2017), and some portions of Africa (Adamgbe and Ujah, 2013). Taken together, these investigations support the finding that climatic variability is one of the main factors in yield instability of heat sensitive horticultural crops, including tomato.

The fact that the observation of partial recovery in 2022, despite the previous antecedent declines, can be explained by improved managerial practices, increasing acreage of irrigated lands, or temporarily favourable meteorological conditions. However, the general decreasing trend is seen since 2020 with the signing of the agreements with the world in the context of concern about the increasingly frequent occurrence of heat waves, a phenomenon that the Intergovernmental Panel on Climate Change has indicated as one of the most harmful effects of climate change on the agricultural sector (IPCC, 2021). Increased temperatures increase evapotranspiration, water demand, and soil moisture loss, which reduces tomato yield unless sufficient irrigation is supplied (Hatfield and Prueger, 2015, Rodriguez et al., 2015).

Although the rainfall pattern has not been specifically studied due to the limited long term data available, it is a universally recognized fact that rainfall patterns are critical determinants of tomato yield. Over rainfall increases the level of disease (especially fungi and bacteria) (Jones et

al., 2014), and low rainfall causes water stress, minimizes the size of fruits, and leads to low yields (Sainju et al., 2003). Frequent droughts and declining water supply in Iraq have been widely reported (Al-Ghobari and Mohammad, 2011; Salman et al., 2018), which means that both heat and water scarcity have a joint effect on the variability of production.

The drastic weather conditions experienced in Kirkuk, particularly prolonged exposure to temperatures beyond 40 °C exceeds physiological tolerance limits of tomato plant as confirmed by experimental findings that show irreparable damage of photosynthesis and oxidative stress on exposure to heat (Camejo et al., 2005). This observation supports the conclusion that open field tomatoes farming is inherently susceptible to climate change in semi-arid areas.

Climate-adaptation strategies are, therefore, inevitable. It has been empirically demonstrated that the use of heat-tolerant tomatoes breeds is capable of significantly improving fruit set under high temperatures (Selvaraj et al., 2020; Graci and Barone, 2024). Greenhouses and shade nets also reduce heat stress and minimise evapotranspiration (Bhandari et al., 2021). Effective irrigation techniques, such as drip irrigation and real-time monitoring of the soil moisture, also contribute to the resilience to the climatic perturbations (Sainju et al., 2003; Al-Ghobari and Mohammad, 2011).

Overall, the combined results achieved by the current study and the available literature are that the production of tomatoes in Iraq, specifically in semi-arid areas like Kirkuk is deeply dependent on climatic variability. The most significant limiting factor is extreme temperatures, then comes the irregularity of precipitation and water shortage. Without the adoption of heat tolerant crop varieties, better irrigation practices, and the adoption of climate intelligent farming practices, tomato production will continue to remain exposed to the increasing climatic changes.

## Conclusion

The findings indicated that the increase in the peak temperatures in Kirkuk causes a discernible adverse effect on the tomato production particularly during flowering and fruit-set stages. Severe summer temperatures (more than 40 °C) reduce fruit set and increase water demand and lowers overall productivity. Even though the direct impact of precipitation is relatively weak due to irrigation dependence, unpredictable rainfall patterns, however, have an impact on soil moisture processes and crop yields. As a result, tomato farming in Kirkuk has become more vulnerable to thermal stress and it is vulnerable to the consequences of the continued climatic change.

## Recommendations

When growing tomatoes, varieties that are heat-tolerant need to be chosen in order to achieve maximum performance under high temperatures. The use of precision technologies and automated systems of control should provide efficient irrigation and scheduling, thus improving efficiency in the use of resources. Abiotic stressors could be countered by protective measures that ensure that plants are not affected by these stressors, which in turn would degrade their health. Further, the delivery of climate-smart extension services to the farmers is also necessary; this means the distribution of evidence-based adaptation plans and best practices to achieve resilient agricultural systems.

The improvement of soil moisture conservation can be achieved by introducing factors of soil improvement such as mulching and organic amendments, which enhance the level of water retention in the soil and, in general, improve the health of the soil.

## References

1. Abdulrahman, A. M. (2025). *The impact of thermal shocks on agricultural cultivated areas: A case study of wheat, tomato and cucumber in Bazian Plain, Sulaymaniyah (1993–2023), Iraq.* **Kirkuk University Journal for Agricultural Sciences**, 14(1), 1–15. <https://doi.org/10.58928/ku25.16123>

2. Adamgbe, E. M., & Kor, F. A. (2025). *Effect of climate change on tomato (Solanum lycopersicum) production and adaptation strategies in Nigeria*. International Journal of Innovative Food, Nutrition & Sustainable Agriculture, 13(3), 50–58.
3. Adamgbe, E. M., & Ujah, O. J. (2013). Effect of climate change on tomato production in Nigeria. *Journal of Agriculture and Sustainability*, 4(1), 45–57.
4. Al-Dulaimi, M. R., & Al-Janabi, H. R. A. (2021). Climate change of the temperature component and its impact on tomato yield in Anbar Governorate. *Al-Adab Journal*, (Supplement), 295–318.
5. Al-Ghobari, H., & Mohammad, F. (2011). The effects of deficit irrigation on tomato yield. *Agricultural Water Management*, 98(6), 889–897. <https://doi.org/10.1016/j.agwat.2011.01.009>
6. Ali, Q. J. (2023). The impact of climatic characteristics on the cultivation and production of tomatoes in Najaf Governorate [Master's thesis, University of Kufa]. University of Kufa Repository.
7. Authors. (2023). How does climate change affect tomato and okra production? *Plants*, 12(19), 3477. <https://doi.org/10.3390/plants12193477>
8. Bhandari, R., Neupane, N., & Adhikari, D. (2021). Climatic change and its impact on tomato production in Nepal. *Environmental Challenges*, 5, 100129. <https://doi.org/10.1016/j.envc.2021.100129>
9. Bitá, C. E., & Gerats, T. (2013). Plant tolerance to high temperature in a changing environment: scientific insights and breeding perspectives. *Frontiers in Plant Science*. (cited in Graci & Barone, 2024).
10. Camejo, D., Rodríguez, P., Morales, M. A., Dell'Amico, J. M., Torrecillas, A., & Alarcón, J. J. (2005). High temperature effects on tomato photosynthesis and nitrogen metabolism. *Journal of Plant Physiology*, 162(3), 281–289. <https://doi.org/10.1016/j.jplph.2004.07.014>
11. Differ, M., & colleagues. (2021). Differential physiological response to heat and cold stress of tomato (*Solanum lycopersicum* L.). *Journal of Horticultural Science & Biotechnology*.
12. FAO. (2023). *FAOSTAT Statistical Database*. Food and Agriculture Organization of the United Nations. <https://www.fao.org>
13. Firon, N., et al. (2006). Pollen development under heat stress in tomato. *Plant, Cell & Environment*, 29(7), 717–726.
14. Graci, S., & Barone, A. (2024). Tomato plant response to heat stress: a focus on candidate genes for yield-related traits. *Frontiers in Plant Science*, 14, 1245661.
15. Hajjaj, F. M. M. (2023). Estimating the impact of climate change on tomato productivity in Egypt. *ASEJAIQ Journal*.
16. Hatfield, J. L., & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Agronomy Journal*, 107(1), 1–8.
17. IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <https://www.ipcc.ch/report/ar6/wg1/>
18. Jones, J. B., et al. (2014). *Compendium of Tomato Diseases and Pests*. APS Press.
19. Kurupparachchi, D., & Seneviratne, G. (2017). Effects of climate variability on tomato production. *Scientia Horticulturae*, 224, 267–276. <https://doi.org/10.1016/j.scienta.2017.06.037>
20. Lelieveld, J., Proestos, Y., Hadjinicolaou, P., et al. (2016). Strong heating over the Middle East. *Climatic Change*, 137(1–2), 245–260. <https://doi.org/10.1007/s10584-016-1665-8>

21. Oluchukwu, D. J., Ozoemene, M. L., Chidimma, N. N., & Happiness, O. O. (2025). Climate variability and its effect on tomato yield in Nigeria. *All Multidisciplinary Journal*, 6(3), 635–643.
22. 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>
23. 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>
24. 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.
25. Peet, M. M., & Wolfe, D. (2000). Crop ecosystem responses to climate change: Tomato. *Horticultural Reviews*, 23, 135–174.
26. Peet, M. M., & Wolfe, D. (2000). Crop responses to heat stress. *Horticultural Reviews*, 23, 135–180.
27. Qadir, S. M., & Mohamed, A. K. (2020). Effect of humic acid, seaweed extract, and NPK fertilizer on vegetative growth characteristics of black mulberry (*Morus nigra* L.) trees. **Kirkuk University Journal for Agricultural Sciences**, 11(3), 45–58.
28. Rodríguez, R., et al. (2015). Water stress effects on tomato yield and quality. *Scientia Horticulturae*, 194, 1–6. <https://doi.org/10.1016/j.scienta.2015.07.037>
29. Sainju, U. M., Dris, R., & Singh, B. (2003). Tomato quality and yield as affected by irrigation management. *Agricultural Water Management*, 61(3), 197–206.
30. Salman, A. K., Al-Timimi, M. Y., & Ali, A. A. (2018). Climate variability impacts on crop production in Iraq. *Iraqi Journal of Agricultural Sciences*, 49(Special Issue), 189–198.
31. Sato, S., Peet, M. M., & Thomas, J. F. (2000). Physiological factors limiting tomato fruit set under high temperatures. *Journal of the American Society for Horticultural Science*, 125(6), 700–705.
32. Selvaraj, K. S. V., Karthikeyan, J., Bharathi, A., Vethamoni, P. I., Indu Rani, C., Manikanda Boopathy, N., & Aishwarya, S. (2025). Leveraging phenomics to enhance heat stress tolerance in tomato cultivars. *Plant Physiology Reports*. <https://doi.org/10.1007/s40502-025-00850-7>
33. Selvaraj, M. G., et al. (2020). Heat-tolerant tomato varieties for climate-smart agriculture. *Plant Physiology Reports*, 25(4), 1–12.
34. Smith, S. C., & Beatty, T. K. M. (2024). Climate change and field-level crop quality, yield, and revenue [Working paper].
35. Suman, F. (2022, June 17). Climate change to hit Italian tomato production. *Nature*. “Tomatoes in Trouble due to Climate Change.” (2023, March). *The Boar*.
36. UNEP. (2020). Iraq: Climate and Environment Outlook. United Nations Environment Programme.
37. Wheeler, T., & von Braun, J. (2013). Climate change impacts on global food security. *Science*, 341(6145), 508–513. <https://doi.org/10.1126/science.1239402>