



Scientific Facts on Biochemical and Physiological Traits in Olive Trees in Relation to Climate change

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حقائق علمية حول السمات البيوكيميائية والفسيوولوجية في أشجار الزيتون وعلاقتها بتغير المناخ

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الملخص:

تقع ليبيا في أكثر المناطق القاحلة وشبه القاحلة في العالم، لذا يجب أن تكون أبحاث تغير المناخ هي القضية البحثية الرئيسية. المناخ جاف في ليبيا، وداخل ليبيا تم التعرف على ما يصل إلى خمس مناطق مناخية مختلفة، ولكن التأثيرات المناخية السائدة هي البحر الأبيض المتوسط والصحراء. يشير آخر تقرير للمركز الوطني للمناخ لعام 2010 إلى أن كافة مناطق ليبيا، وتحديدًا المنطقة الغربية، مرت بموسم جاف واضح، مع ارتفاع درجات الحرارة وانخفاض هطول الأمطار خلال شهري نوفمبر وديسمبر لعام 2009 مقارنة بالمعدلات العامة السابقة وحتى الفترات القادمة. تعتبر المياه أثنى الموارد الطبيعية في ليبيا، ويعد نقص المياه أحد التحديات البيئية الرئيسية التي واجهت تحديث ليبيا في الماضي وستظل كذلك في المستقبل أيضًا. ويهدد النقص التنموية الاجتماعية والاقتصادية لليبيا في القرن الحادي والعشرين، ويعد أحد أبرز مؤشرات التغير المناخي. واليوم، تواجه بساتين الزيتون تحديات جديدة. والتهديدات بسبب التغير المناخي المستمر. ارتفاع درجات الحرارة والجفاف وتزايد تواترهما الأحداث الجوية المتطرفة، مثل موجات الحر والأمطار الغزيرة، وطقس البارد جدا هي بعض المشاكل التي يواجهها مزارعو الزيتون وسيتعين عليهم مواجهتها في العقود القادمة. ومن المتوقع أن يشهد حوض البحر الأبيض المتوسط تغيرات مناخية كبيرة في درجات الحرارة وهطول الأمطار وزيادة نسبة الملوحة وكثرة الأمراض والآفات. وتتوقع السيناريوهات الأكثر تطرفاً ارتفاعاً بنحو 5 درجات مئوية بحلول نهاية القرن الحادي والعشرين إذا لم يتم تحقيق أهداف التخفيف من حدة ظاهرة الاحتباس الحراري. يخل تغير المناخ بوظائف أشجار الزيتون من خلال تغيير العمليات الكيميائية الحيوية الأساسية، مثل التمثيل الضوئي والتنفس ونشاط مضادات الأكسدة. ويُحَقِّز الإجهاد التأكسدي، مما

يؤدي إلى تراكم أنواع الأوكسجين التفاعلية وتلف الخلايا. كما يتأثر التوازن الهرموني، لا سيما هرمونات مثل حمض الأبسيسيك والأوكسينات والجبريلينات، التي تنظم النمو والاستجابة للإجهاد وتطور الثمار. وعلى المستوى الخلوي، يؤثر الإجهاد المناخي على نشاط الإنزيمات واستقرار الأغشية والمسارات الأيضية. وتقل هذه التأثيرات المُجمعة من إنتاجية الأشجار، وتُضعف جودة الثمار، وتُضعف قدرة النبات على الصمود بشكل عام.

الكلمات الدالة: تغير المناخ العالمي. مؤشرات تغير المناخ. الإجهاد الناجم عن تغير المناخ في أشجار الزيتون.

Abstract

Libya is located in the most arid and semi-arid regions in the world, so climate change research should be the main research issue. The climate is dry in Libya, and within Libya, as many as five different climatic zones have been recognized, but the dominant climatic influences are Mediterranean and Saharan. The latest report of the National Climate Center for 2010 indicates that all regions of Libya, specifically in the western region, went through a clear dry season, with a rise in temperatures and a decrease in rainfall during the months of November and December of 2009 compared to the previous general rates and even the coming periods. Water is the most precious natural resource in Libya, and water shortage is one of the major environmental challenges that faced Libya's modernization in the past and will remain so in the future as well. The shortage threatens Libya's social and economic development in the twenty-first century, and is one of the most prominent indicators. Today, olive groves face new challenges, and threats, because of ongoing climate change. Higher temperatures and drought and their increasing frequency of Extreme weather events, such as heat waves and heavy rain are some of the problems that olive growers face and will have to face in the coming decades. The Mediterranean basin is expected to witness significant climate changes in temperatures, rainfall, increased salinity, and an abundance of diseases and pests. The most extreme scenarios expect a rise of about 5 degrees Celsius by the end of the twenty-first century if goals to mitigate global warming are not achieved. Climate change disrupts olive tree physiology by altering key biochemical processes such as photosynthesis, respiration, and antioxidant activity. It induces oxidative stress, leading to the accumulation of reactive oxygen species and cellular damage. Hormonal balance is also affected, particularly hormones like abscisic acid, auxins, and gibberellins, which regulate growth, stress response, and fruit development. At the intracellular level, climate stress impacts enzyme activity, membrane stability, and metabolic pathways. These combined effects reduce tree productivity, impair fruit quality, and weaken overall plant resilience.

Keywords: Global climate change. Climate change indicators. Climate change induced stress in olive trees.

Introduction

The Mediterranean Basin is considered a climate change “hotspot” IPCC.(2012), since future projections hint at considerable warming trends and an increase of consecutive dry days Giorgi,F.(2006) , leading to an overall increase in aridity. In this context, climate change may be-come particularly challenging for olive growers. Scientific facts regarding the effects of climate change on olive trees in Libya are becoming increasingly evident. Libya is already experiencing reduced rainfall, and climate change is expected to exacerbate this. Olive trees, while drought-tolerant, are still negatively affected by prolonged and severe water shortages. Lack of water during critical growth stages, especially around flowering and fruit development,

leads to a decrease in the number and size of olives produced per tree. Some farmers in Libya have reported a significant drop in oil extraction from the same quantity of olives. Rising average temperatures and more frequent heat waves can negatively impact olive trees. Scientific facts overwhelmingly indicate that climate change is significantly impacting olive trees across the Arab world, a region where olive cultivation holds immense economic, social, and cultural importance Alsherif, S. A., & Almabrouk, A. E. (2020). The Arab region is already characterized by arid and semi-arid climates. Climate change models predict a further decrease in precipitation and an increase in evapotranspiration due to rising temperatures, leading to more severe and prolonged droughts. The Arab region is characterized by arid and semi-arid climates. Lack of sufficient water, especially during critical periods like flowering and fruit development, directly leads to a decrease in the number and size of olives produced. Countries like Morocco and Egypt have already reported significant drops in olive production due to drought. Levant (Lebanon, Palestine, Jordan): Studies indicate that rising temperatures could make some traditional olive-growing regions in the Levant too hot for optimal production by mid-century. Changes in rainfall patterns are also affecting olive chemistry and yield. Jordan is exploring GIS-based methods to identify optimal future olive cultivation areas in the face of climate change. North Africa (Tunisia, Morocco, Libya, Egypt): Tunisia's olive production is predicted to potentially halve by 2030 due to climate extremes. Morocco is facing a decline in olive harvest due to prolonged drought. Libya is experiencing severe drought threatening millions of trees. Egypt has also reported a significant drop in olive production attributed to increasingly severe weather conditions ESCWA (2020).The world is facing increasing problems and challenges in the field of agricultural production, most notably the phenomenon of severe climate change and the future uncertainty surrounding this phenomenon, which has begun to affect not only agricultural production, but also all other aspects of life. At the level of the Arab world, the latest report issued by the Arab Forum for Environment and Development indicates that climate change will be one of the main factors for reducing levels of food security in the Arab world during the next few decades through a sharp decline in agricultural productivity due to rising temperatures and decreased rainfall. In addition, soil erosion rates increase and organic matter content decreases as a result of these changes FAO. (2023).The current global annual consumption of olive oil is ~3.2 million tons International Olive Council.)2021), with close to 95 percent of production in regions surrounding the Mediterranean Sea. Olives are grown in many regions of the world with a Mediterranean climate, such as Spain, Tunisia, Morocco, Turkey, Libya, South Africa, Chile, Peru, Pakistan, Australia, and California, and in regions with a temperate climate such as New Zealand International Olive Council(2025). It has been known to reduce blood sugar, cholesterol, and uric acid. It has also been used to treat diabetes, hypertension, inflammation, diarrhea, respiratory and urinary tract infections, stomach and intestinal diseases, asthma, hemorrhoids, rheumatism, laxative, mouth cleanser, and as a vasodilator. The Olive trees benefit the environment in many ways. They contribute to the preservation of natural resources and biodiversity. The trees act as agents in combating global warming and desertification. Evidence shows that olive growing increases atmospheric carbon dioxide fixation in the soil. The abrupt differences due to changing climate forces plants to migrate or go extinct. Increasing temperatures have brought about earlier bloom times for plants, creating a potential for timing mismatch between pollinators and plants. Pathogens and pests are often also more active in warmer temperatures. Environmental stress weakens a plant and makes it more susceptible to disease or insect attack. Environmental factors that affect plant growth include light, temperature, water, humidity and nutrition. It's important to understand how these factors affect plant growth and development. With a basic understanding of these factors, whether for increased leaf, flower or fruit production. By recognizing the roles of these

factors, you'll also be better able to diagnose plant problems caused by environmental stress. Climate change reveals a close relationship between the increase in greenhouse gases [carbon dioxide (CO₂), methane (CH₄), nitrogen dioxide (NO₂), nitrates (NO₃)] and rising temperature, i.e. global warming. Carbon dioxide does not have a negative effect on olive trees. The worrying aspect is the effect of rising temperatures on olive trees due to greenhouse gases. Ayesha Tandon ., (2023)

2.0 -Number of olive trees and productivity (locally and Globally)

At the global level, a total of 11,512,015 hectares dedicated to the plantation and cultivation of the olive grove are currently registered. Of its olive production, 13.39 percent is dedicated to table olives, while 86.61 percent is dedicated to the production of olive oil. Starting from table 1, it can be seen that Europe is the world's largest olive producer, followed by Africa and Asia by a great length is classification can also be applied when we break down the two large productions derived from olive farm lands.

Table (1):The world's largest exporters of this commodity group in 2022

Rank	Country	Share of world Exports (%)	Export Value
1	Spain	48%	\$4.23 billion
2	Italy	21%	\$1.86 billion
3	Portugal	11.1%	\$983 million
4	Greece	9.58%	\$843 million
5	Turkey	3.84%	\$338 million
6	Argentina	1.17%	\$103 million

Some 850 million olive trees are grown in the world on approximately 8.7 million hectares of land. He added that there are about 10 to 12 million olive trees in Libya producing an average of 20 kg / tree with 3.1 million trees in the desert areas International Olive Growing . (2018)

Table (2) -Shows the leading countries in the world in area and Productivity of olive trees.

Country	Area (hectare)	Productivity (tons)
Spain	2.573.493	6.559.884
Greece	887.177	2.343.383
Italia	1.165.562	2.092.175
Turkey	845.542	1.730.000
Morocco	1.008.365	1.416.107
Syria	765.603	899.435
Tunisia	1.646.060	700.000
Algeria	424.028	696.962

Egypt	67.293	694.309
Portugal	335.075	617.610
Libya	357.797	188.975
Argentina	61.942	175.094
America	14.102	159.600
World	20.337.435	10.185.151

Source / FAOSTAT. Food and Agriculture Organization of the United Nations Statistical Data set; FAO: Rome, Italy, 2018

That there are about 10 to 12 million olive trees in Libya producing an average of 20 kg/tree with 3.1 million trees in the desert areas. Global olive oil consumption is projected to increase by 10% in the 2024/2025 crop year. The European Union is expected to see increased consumption Ibrahim Sunusi ,(2023). Other statistics indicate that Libya has approximately 30 to 40 million olive trees. The cities of Tarhuna, Bani Walid, and Misrata alone contain around 3 million trees. Olive trees in Libya are planted on an estimated 800,000 hectares. Olive production reached approximately 143,000 tons in 2022, 155,500 tons in 2024, and 162,200 tons in 2025.

Source: Abdulwahab Al-Azraq et al. (2021), Al-Ain News Agency (2025)

Table (3): Some famous olive varieties in Libya

Variety	Oil ratio %	Productivity (Kg)	Agriculture areas
Endory	22	42.6	Tripoli.Gharyan.Zlitan
Shemlaly.S	23	95.6	Zoira.Rigdalin.Aljmil.Zalton. The coast
Roghiani	16	68	Tripoli.Sayead.Alharsha.Soug Aljima.
Frantoyo	43- 46	45	Tarhona. Coastal areas.
Rasly	25	48.6	The coast . Soug Alghamis . Bani Walid
Hammody	25	20	Emsalata

Source / Arab Organization for Agricultural Development. 2022 .

Table (4) :The best species of olive trees in the world

Variety	Percentage %	Producing country
Picual	20 - 27	Spain
Arbequina	10%	Spain
Hojiblanca	17 – 19%	Spain
Leccino	18 – 21%	Italy
Frantoio	23 – 28%	Italy
Coratina	Up to 25%	Italy
Kalamata	7	Greece
Koroneiki	50 – 60 %	Greece
Cobran Gosa	10%	Portugal
Mission	50%	USA

Source / Daniel Dawson, 2020.Article in olive oil times.

3.0 - The effects of climate change on olive trees

We can begin with this conceptual model, which describes the impact of climate change on olive production and oil quality through several important stages, as follows:

- Step 1 – Climate change factors influence agricultural systems.
- Step 2 – Agronomic practices interact with climatic stressors.
- Step 3 – Olive trees experience physiological stress (water deficit and oxidative stress).
- Step 4 – Flowering and fruit set become unstable.
- Step 5 – Fruit growth and biochemical composition are altered.
- Step 6 – Olive oil quality and stability decline.
- Step 7 – Long-term impacts include economic losses and environmental degradation.

Having identified a set of fundamental stages that contribute to various physiological and biochemical changes in different parts of the olive tree, we will now move on to the mechanisms and methods by which the prevailing climatic factors in the Mediterranean basin affect each part of the olive tree, and the extent of their harmful effects.

1. Climate Change Stressors .3

- * - Rising temperatures, decreased/increased precipitation, and extreme weather events (heatwaves, droughts, storms).
- * - Promote the spread of pests and diseases.

2. Impact on Olive Tree Physiology .4

- * - Water stress due to less rainfall or drought.
- * - Reduced photosynthesis, impacting energy production in the plant.
- * - Oxidative damage to plant tissues.
- * - Growth disorders, like stunted or irregular development.

3. Effects on Flowering and Fruit Set .5

- * - Leads to deformed or fewer flowers/fruits.
- * - Incomplete or failed fertilization.
- * - Results in lower fruit yield.

4. Changes in Fruit Growth & Composition .6

- * - Lower oil content in olives.
- * - Changes in fatty acid profiles, affecting nutritional and commercial value.

5. Impacts on Oil Quality .7

- * - Reduced oxidative stability, meaning the oil spoils faster.
- * - Lower levels of polyphenols, which are antioxidants and flavor compounds.
- * - Changes in taste, aroma, and sensory qualities.

6. Economic & Environmental Consequences .8

- * - Reduced sustainability and competitiveness of olive farming.
- * - In some cases, farmers may abandon groves, increasing the risk of desertification in affected areas.

Climate change and new challenges for olive cultivation. Create climate changes that have affected the entire planet in recent years. Alarm from different points of view: High temperatures, natural disasters, and sudden events produce unfavorable conditions that also naturally affect olive cultivation, with consequent consequences for cultivation, Production, and agriculture. Regarding the availability of food and the economic effects that this can have. The most important of these effects is the following: -

3.1- Temperature degree

The Optimal Range of Olive trees thrive in an average annual temperature of around 17°C. They require a period of chilling (temperatures between 5-15°C) during winter for proper flowering in the spring, typically needing 200 to 600 hours below 10°C, depending on the variety. Warmer winters result in insufficient chilling hours, which can disrupt the flowering process, leading to reduced fruit set and lower yields. Temperatures exceeding 30°C during the summer can impair photosynthesis, affecting fruit development and oil quality. Extreme heatwaves can cause flower abortion and fruit drop. Increased temperatures can lead to earlier flowering and faster fruit ripening. This can disrupt the traditional harvest times and potentially affect oil quality. It can also lead to flowers dropping before fruit sets. In the long term, as temperatures rise, olive cultivation may become more viable in more northern latitudes. Warmer temperatures and altered humidity can favor the spread and increase the life cycles of olive pests like the olive fruit fly and olive moth, as well as fungal and bacterial diseases. Climate change can affect the chemical composition of the olive fruit, potentially altering the quality and sensory characteristics of the olive oil. [Cátia Brito et al. \(2024\)](#). Here's a summary of the key physiological phenomena associated with high temperatures in olive trees:

3.1.1. Photosynthesis and Carbon Assimilation:

Reduction in photosynthetic capacity: High temperatures, especially those exceeding 35-40°C, can significantly reduce the rate of photosynthesis. This is often due to a decline in the activity of key enzymes like RubisCO (L&S structure), which is crucial for carbon fixation. **Damage to Photosystem II (PSII):** PSII, a vital component of the photosynthetic machinery, is highly sensitive to heat stress. Damage to PSII can lead to reduced electron transport and overall photosynthetic efficiency. **Increased photorespiration:** High temperatures can favor photorespiration over photosynthesis, leading to a less efficient use of absorbed light energy and reduced carbon gain. **Reduced stomatal conductance:** While initially stomata might open to cool the leaf, prolonged high temperatures, often coupled with drought, lead to stomatal closure to conserve water. This reduces CO₂ uptake, further hindering photosynthesis.

Impaired carbon efficiency: Overall, heat stress negatively impacts the carbon efficiency of olive trees, leading to a reduced net accumulation of carbon.

3.1.2. Water Relations:

Decreased Leaf Relative Water Content (RWC): High temperatures increase transpiration rates, leading to a significant loss of water from leaves and a decrease in RWC, especially when temperatures exceed 50°C. **Loss of turgidity:** The reduction in water content can cause a loss of turgor, impacting cell expansion and overall plant growth. **Increased irrigation needs:** Elevated temperatures necessitate higher water requirements for olive trees to maintain their water status, especially during critical growth stages.

3.1.3. Membrane Integrity and Oxidative Stress:

Membrane damage and lipid peroxidation: Temperatures above 50°C can significantly increase membrane damage and lipid peroxidation in olive leaves, indicating oxidative stress. This compromises cell integrity and function. **Reactive Oxygen Species (ROS) accumulation:** High temperatures, particularly when combined with water stress, can lead to an increase in ROS (e.g., hydrogen peroxide, superoxide radical), which can cause irreversible damage to cellular

components. Antioxidant system adjustments: Olive trees attempt to cope with oxidative stress by activating antioxidant enzymes (e.g., guaiacol peroxidase, superoxide dismutase) and accumulating antioxidant compounds (e.g., flavonoids). However, the effectiveness of these responses can vary by cultivar and stress severity.

3.1.4. Reproductive Physiology and Yield:

Flowering damage and fruit set: Flowers are particularly sensitive to heat stress. Temperatures over 30°C can decrease pollen germination and fruit set, with complete flower death and crop failure observed at temperatures exceeding 35°C.

Pistillary abortion: High temperatures before flowering can lead to the premature development of inflorescences and an increase in pistillary abortion, resulting in more male flowers that only produce pollen and fewer fertile flowers. Reduced fruit weight and oil concentration/quality: Elevated temperatures during fruit development and maturation negatively impact fruit dry weight, oil concentration, and oil quality. This includes changes in fatty acid composition (e.g., decreased oleic acid, increased linoleic acid).

3.1.5. Vegetative Growth:

Altered shoot elongation and leaf area: Some studies indicate that elevated temperatures can promote vegetative growth, leading to greater whole-tree leaf area and shoot elongation, though this can be at the expense of fruit production. Phenological changes: Increasing temperatures can cause olive trees to flower earlier and potentially lengthen their growth period, although this can also lead to issues with chilling requirements for bud dormancy break.

3.1.6. Cultivar-Specific Responses:

It is crucial to note that the physiological responses to high temperatures are highly genotype-dependent. Different olive cultivars exhibit varying degrees of tolerance and deploy different adaptive mechanisms. This highlights the importance of selecting heat-tolerant varieties for future olive cultivation in regions affected by climate change.

4.0. Laboratory Study Methodologies:

Laboratory studies often utilize controlled environments such as growth chambers, phytotrons, or open-top chambers (OTCs) to precisely control temperature, humidity, and light conditions.

4.1. Measurements typically include:

Gas exchange parameters: Net photosynthesis rate (PN), stomatal conductance (gs), transpiration rate (E), and intercellular CO₂ concentration (C_i). Chlorophyll fluorescence: Parameters like maximum quantum efficiency of PSII (F_v/F_m) and effective quantum efficiency of PSII (ΦPSII) to assess photosynthetic efficiency and damage. Water status indicators: Leaf relative water content (RWC), water potential (Ψ), and turgor pressure. Oxidative stress markers: Malondialdehyde (MDA) content (an indicator of lipid peroxidation), hydrogen peroxide (H₂O₂) and superoxide radical (O₂⁻ levels), and activity of antioxidant enzymes (e.g., SOD, CAT, APX, GPOX).

4.1.1. Biochemical analysis:

Chlorophyll content, soluble sugars, proline, phenolic compounds, and fatty acid composition in fruits. Morphological parameters: Shoot length, leaf area, and fruit development. Understanding these physiological responses through controlled laboratory studies is vital for developing strategies to mitigate the negative impacts of climate change on olive production, including breeding for heat-tolerant cultivars and implementing appropriate agricultural management practices.

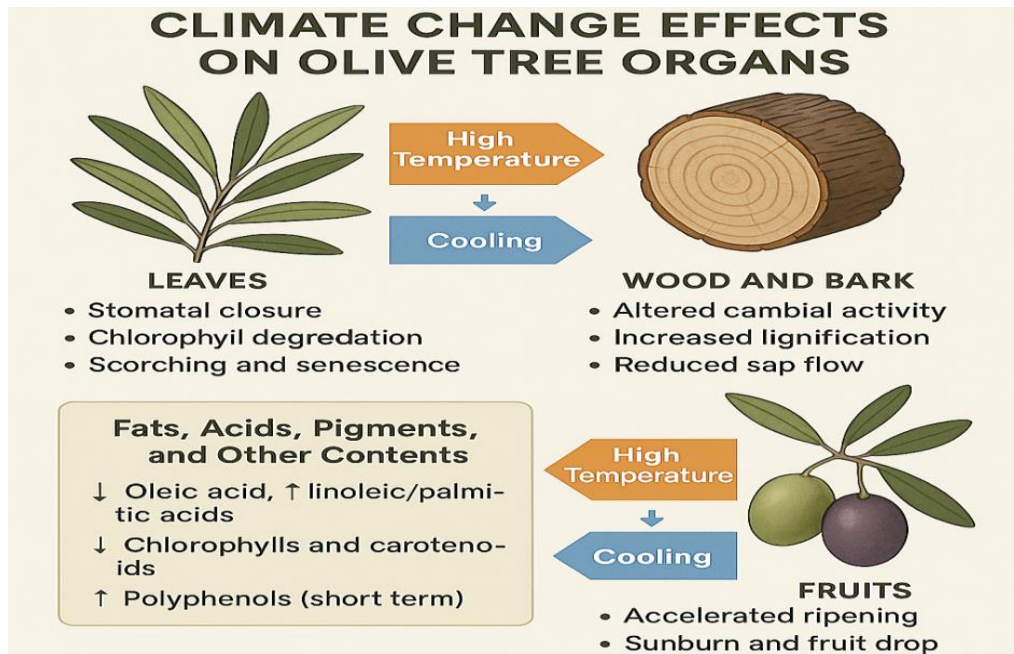


Figure (2) - It shows the effect of climate change on some components of the olive

mechanisms induced by climate change in olive trees under both heat and cold stress conditions. In leaves, heat stress leads to stomatal closure and a reduction in photosynthetic activity. This is accompanied by an increase in protective biochemical compounds such as carotenoids, phenolic compounds, and proline, which help mitigate oxidative damage. In the bark and wood, elevated temperatures result in a slowdown of cambial activity and an increase in lignification. Biochemically, this is reflected by higher levels of lignin, volatile organic compounds (VOCs), and phenolic substances, contributing to structural reinforcement and stress tolerance. For fruits, heat stress accelerates ripening, increases the risk of sunburn, and may lead to fruit drop. These physiological changes are associated with a decline in oleic acid content and an increase in linoleic and palmitic acids, ultimately affecting oil quality. Under cold stress, fruits exhibit abortion of flowers or developing fruits. This is linked to a reduction in the activity of oil synthesis enzymes and a decrease in pigment content, negatively impacting both yield and quality Mohamed EL yamani et al .,(2019).

Table (5) shows a summary of the mechanisms that occur when there are climate changes, whether rising temperatures or severe cooling.

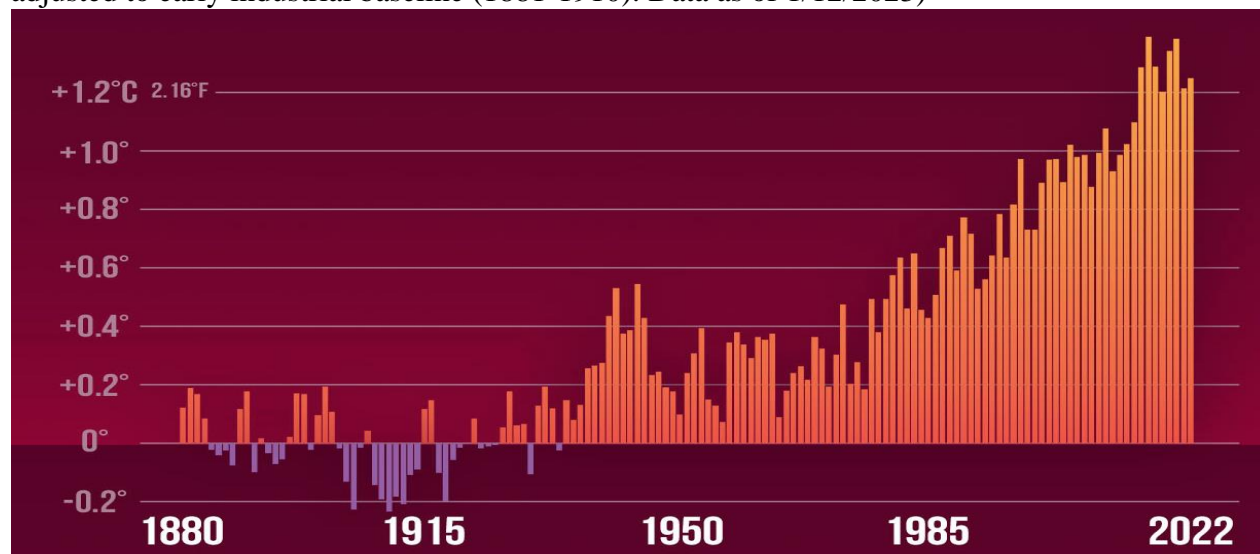
Organ	Stress	Structural/Physiological Effect	Biochemical Changes
Leaves	Heat	Stomatal closure, reduced photosynthesis	↑ Carotenoids, phenolics, proline
Bark/Wood	Heat	Cambial slowdown, ↑ lignification	↑ Lignin, VOCs, phenolics
Fruits	Heat	Rapid ripening, sunburn, fruit drop	↓ Oleic acid, ↑ linoleic/palmitic acids
Fruits	Cold	Abortion of flowers/fruits	↓ oil synthesis enzymes, ↓ pigment content

Table (6) Illustrative Diagram: Impact of Temperature on Olive Tree Life Cycle.

Early Spring (Flowering)	Summer (Fruit Development)
Autumn (Ripening & Harvest)	Winter (Rest & Chilling)
Extremely Low Temperatures (below 0°C) ----> Damage to flowers and fruits	
Optimal Temperatures (5-15°C) in Winter ----> Healthy flowering	
Optimal Temperatures (17-25°C) in Summer ----> Good fruit growth and oil quality	
Extremely High Temperatures (above 30°C) ----> Flower and fruit drop, weak photosynthesis .	

Increased temperatures and altered humidity patterns can lead to the spread and increased life cycles of olive pests like the olive fruit fly and olive moth, as well as fungal and bacterial diseases. Climate change can also affect the chemical composition of olive fruit, potentially altering the quality and sensory characteristics of olive oil. These challenges require olive growers around the Mediterranean basin to adapt to changing climatic conditions to ensure the sustainability of this vital agriculture. Dag, A., et al .(2014).

Figure(3)- Global Average Temperature Anomalies, departure from 1881-1910. (Climate Central; Data: NASA GISS and NOAA NCEI. global temperature anomalies averaged and adjusted to early industrial baseline (1881-1910). Data as of 1/12/2023)

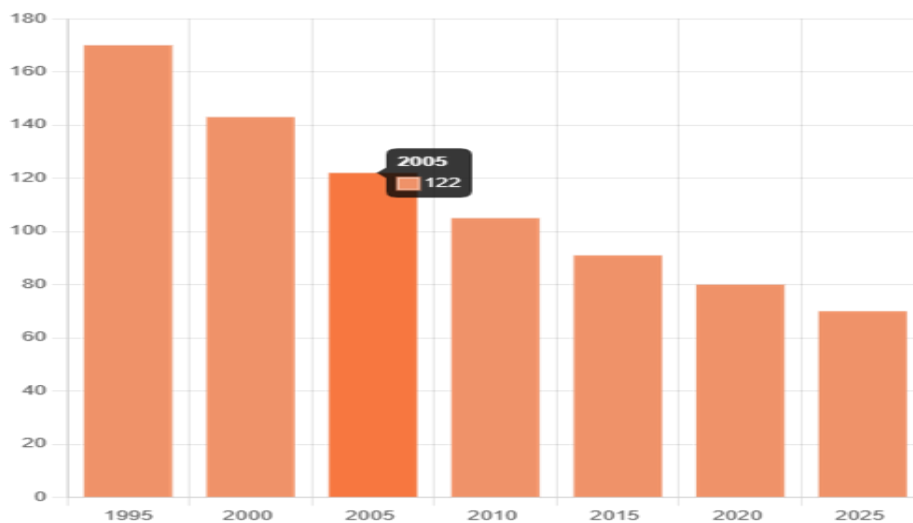


3.2 – The amount of water

Climate change is severely impacting olive trees, despite their resilience. Rising temperatures and decreased rainfall are leading to increased evapotranspiration, causing significant water stress. This stress impairs the trees' physiological functions, resulting in:

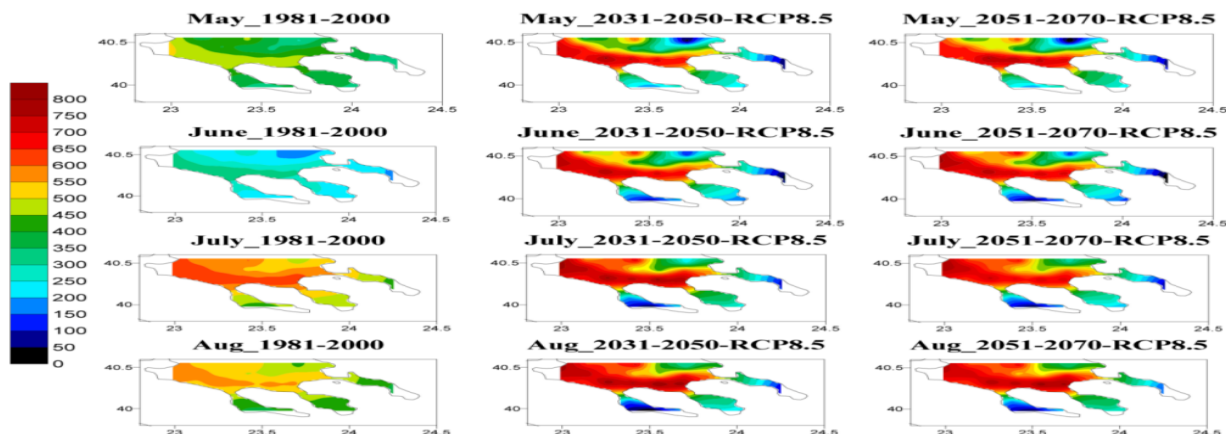
1 - Stunted growth . 2 - Reduced leaf area. 3 - Decreased overall productivity. Crucially, insufficient water during fruit development leads to poor fruit set, smaller fruit size, and lower oil content and quality. Furthermore, water-stressed trees have weakened defense mechanisms, making them more susceptible to pests like the olive fruit fly and various diseases. Changes in water availability can also alter the fatty acid composition and phenolic content of olives and their oil, sometimes increasing bitterness due to higher phenolic compounds. This decline is compounded by dwindling water resources; projected renewable water resources per capita are expected to drop from 170 cubic meters in 1995 to just 70 cubic meters in 2025. Ben Ahmed C.,et al(2007).

Figure (4): Projected water balance in Libya (1995-2025)



Resource - General Water Authority , 2014.Libya

Figure (5).The impact of climate change on olive crop production in drought years using a multi-year simulation program

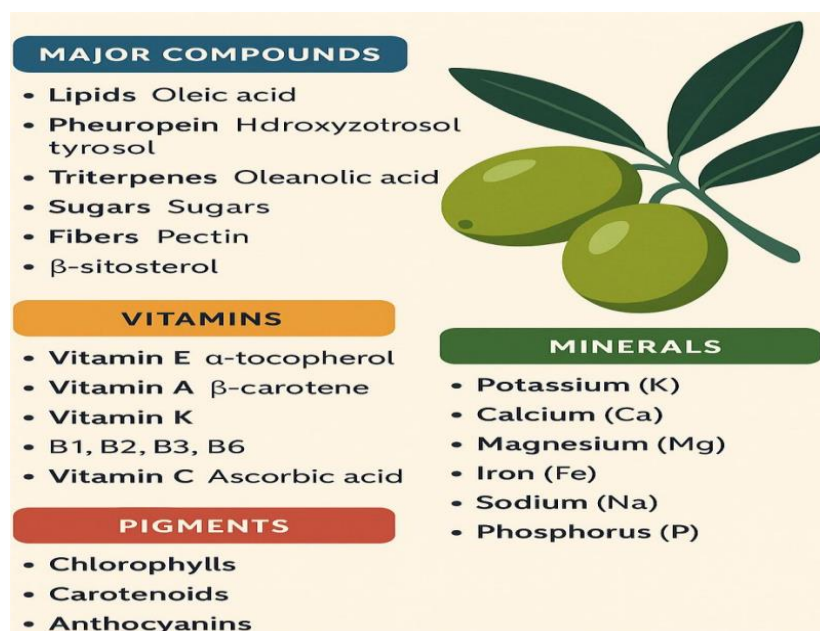


Resource/ The Impact of Climate Change on Olive Crop Production in Halkidiki, Greece. by Ilias Kalfas .et al .,(2023)

Water availability during late summer and fall is critical for olive tree productivity. Water deficit during this period delays flowering, reduces the number of productive flowers, and decreases fruit set in the following season, ultimately lowering yield. In contrast, adequate water supply enhances subsequent production. Physiologically, reduced soil moisture increases abscisic acid (ABA) levels in olive leaves, leading to stomatal closure. This reduces stomatal conductance and limits transpiration, helping conserve water but also restricting photosynthesis. From a biochemical perspective, water stress alters olive composition. It can modify fatty acid profiles, affecting oil quality, stability, and nutritional value (Maria Benlloch et al., 2018). Additionally, it influences phenolic compound accumulation, often increasing their levels and contributing to greater bitterness in olive oil (Nouredine Benguennouna et al., 2025; Marcia Araujo et al., 2024). Future projections indicate increasing water stress, with simulation models predicting up to a 40% rise in evaporation in Mediterranean regions such as Halkidiki, Greece, further challenging olive cultivation.

3.4 – Fruitfulness

Figure (6) - Olive Fruit Composition: Biochemical and Physiological Traits in Relation to Climate Variability

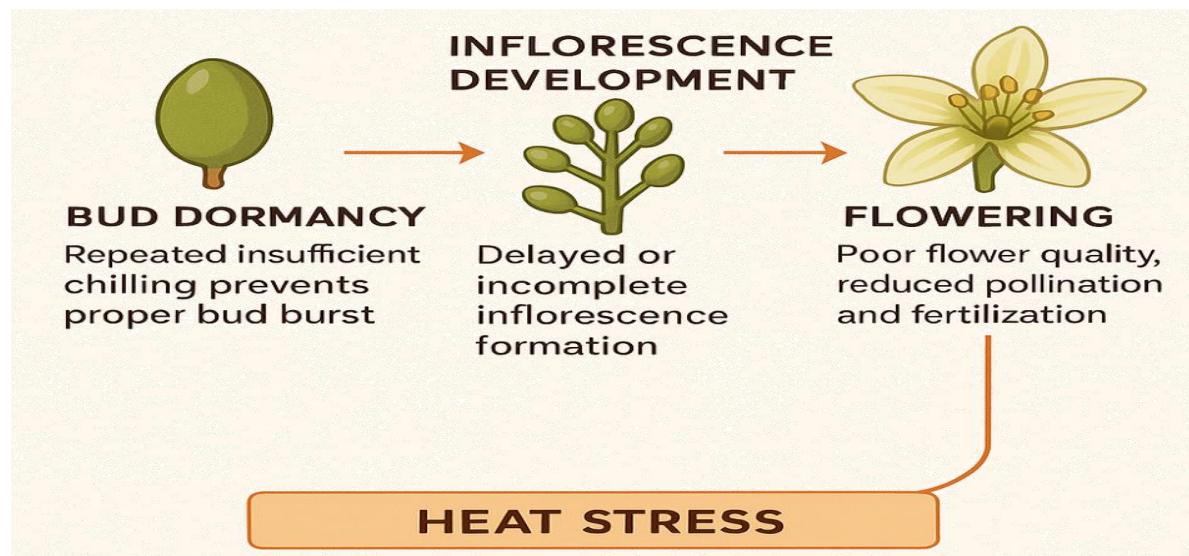


In Figure (6), the main components of the olive fruit are illustrated. This section highlights the effects of reduced water availability on olive tree physiology, biochemistry, and productivity during fruit development and ripening. Water deficit is a major limiting factor for olive productivity, affecting flowering, fruit set, and final yield. Under drought conditions, olive trees experience reduced fruit set (normally only 1–3%), increased fruit drop, and smaller fruit size due to limitations in cell expansion. Since fruit growth depends mainly on cell enlargement rather than cell division—which ceases about 6 weeks after flowering—water stress significantly restricts final fruit size Rallo & Rapoport, 2001; Rosati et al., (2009, 2012). Environmental factors such as water and nutrient availability strongly regulate these processes, often creating a trade-off between cell number and size Tsukaya, (2006). Improving physiological status through proper management can enhance yield Costagli et al., 2003; Bergh, 1985; Adolfo Rosati et al.,(2023). Physiologically, water stress disrupts hormonal balance. It alters levels of auxins and gibberellins, leading to poor flower development and increased abortion. Reduced auxin production by developing embryos promotes the formation of abscission layers, resulting in premature fruit drop under stress conditions. This reflects a resource-regulation mechanism of the tree under limited water supply. Biochemically, water deficit significantly affects fruit composition. It modifies fatty acid biosynthesis, with increased oleic acid (major component of olive oil), decreased palmitic acid, and potential increases in linoleic acid Ayman El Sabagh et al. (2022). Phenolic compounds (e.g., oleuropein, hydroxytyrosol) may accumulate under water stress, enhancing bitterness and antioxidant capacity, although they generally decline during ripening. In contrast, soluble sugars decrease as they are converted into oil, while organic acids and pigments (chlorophyll, anthocyanins, carotenoids) undergo significant changes during maturation. These biochemical shifts ultimately influence oil quality, stability, and sensory characteristics Alisson L. Figueiredo, et al. (2024). Climate change significantly affects olive fruit formation and production in several important areas, including:

- 1 - High temperatures reduce oleuropein, a key phenolic compound with antioxidant benefits.
- 2 - Drought stress increases oil content but may lower overall fruit size and quality.
- 3 - Ozone exposure reduces lutein, an important pigment and antioxidant.
- 4 - These changes impact the nutritional value, taste, and color of the fruit.
- 5 - Combined, they alter levels of phenolics, oil, and pigments, reducing fruit quality.

3.5 – Flowers

Figure (7) - The impact of climate change on the stages of flower quality in olive trees and the decrease in pollination rates.



Olive tree production in the Mediterranean region is increasingly affected by climate change, particularly through altered temperature regimes that disrupt flowering and yield Carla Inês et al., (2023). Flowering originates from axillary buds formed on the previous year’s shoots, which develop from spring to autumn and enter dormancy until the following spring Rapoport, (2008). Bud dormancy is regulated by hormonal balance, primarily high levels of abscisic acid (ABA), which maintains dormancy, and reduced levels of gibberellins (GAs) and cytokinins, which are associated with growth inhibition. Dormancy release requires sufficient winter chilling, which reduces ABA levels and promotes the accumulation of GAs, cytokinins, and auxins (IAA), enabling bud burst and floral differentiation Pinney & Polito, 1990; Rallo & Martin, (1991). Inadequate chilling or warm interruptions can disrupt this balance and delay or inhibit flowering De Melo-Abreu et al., (2004). During the transition to flowering, physiological activity increases, supported by carbohydrates (e.g., soluble sugars and starch) and metabolic compounds such as phenolic compounds, which influence floral induction and development. Rising spring temperatures accelerate bud development, but excessive heat can shorten the flowering period, reduce pollen viability, and impair fertilization Alcalá & Barranco, (1992); Barranco et al., (1994). Prolonged high temperatures also reduce inflorescence formation Aybar et al., (2015); De Melo-Abreu et al., (2004); Malik & Perez, (2011). Recent warming trends in April and May have advanced flowering (stage 55), potentially causing phenological mismatches with optimal pollination conditions and negatively affecting fruit set and development (Carla Inês et al., 2023). Consequences for yield and quality include: reduced flowering intensity, lower fruit set, decreased yield, and declines in oil quantity and quality.

9. Table (7):Timeline of Phenological Stages and Temperature Influence

Stage	Phenological Phase	Time (Northern	Temperature Sensitivity	Notes

		Hemisphere)		
0	Bud Dormancy	Nov – Jan	Needs cold (chilling units)	Dormancy release depends on sufficient chilling
1	Bud Swelling	Feb – Mar	Sensitive to warm spells	Warm spells can reverse dormancy progress
2	Bud Burst	Mar – Early Apr	Accelerated by heat	Earlier budburst may misalign with pollination
3	Inflorescence Development	Apr – Mid May	Vulnerable to heat stress	High temperatures reduce inflorescence formation
4	Flowering (Stage 55)	Late Apr – May	Highly sensitive to extreme heat	Shortened window for pollination

3.6 – Productivity

The current global annual consumption of olive oil is ~3.2 million tons International Olive Council.(2021), with close to 95 percent of production in regions surrounding the Mediterranean Sea. With global warming, mean winter temperatures are predicted to increase. Therefore, understanding how warmer winters will affect the levels of olive flower induction is essential for predicting the future sustainability of olive oil production under different climactic scenarios. The increase in temperature, especially in the winter season, seems to impact flowering buds. The small number of days with low temperatures resulting in reduced flowering during spring will decrease the quantity and quality of olives and oil.(Ilias Kalfas.,2023). Extra virgin olive oil prices have skyrocketed to an unprecedented level, a direct consequence of the harsh realities of climate change and the burden of high interest rates. The most influential olive markets in the EU — Bari (Italy), Chania (Greece) and Jaén (Spain) — are grappling with historic price surges, while global production has plummeted from 3.4 metric tons last year to 2.3 metric tons this years. Prices have skyrocketed to unprecedented levels, mainly due to- Climate stress ,Production decline ,Economic pressures (e.g., high interest rates) Food ingredients Frist.,(2024).

Table (8) Global Olive Oil Production (Tons and Liters)

Crop Year Olive Oil Production (Tons) Olive Oil Production (Liters)

2022/23	2,760,000	3,000,120,000
2023/24	2,564,000	2,787,068,000
2024/25	3,375,500	3,669,168,500

The table (8) shows marked variations in global olive oil production over recent years. In 2022/23, production was at a relatively high level, but it experienced a sharp decline in the 2023/24 season, such as drought following year, 2023/24. This decline is largely due to severe weather conditions, such as drought and high temperatures in major producing regions. However, olive oil production is expected to see a very strong recovery in the 2024/25 season, with forecasts indicating production reaching record levels. This recovery is good news for consumers and may contribute to stabilizing prices, which have recently risen significantly due to tight supply.

4.0 - Recommendations

- 1 - The availability of suitable climatic conditions has an impact on cross-pollination on the value of the fruits between olive varieties, as well as the synchronization of flowering and fruit set, in the Mediterranean environment, which gives great importance to improving olive productivity.
- 2 - Interest in improving and developing varieties that are resistant to environmental conditions such as salinity and drought, and varieties that can resist diseases and pests.
- 3 - Cultivation should be moved or expanded to regions with adequate winter chilling (e.g., highlands like Al-Jabal Al-Akhdar, and some high areas in Bani Walid and Tarhouna, Libya).
- 4 - Implement irrigation strategies, such as supplemental watering during flowering and fruit set, and shade or windbreaks to reduce heat stress.
- 5 - Develop water-efficient systems, such as drip irrigation, rainwater harvesting, and scheduling irrigation during critical growth stages.
- 6 - Hybridize or introduce selected global varieties into Libyan cultivation programs to improve resilience and productivity.
- 7 - Use GIS and climate modeling (e.g., as done in Jordan and Greece) to map optimal zones for each variety under future climate conditions.
- 8 - Strengthen integrated pest management (IPM) strategies and monitor seasonal pest activity more closely under changing climate scenarios.
- 9 - Promote olive cultivation in reforestation and anti-desertification projects in suitable arid zones.

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