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Phenological of *Quercus coccifera* L. trees in Al-Jabel Al-Akhder region, Libya

Amel Fathi Tashani [*1], Saleh Attia Bogarsa[2] , Saad Mohamed Saad [3]
[1] Department of Forestry and Range Science, Faculty of Natural Resources and Environmental Sciences, University of Derna, Libya
[2] Department of Environmental Sciences, Faculty of Natural Resources and Environmental Sciences, University of Omar Al-Mukhtar, Libya
[3] Department of Environmental Sciences, Faculty of Natural Resources and Environmental Sciences, University of Derna, Libya

الظواهر الفنولوجية لشجرة البلوط القرمزي بمنطقة الجبل الأخضر، شرق ليبيا

أمل فتحي الطشاني[*1] ، صالح عطية بوغرسة [2]، سعد محمد سعد [3]
[1] قسم الغابات والمراعي، كلية الموارد الطبيعية وعلوم البيئة، جامعة درنة، درنة، ليبيا
[2] قسم علوم البيئة، كلية الموارد الطبيعية وعلوم البيئة، جامعة عمر المختار، البيضاء، ليبيا
[3] قسم علوم البيئة، كلية الموارد الطبيعية وعلوم البيئة، جامعة درنة، درنة، ليبيا

[*]Corresponding author: a.tashni@oud.edu.ly

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Abstract:
This study examined how climatic and soil factors influenced the phenological of *Quercus coccifera* L. at different altitudes Lamlouda, Arqoub Al-Abyad, and Sidi Khaled in Al-Jabel Al-Akhder region, Libya during 2022–2023. In 2022, warmer temperatures and higher rainfall in Lamlouda correlated with earlier bud emergence (25 Feb) and acorn ripening (4 Oct). Conversely, cooler and drier conditions in Arqoub Al-Abyad were associated with delayed bud break (8 Mar) and prolonged flowering (up to 12 May in 2023). Relative humidity influenced flowering duration, with higher values in 2023 at Lamlouda coinciding with compact flowering periods, while moderate humidity in Arqoub Al-Abyad extended flowering. Solar radiation, though similar between sites, was higher in 2023 and may have accelerated bud and fruit development across all locations. Soil properties also played a role: higher organic matter in Sidi Khaled coincided with later bud emergence but balanced flowering, while elevated salinity, phosphorus, and nitrogen in Arqoub Al-Abyad were linked to extended reproductive phases but delayed fruit maturation. Higher potassium in Lamlouda corresponded with earlier and faster fruit ripening. These findings suggest that warmer, wetter conditions combined with favorable soil fertility (high potassium and moderate salinity) promote earlier phenological events, whereas cooler, drier climates with high salinity and nutrient imbalance delay developmental stages but may extend flowering periods Integrated management of climate adaptation strategies and soil nutrient optimization is recommended to enhance productivity and reproductive success of *Q. coccifera* in variable Mediterranean environments.

Keywords: *Quercus coccifera* L. , phenology, Al-Jabel Al-Akhder, altitude.

الملخص
بحثت هذه الدراسة تأثير العوامل المناخية والتربة على الظواهر الفينولوجية لشجرة البلوط القرمزي بمنطقة الجبل الأخضر في مواقع مختلفة في الارتفاع عن سطح البحر (لملودة والعرقوب الأبيض وسيدي خالد خلال الموسم 2022-2023. في عام 2022، ارتفعت درجات الحرارة وزادت هطول الأمطار في لملودة مع ظهور البراعم في وقت مبكر (25 فبراير) ونضج الثمار (4 أكتوبر). على العكس من ذلك، ارتبطت الظروف الأكثر برودة وجفافًا في العرقوب الأبيض بتأخر ظهور

البراعم (8 مارس) وإطالة فترة الإزهار حتى 12 مايو خلال الموسم 2023. كذلك أثرت الرطوبة النسبية على مدة الإزهار، حيث تزامنت القيم الأعلى خلال الموسم 2023 في لملودة مع فترات إزهار مكثفة، في حين أدى التوازن في الرطوبة في العرقوب الأبيض إلى إطالة فترة الإزهار. كانت الإشعاعات الشمسية، على الرغم من تشابهها بين المواقع، أعلى في الموسم 2023 وربما أدت إلى تسريع نمو البراعم والثمار في جميع المواقع. كما لعبت خصائص التربة دورًا واضح حيث تزامنت المادة العضوية الأعلى في سيدي خالد مع ظهور البراعم في وقت متأخر، في حين ارتبطت الملوحة المرتفعة والفوسفور والنيتروجين في العرقوب الأبيض بتأخير نضج الثمار. تزامن البوتاسيوم الأعلى في لملودة مع نضج الثمار في وقت مبكر وأسرع. يوصى بالإدارة المتكاملة لاستراتيجيات التكيف مع المناخ وتحسين مغذيات التربة لتعزيز الإنتاجية ونجاح التكاثر في بيئات البحر الأبيض المتوسط.

الكلمات المفتاحية: البلوط القرمزي، فينولوجيا، الجبل الأخضر، الارتفاع عن سطح البحر.

Introduction

The oak genus Quercus is ecologically diverse and economically important throughout its historical range, especially through the value of its hardwoods [21]. Oak trees are a refuge for large species of endangered wildlife such as the Spanish vulture and the Caucasian lynx, and they are the preferred type of shelter to promote the growth of the highly nutritious mycorrhiza fungus [5][10].

Quercus species produce a fruit known globally as Acorn, which in addition to the bark and leaves is used in folk medicine as an antiseptic or in the treatment of intestinal disorders, and because of its nutritional importance, Acorn fruits have been used as food for humans and animals. Phenological stages are considered sensitive and accurate indicators of climate change [3]. Phenological events such as bud burst and flowering have received wide attention to understand global warming [16].

Temperature, water availability and photoperiod are the most important proximate environmental indicators that control plant phenology [18][17].

The performance of trees depends largely on their ability to grow primary and secondary growth and that the basis of growth is the extension of shoots and roots, both of which are related to many factors, most importantly the size and age of trees, site conditions and climatic conditions [2] Growth processes, crown development and fruit production in oak species growing in the Mediterranean basin are significantly affected by climate, especially summer droughts [12], [4].

Oak productivity is also influenced by many factors, most importantly tree density, spring rainfall, the amount of water available to the plant during the summer and soil properties

[4].

The time of year in which the life cycle occurs is an advantage that allows plants to adapt to seasonally changing environments [19]. The flowering period is one of the most sensitive periods because it determines the success of the reproductive process, the flowering process is controlled by internal and external factors that include the genetic system and environmental conditions [6] [13] [20] and includes the consistency and balance of the flowering process with the appropriate season depending on the different pollination methods, in the case of plants that depend on the wind for pollination, favorable conditions are associated with low humidity and high temperature. These conditions usually occur in the Mediterranean region during the spring, when most plants, including the genus Quercus, flower.

Q. coccifera L. trees face many challenges in semi-arid regions as climate change leads to more severe droughts and higher temperatures, as well as unregulated grazing can damage trees and prevent their regeneration, and the removal of oak forests for various reasons such as agriculture and construction leads to the loss of ecosystems [15], so we found it important to pay attention to this local plant species and shed light in order to preserve it, develop it and ensure its survival and regeneration in the Al-Jabel Al-Akhder region.

This research aims to study the growth of *Q. coccifera* L. trees at different altitudes in the Al-Jabel Al-Akhder region by observing and documenting the phenological stages of the trees at various sites.

Material and methods

Study sites

The study was conducted in Al-Jabal Al-Akhdar, Libya, during the 2022/23 seasons. Three sites at different altitudes were selected (Lamlouda 608m, Arqoub Al-Abyad 493m and Sidi Khaled 333m), shown in Fig. (1).

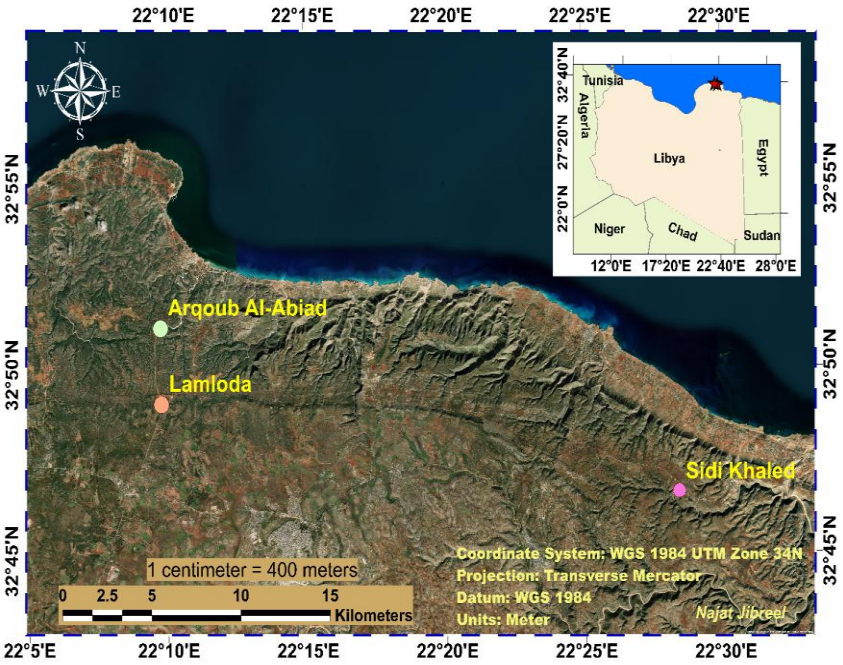

Figure1: Description of sites.

Research methods

Climatic study:

As there are no meteorological stations at the study sites, data were obtained from NASA's website (NASA.nid) [14].As for the rainfall rates, the values extracted from NASA are for a variable known as 'corrected precipitation', which are often small. Therefore, they were not relied upon and only the annual total rainfall for the 2022 season was obtained. Rainfall data for the 2023 season could not be obtained. The annual averages for the 2022 season were extracted using the Isohyet rain lines method from the National Oceanic and Atmospheric Administration (NOAA) website.
https://oceanfdn.org/noaa-the-ocean-foundation-team-up-to-advance-ocean-science/

Phenological :

The phenological of ten *Q. coccifera* L. trees were studied at each site during the 2022/23 seasons. These stages were divided into different phases based on the start of each phase, its duration and weekly observations made over two consecutive seasons. The following observations were recorded:
- Flower bud swelling time
- Flowering and acorn (onset acorn/acorn maturity)

Soil analysis:

Soil sections were excavated using a 30 cm auger. Five random samples were taken from each site, mixed together and analysed in the Al-Qamma laboratory in Al Bayda City, according to [1].

Results and discussion

Climate data:

There was a difference in temperature between the study sites in both seasons: the highest temperature in the 2022 season was recorded in the Lamlouda site (20.17°C), while the lowest temperature was recorded in the Arqoub Al-Abyad site (19.2°C). In the 2023 season, the temperature was almost equal in all three sites. Additionally, the average annual rainfall for 2022season differed between the sites, with the Lamlouda site experiencing the highest rainfall rate (425 mm/year) and the Arqoub Al-Abyad site experiencing the lowest (315 mm/year). The average relative humidity values during the two seasons of the study showed little difference between the three sites: 71.5%, 71.8% and 72.2% in Lamlouda, Arqoub Al-Abyad and Sidi Khaled, respectively. However, during the 2023 season, the relative humidity values differed: the highest percentage of humidity was 74.3% in Lamlouda, while the lowest was 71.87% in the Arqoub Al-Abyad site. The average values of incident solar radiation on the three sites showed no difference between the sites during the two seasons of the study. Overall, the average annual solar radiation on the three sites was greater in 2023 than in 2022.

Soil analysis:
With regard to the soil study, the results of the mechanical and chemical analysis of the soil. The results showed that the soil type at the three sites is alkaline clay, and the electrical conductivity values, which are used as an indicator of soil salinity, showed that the highest value was at the Arqoub Al-Abyad site (µS/cm²), indicating that the soil is more saline there than at the other two sites. Conversely, the highest percentage of organic matter was 7.73% in the Sidi Khaled site and the lowest was 5.42%. The highest percentages of phosphorus (19.20%) and nitrogen (0.38%) were found in the Arqoub Al-Abyad site, while the lowest percentages were found in the Sidi Khaled site. The highest percentage of potassium was 0.8% in Lamlouda, while the lowest was 0.1% in Arqoub Al-Abyad.

Phenological Study
Phenological observations were recorded in tables 1 and 2 through follow-up and observation of the *Q. coccifera* L. trees in the three sites during two consecutive seasons (2022/23).
The phenological phenomena observed during the first season (2022): The date of emergence of vegetative buds was recorded, starting with the Lamlouda site on 25 February, followed by the Arqoub Al-Abyad site on 8 March and the Sidi Khaled site on 28 March. At the Lamlouda site, the emergence of vegetative buds occurred at the beginning of March (8 March), followed by the Sidi Khaled site in mid-April (11 April) and then the Arqoub Al-Abyad site (22 April). The start and end dates of flowering differed between sites (Table 1), with flowering starting at the beginning of March (8 March) in Sidi Khaled and extending until the beginning of May (4 May). In contrast, flowering started in mid-April (13 April) in Lamlouda and Arqoub Al-Abyad, with a shorter flowering period of about two weeks until the end of April (27 April). Also, Acorn began at the end of April for all sites (27 April). In contrast, the Acorn ripening date at the Lamlouda site was at the beginning of October (4 October), followed by the Argoub al-Abyad site (20 October) and the Sidi Khaled site at the end of October (27 October). Secondary flowering was also observed at the Argoub al-Abyad site on 28 October and continued for approximately one month before the flowers fell off. This was followed by the Sidi Khaled site on 22 November and the Lamlouda site on 25 November.

Table (1): Phenological stages of *Q. coccifera* L trees during the 2022 season.

Sites	Budding	Flowering period	Start of fruiting	Acorn ripening
Lamloda	February25/March8	April 13/April 27	October 4	April 27
Arqoub Al-Abyad	March 8/April 22	April 13/April 27	October 20	April 27
Sidi Khaled	March 28/April 11	March 8/May 4	October 5	April 27

Through continuous observation in the 2023 season, it was found that the date of appearance of green buds on scarlet oak trees did not differ between the three sites, with green buds appearing at the end of March (31 March) (Table 2). The dates of the beginning and end of flowering also differed between sites. For example, at the Lamlouda and Sidi Khaled sites, flowering began at the end of March (31 March) and continued until the end of April. In contrast, at the Arqoub Al-Abyad site, flowering began at the end of March (31 March) and continued until 12 May, making it the longest flowering period, lasting approximately one and a half months. The fruiting stage began at the Lamlouda site on 20 April, followed by the Sidi Khaled site on 28 April, and finally the Al-Arqoub Al-Abyad site on 12 May. The dates of the beginning of acorn ripening are also shown: the Lamlouda site began ripening on 16 August and was fully ripe by 5 September, while ripening was delayed in Sidi Khaled and Arqoub Al-Abyad sites, The beginning of acorn ripening occurred on 6 October at the Arqoub Al-Abyad sites, the beginning of acorn ripening occurred on 6 October and full acorn ripening occurred on 1 November. The appearance of terminal buds was also observed in the Sidi Khaled and Arqoub Al-Abyad sites on 5 September, while buds appeared 15 days later in the Lamluda sites than in the previous two sites, on 20 September. Secondary flowering in autumn occurred earlier than in the previous season, with inflorescences appearing in the three sites on 20 September and falling on 1 November.

Table (2): Phenological of *Q. coccifera* L trees during the 2023 season.

Sites	Budding	Flowering period	Start of fruiting	Acorn ripening
Lamloda	March 31/April 14	March 31/April 28	September 5	April 20
Al-Arqoub Al-Abyad	March 31/April 14	March 31/May 12	November 1	May 12
Sidi Khaled	March 31/April 7	April 7/April 28	November 1	April 28

Studying the phenology of *Q. coccifera* L. helps us to understand its relationship with the environment, its adaptation to climate change and its protection and management, given its important economic and ecological value. At the Argoub al-Abyad site, the bud emergence date in the 2023 season was at the beginning of March, which was 23 days later than in the previous season. This may be due to the difference in precipitation rates in March, which decreased in the 2023 season compared to the 2022 season. There was also a difference in temperature in March during the 2023 season. The temperature reached 15°C in 2023 compared to 13°C in 2022. The flowering period also differed between the two study seasons: in 2023, it lasted a month and a half, from the end of March to mid-May, as temperatures increased in March and April (13°C and 15°C respectively). During the 2023 season, temperatures increased from 13° to 15°. Conversely, the date of acorn ripening differed between the two seasons, with the 2023 season experiencing a delay of 10 days compared to the 2022 season. In the latter, fruits ripened at the beginning of November due to lower temperatures in October and November compared to the 2023 season. At the Sidi Khaled site, there was no difference in bud emergence dates during the 2022/23 seasons, with buds appearing at the end of March. However, there was a difference in flowering period dates, with flowers appearing 10 days later in the 2023 season than in the 2022 season. The flowering period also differed in length between the two seasons, lasting almost two months (8 March to 4 May) in the 2022 season. In the 2023 season, the flowering period was short, lasting 20 days (7 April to 28 April). This difference in flowering period length is also due to the difference in temperature and relative humidity between the two seasons. The relative humidity in the 2023 season decreased to 72%, compared to 74% and 73% in the 2022 season. Fruit ripening in the 2023 season (1 November) was delayed by about a month compared to the 2022 season, also due to the difference in temperatures between the two seasons, which is the main determinant of flowering. In contrast, at the Lamluda site, the date of bud emergence differed between the two seasons. The buds appeared on 31 March in the 2023 season, which was about a month later than in the 2022 season. This may be due to differences in soil moisture, which is consistent with [8]. He noted that the average number of buds and their diameter are affected by soil moisture. The flowering period also differed between seasons: it lasted a full month (31 March to 28 April) in 2023, whereas it was shorter (13 April to 27 April) in 2022. Fruit also ripened about a month earlier in the 2023 season than in the previous 2022 season. This is due to higher temperatures in October (19.33 °C) and November (16.01 °C) in the 2023 season compared to the 2022 season.

During the 2022 season, it was observed that the dates of bud emergence differed between the three sites. The buds first appeared in the Lamlouda site on 25 February, followed by the Arqoub Al-Abyad site on 8 March and the Sidi Khaled site on 28 March. This was due to the high temperature in February (19°C). in the Lamlouda site compared to the other sites. On the other hand, the flowering period for the growing trees in the Sidi Khaled site was longer, lasting 37 days, compared to two weeks in the other two sites. The Acorn ripened in all three sites in October. Sidi Khaled and Lamlouda ripened on the same date (4 October), while in Arqoub Al-Abyad, the ripening date was delayed until 20 October.

During the 2023 season, the date of bud emergence did not differ between the three sites, with buds appearing on 31 March for all sites. However, the flowering period differed; the longest was at the Al-Arqub Al-Abyad site (31 March–12 May), followed by the Lamlouda site (31 March–28 April) and the Sidi Khaled site (7 April–23 April). The date of Acorn ripening also differed: acorn ripened in the Lamlouda site on 5 September, while ripening was delayed until 1 November in the Argoub Al-Abyad and Sidi Khaled sites, despite similar climatic conditions in all three sites. The difference in the date of acorn ripening between the Sidi Khaled and Argoub Al-Abyad sites may be due to genetic rather than environmental factors, as suggested by Gafenco *et al*. (2022), who found that phenological stages are genetically controlled. [11] carried out a study on *Quercus ilex* L. located at four sites of different elevations in Sicily, Italy. They reported that, when considering the total life span, most of the phenological stages were fairly similar among the study sites. The study showed that the phase of vegetative branch elongation was shorter at higher elevation sites and that the most significant differences between sites were related to the timing of different phenological events or phenomena. It was reported that bud emergence in the lowland area started approximately 45 days earlier than in the highland area. The general behaviour or trend of *Q. ilex* in the Seychelles, as well as the differences between sites, can be attributed to temperature and water availability. In contrast, the reason for the delay or cessation of most stages is the early onset of the summer season, which includes a decrease in rainfall and insufficient soil water storage capacity. This study corroborates the findings of [11] that flowering was delayed by approximately six weeks, with Acorn ripening occurring from mid-September to the end of October. This period was observed in both seasons, particularly at the Al-Argoub Al-Abyad site, in 2022 and 2023. Secondary flowering was also observed in autumn at all three sites during the two-season study: the flowers reappeared at the Argoub Al-Abyad site at the end of October in the 2022 season, lasting on the trees for about a month before falling off. At the Lamlouda and Sidi Khaled sites, the flowers appeared at the end of November. During the next season (2023), the phenomenon of secondary flowering was also observed in autumn, but earlier than in the previous season. The inflorescences appeared on the three sites on 20 September and remained on the trees until 1 November, after which they fell off. The reason for the occurrence of secondary flowering may be the difference in temperatures during September and October in the two study seasons, as this can significantly affect the occurrence of the phenomenon. [17] indicated the occurrence of flowering in oak trees during the autumn and noted that trees can flower in spring and autumn under certain conditions.

Conclusion

Bud emergence dates differed between the study sites in the 2022 season, but not in the 2023 season. Flowering dates also differed between the three sites during the two seasons. Acorn ripening dates did not differ between sites during the 2022 season, but they did differ during the 2023 season. Secondary flowering was observed in autumn during both seasons of the study, with temperature being the most influential factor in the different phenological stages. To understand the impact of climate change in our region and to preserve and develop this local species, it is recommended that the phenological stages are studied over a longer period of time. This will ensure its survival and renewal in the Al-Jabal Al-Akhdar, east Libya.

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