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Effect of period of receptivity and air temperature on parthenocarpic phenomenon of 'Assiane' date palm cultivar (*Phoenix dactylifera* L.)

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Introduction: In hot arid regions, the productivity of certain date palm cultivars faces a significant challenge wherein non-fertilized flowers can give rise to parthenocarpic singular or triplet fruit.

Aims: The aims of this study, we aimed to investigate the impact of delayed pollination on date palm yield and fruit quality, while also examining the influence of temperature on these processes.

Methods: We conducted this research using 10 15-year-old 'Assiane' palm trees, all situated within the Figuig Oasis environment. Pollination was performed on the same day of spathe opening, as well as up to 16 days after the initial opening. Additionally, we utilized 30 palm trees to analyze the effect of daily average temperatures.

Results and Discussion: Our findings reveal that the optimal period for achieving maximum yield and fruit quality falls between the sixth and eighth day following the cracking of the female spathe. Furthermore, we observed that relatively lower temperatures, ranging from 5 to 20°C, promote the formation of parthenocarpic fruits while inhibiting the development of normal fruits. Moreover, the insights gained from investigating these issues could have broader implications for date palm cultivation in arid regions and offer valuable lessons for the preservation of oasis ecosystems worldwide.

KEYWORDS

unpollinated flowers, pollination, temperature, parthenocarpic fruits, Figuig Oasis

1 Introduction

Phoenix dactylifera L., commonly known as the date palm, is a remarkable and iconic plant species that has played a vital role in the cultural, economic, and culinary heritage of various regions around the world for centuries (Abdelkrim et al., 2023). In these fragile ecosystems, the date palm not only serves as a source of sustenance for local communities but also plays a pivotal role in preserving biodiversity and maintaining the delicate balance of the oasis environment (Cherif et al., 2015; Ahmed et al., 2022a). Among the numerous date palm cultivars, 'Assiane' stands out as a cultivar with remarkable potential, renowned for its exquisite date quality and high yield potential. Belonging to the Arecaceae family, this palm tree species is renowned for its tall, slender trunk, graceful fronds, and, most notably, its prized fruit—the date. With its origins tracing back to the arid regions of the Middle East, North Africa, and South Asia, the date palm has not only thrived in harsh desert environments but has also become a symbol of resilience and sustenance (Rivera et al., 2022).

However, despite its reputation, 'Assiane' date palms in certain regions, particularly in the unique conditions of the Figuig Oasis, have experienced a perplexing phenomenon known as partial fruit set failure (Jdaini et al., 2022). This phenomenon presents a critical challenge to date palm growers and researchers, as it disrupts the expected crop yield and, consequently, the livelihoods of those dependent on date production. Understanding the underlying causes and mechanisms of this partial fruit set failure is imperative for sustaining date palm cultivation in the Figuig Oasis and similar ecosystems (Chandrasekaran and Bahkali, 2013; Oladzad et al., 2021).

The oasis of Figuig is the south-eastern oasis of Morocco located at the eastern extremity of the High Atlas. The climate in this area is arid, with hot summer and cold winter. The average temperature can vary greatly, ranging from 3 to 45°C (Jilali, 2014).

There are approximately 190,000 palm trees in this region, which account for approximately 2.8% of all date palms in Morocco. There are many cultivars in this area with the 'Assiane' cultivar being the most dominant, representing over 51% of the total palm tree population (Sedra, 2015).

One of the major problems that face several date palm cultivars in Figuig valley and especially 'Assiane' cv. is the low fruit set (partial fruit set failure) and/or abnormal flowering.

Pollination is considered the most important factor affecting fruit set, yield, and fruit quality (Ahmed et al., 2022b). Knowing the period when female flowers are receptive to pollen grains is crucial, the pistils of female flowers do not stay receptive for an extended period, this period of receptivity varies with different weather conditions and cultivars (Shahid et al., 2017; Muralidharan et al., 2020) so that pollination outside this period will not lead to fertilization and consequently results in a heavy drop in unfertilized fruits. Previous studies have shown that the longer the pollination is delayed after the opening of the spathe the poorer the fruit set and yield (Salomón-Torres et al., 2021). It has been reported that pollination should not be delayed for more than 3–4 days (Maryam et al., 2015).

In Figuig valley, growers usually pollinate the majority of their cultivars during the week following the opening of the spathe. Some cultivars such as 'Assiane' and "Boufgous" do not pollinate until the third stage, which usually begins 10–12 days after the opening of the spathes. Cultivars pollinated during the first day after the opening of the spathe, are rare.

Environmental conditions can have a significant impact on the pollination and fertilization processes. Optimal temperature is essential for different stages of sexual reproduction in flowering plants, such as pollen formation, pollen transfer, the readiness of stigmas for pollen, pollen germination, the growth of pollen tubes, double fertilization, and seed development (Hedhly et al., 2003, 2005; Snider and Oosterhuis, 2011; Zulkarnain et al., 2019; Ali-Dinar et al., 2021; Alla et al., 2022). Any form of stress during these stages can result in sterility and, ultimately, reduce crop yields. Moreover several environmental factors play a vital role in influencing the success of date palm pollination, as these factors directly impact the behavior of the pollinating agents and the overall reproductive health of the date palm trees (Chao and Krueger, 2007; Salomón-Torres et al., 2021). Climate and temperature: date palms thrive in warm and arid climates. The ideal temperature for date palm pollination ranges between 20 and 35°C. Extreme temperatures, whether too hot or too cold, can adversely affect the pollination process. In regions where date palms are cultivated, the seasonal variations in temperature can influence the timing of flowering and subsequently, the availability of pollen and the activity of pollinators (Dehghan-Shoar et al., 2010; Awad and Al-Qurashi, 2012; Karim et al., 2022). Wind: date palms are primarily pollinated by wind, which carries pollen from male flowers (catkins) to female flowers. Wind speed and direction are critical factors influencing the success of pollination. Adequate wind is necessary to ensure the dispersion of pollen over a sufficient distance. However, excessive wind can lead to the loss of pollen, reducing the chances of successful pollination (Ghnimi et al., 2017; Karim et al., 2022; Alam et al., 2023). Water availability: Date palms require sufficient water for healthy growth and development, especially during the flowering period. Inadequate water supply can lead to stress in the plant, affecting the quality and quantity of flowers produced. Water scarcity may result in reduced pollen production and viability, ultimately impacting the success of pollination (Awad, 2006; Askri et al., 2014). Soil quality: the quality of the soil in which date palms are planted also plays a role in pollination. Well-draining soils with good nutrient content support healthy tree growth and flowering. Poor soil quality can lead to nutrient deficiencies, affecting the overall reproductive health of the tree and the production of viable pollen (Cherif et al., 2015). Pest and disease management: environmental factors influencing pest and disease prevalence can impact date palm pollination. Pests such as insects and mites can damage flowers and interfere with the pollination process. Diseases affecting the reproductive structures of the date palm can reduce the availability of healthy flowers for pollination (Bouhlali et al., 2021).

Understanding and managing these environmental factors are crucial for date palm cultivation and ensuring optimal pollination. Farmers often employ techniques such as controlled irrigation, pest and disease management, and proper nutrient application to create favorable conditions for date palm pollination, ultimately contributing to successful fruit production.

This introductory overview will delve into the partial fruit set failure phenomenon within the 'Assiane' date palm cultivar, emphasizing the distinctive environmental conditions of the Figuig Oasis and its potential impact on date palm cultivation. The key factors that contribute to this enigmatic phenomenon will be explored, and the significance of conducting research to unravel its mysteries will be highlighted.

Analyzing factors such as the timing of receptivity and environmental variables, particularly temperature, in the context of pollination will offer valuable insights for improving fertilization and fruit formation in 'Assiane' date palm trees.

2 Materials and methods

2.1 Period of receptivity

Ten 15-year-old 'Assiane' palm trees, cultivated within the Figuig Oasis under consistent environmental conditions, were selected for this study. Three spathes from each of the first, second, and third whorls were chosen for the pollination experiments. The experimental design employed a split-plot approach, with the main plot consisting of the three whorls and the sub-plot comprising 10 distinct treatments. Each treatment was replicated using three spathes. To ensure the purity of the pollination process, all spathes were securely enclosed in kraft paper bags to prevent any cross-contamination with foreign pollen grains. The timing of spathe opening was closely monitored throughout the experiment.

For pollination purposes, we exclusively used pollen grains from a single male palm to eliminate any potential effects of metaxenia. We conducted 10 different pollination treatments, which included pollination on the day of spathe cracking (serving as the control), as well as 1, 2, 4, 6, 8, 10, 12, 14, and 16 days after spathe cracking.

Data on the following parameters were recorded:

$$\text{Rate of parthenocarpy}\,(\%) = \left[\frac{(\text{Number of parthenocarpic fruits})\,/}{(\text{Total number of flowers})}\right] \times 100$$

2.2 Physical characteristics of fruit

Thirty fruits were randomly chosen from each cluster (replicate) for the purpose of assessing fruit volume, size (length and diameter in centimeters), weight, flesh weight, and seed weight (in grams).

2.3 Effect of air temperature

To investigate the impact of daily maximum and minimum air temperatures on the study, 20 palm trees were utilized. From each of these selected palm trees, three female spathes of roughly similar sizes were chosen. The pollination process exclusively utilized pollen grains from a single male palm. Throughout the pollination period, temperature measurements were recorded at 5-h intervals using a data logger (specifically, a Testostor 175–3 model manufactured by Testo in Lenzkirch, Germany).The data logger was strategically positioned in the central area of the palm grove, positioned at a height of 2 m above ground level. The recorded results were stored in various file formats, including TEXT, EXCEL, or BITMAP, as well as in graphical representations. We specifically extracted and analyzed the minimum and maximum temperature values corresponding to the day of pollination for the 20 palm trees. The average maximum and minimum temperatures during the pollination period have been 32.9 and 6.9°C, respectively. Ten weeks following the pollination process, we proceeded to assess the percentage of fruitlets that were classified into four categories: normal, parthenocarpic, aborted, and non-developed.

2.4 Statistical analysis

The data were analyzed statistically by running ANOVA of Statistical Package for the Social Sciences (SPSS) version 13.0. The mean values were compared using the Tukey multiple range test ($p = 0.05$).

3 Results and discussion

3.1 Effect of time of pollination

Data in Table 1 indicated that the average bunch weight was not significantly affected by the time of pollination. Whereas, the Parthenocarpy rate dates vary depending on the time of pollination, the highest Parthenocarpy rate 64.52% was observed when pollination was performed at the 16th day after the spathes' opening. The minimum Parthenocarpy rate, 45.53 and 45.59% were obtained on the 8 and 10th day after the spathes opening, respectively.

The results clearly showed an increase in seedless fruit in spathe with delaying pollination to the second week of spathe cracking, There are many reasons for parthenocarpic fruit development such as male or female incompatibility (Sharma et al., 2023), environmental factors (Pandolfini et al., 2018), hormonal deregulation (Jacobsen and Olszewski, 1993), delay or rapid growth of the ovary due to the changes in the regulation of gibberellin (Vivian-Smith and Koltunow, 1999), and low (8–20°C) temperatures (Cohen et al., 2016), in the present study delaying pollination leads to natural thinning consequently increased from cell division and cell enlargement as well as the biosynthesis of carbohydrates concerning and proteins.

TABLE 1 Mean values of bunch weight and parthenocarpy rate of 'Assiane' date palm cultivar as affected by delaying pollination from female spathe cracking.

Pollination time (days after spathe opening)	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Seed weight (g)	Seed length (mm)	Seed width (mm)
Control	6.18^{a}	36.18^{ab}	16.18^{a}	0.98^{a}	22.56^{a}	7.84^{a}
1	7.69^{abc}	37.15^{ab}	17.31^{ab}	2.47^{a}	22.53^{a}	8.08^{a}
2	7.71^{abc}	34.56^{a}	17.14^{ab}	1.11^{a}	22.96^{a}	8.18^{a}
4	7.40^{ab}	38.05^{abc}	17.96^{ab}	1.01^{a}	22.37^{a}	8.21^{a}
6	8.87^{bc}	38.00^{abc}	18.07^{ab}	1.07^{a}	22.78^{a}	8.23^{a}
8	8.45^{bc}	40.12^{bc}	18.90^{b}	1.10^{a}	22.53^{a}	8.32^{a}
10	7.15^{ab}	38.22^{abc}	18.15^{ab}	1.18^{a}	23.22^{a}	8.35^{a}
12	7.52^{abc}	35.79^{a}	17.02^{ab}	1.69^{a}	23.00^{a}	8.46^{a}
14	8.26^{bc}	40.31^{bc}	18.57^{b}	2.44^{a}	24.64^{a}	8.63^{a}
16	9.29^{c}	41.67^{c}	18.63^{b}	1.14^{a}	24.11^{a}	8.70^{a}
Signification						0.408

*Means within each column with the same letter are not significantly different at $p \leq 0.05$.

TABLE 2 The physical fruit properties of 'Assiane' date palm cultivar as affected by delaying pollination from female spathe cracking.

Pollination time (days after spathe opening)	Parthenocarpy (%)	Bunch weight (kg)
Control	61.42[bc]	6.33[a]
1	53.25[abc]	6.66[a]
2	52.55[abc]	9.00[a]
4	59.92[abc]	5.50[a]
6	47.14[ab]	6.66[a]
8	45.59[a]	6.00[a]
10	45.53[a]	6.00[a]
12	56.81[abc]	5.00[a]
14	52.86[abc]	4.16[a]
16	64.52[c]	8.33[a]
Signification	0.090	

*Means within each column with the same letter are not significantly different at $p \leq 0.05$ ($N = 30$).

TABLE 3 Mean values of parthenocarpy rate of 'Assiane' date palm cultivar as affected by mean daily temperatures.

Average temperature class	*N*	Parthenocarpy (%)	Bunch weight (kg)
(25–30)	3	39.7717[a]	3.33[a]
(20–25)	11	50.3060[b]	6.00[ab]
(15–20)	3	58.7151[bc]	6.86[ab]
(10–15)	3	63.8897[c]	7.66[b]

*Means within each column with the same letter are not significantly different at $p \leq 0.05$.

TABLE 4 Mean values of physical fruit properties of 'Assiane' date palm cultivar as affected by mean daily temperatures.

Average temperature class	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Seed weight (g)	Seed length (mm)	Seed width (mm)
(25–30)	7.69[a]	36.83[a]	17.45[a]	1.02[a]	22.63[a]	8.00[a]
(20–25)	7.92[a]	36.85[a]	17.71[a]	1.10[a]	22.99[a]	8.39[a]
(15–20)	8.25[a]	37.79[a]	18.00[a]	1.33[a]	23.12[a]	8.41[a]
(10–15)	8.37[a]	39.23[a]	18.20[a]	2.49[a]	23.86[a]	8.59[a]

*Means within each column with the same letter are not significantly different at $p \leq 0.05$, ($N = 30$).

Some studies have shown a 25% drop in fruit set for some dry date cultivars when pollination was delayed until the second week of spathe cracking (Kadri et al., 2022). In cv. Zaidi, the pollination practice can be performed within 5 days after spathe opening, however in cv. Khalas, 4 days after spathe opening was reported as the best pollination time (Dowson et al., 1982). Similarly, it was suggested that cv. Dhakki should be pollinated within 4 days after spathe cracking (Iqbal et al., 2004).

Table 2 showed that the impact of varying pollination days was statistically significant ($p < 0.05$) with regard to the fresh weight, length, and width of the fruit. On the other hand, there was no significant impact of pollination days on seed weight and seed length. Maximum (9.29 g) and minimum (6.18 g) fruit weights were obtained on the 16 and the 8th day after the spathes' opening. Maximum (41.67 mm) and minimum (36.18 mm) fruit length was recorded the 16th day after the spathe opening and on the same day of the spathe cracking. Similarly, the maximum (18.63 mm) and minimum (16.18 mm) fruit diameter was observed 16th day after the spathe opening and on the same day of the spathe opening. These results are in agreement with those reported by Iqbal et al. (2004), where it was noted that applying pollens up to 8 days after spathe opening resulted in higher fruit weight and size in cv. Dhakki. Similarly, Iqbal et al. (2018) found that in cv. Gulistan, the optimal time for pollination was 9–12 days after the spathe opening, which also led to increased fruit weight and size. However, Shafique et al. (2011) observed that the physical characteristic of fruit in cv. Dhakki was not affected by different pollination days. Delaying pollination was found to decrease fruit set and the number of fruits per bunch. However, this reduction in fruit number was actually beneficial, as it led to an improvement in the weight and volume of individual fruits. As a result, it has become important to strike a balance between the fruit set and the average weight of dates produced.

3.2 Effect of air temperature

According to the results presented in Tables 3, 4, there was a statistically significant impact ($p < 0.05$) of mean daily temperatures

TABLE 5 Correlation test between the mean temperature and the Parthenocarpy rate and physical fruit properties.

		Mean temperature
Parthenocarpy (%)	Pearson correlation	−0.846**
	Sig. (bilateral)	0.000
Bunch weight (kg)	Pearson correlation	−0.175
	Sig. (bilateral)	0.461
Fruit weight (g)	Pearson correlation	0.221
	Sig. (bilateral)	0.348
Fruit length (mm)	Pearson correlation	0.146
	Sig. (bilateral)	0.538
Fruit diameter (mm)	Pearson correlation	0.047
	Sig. (bilateral)	0.845
Seed weight (g)	Pearson correlation	−0.450*
	Sig. (bilateral)	0.047
Seed length (mm)	Pearson correlation	0.113
	Sig. (bilateral)	0.634
Seed width (mm)	Pearson correlation	−0.249
	Sig. (bilateral)	0.289

*Means within each column with the same letter are not significantly different at $p \leq 0.05$, ($N = 30$). **Level of signification.

on the Parthenocarpy rate and Bunch weight. However, there was no significant impact of mean daily temperatures on the seed weight, seed length, fresh weight, length, and width of the fruit. The highest parthenocarpy rate (63.88%) was observed at the range (10–15°C) and the lowest (39.77%) was registered at the range (25–30°C). These results are in agreement with [3,24] that show the fastest germination and pollen tube elongation in styles at 25 and 28°C. The higher occurrence of parthenocarpic fruits at lower temperatures (10–15°C) suggests that the reduced growth rate of pollen tubes may have hindered efficient fertilization.

While there was a negative correlation ($r = -0.846^{**}$) observed between the daily mean temperature and the rate of parthenocarpy, there was no significant correlation observed between the daily mean temperature and the other parameters listed in Table 5.

High temperatures were found to enhance pollen germination and promote the growth of pollen tubes, resulting in an increased number of pollen tubes that successfully reach the base of the style. This effect of increased temperature on improving pollen tube growth has also been observed in various herbaceous and woody species (Hedhly et al., 2005). It has also been shown that increasing temperatures accelerate ovule degeneration (Postweiler et al., 1985; Cerović et al., 2000) and stigma degeneration (Hedhly et al., 2003). This apparently opposite impact of rising temperatures on the male and female stages may provide an explanation for the erratic yields observed in various fruit tree species, which are influenced by the environmental conditions during the flowering season.

4 Conclusion

The findings indicated that postponing pollination until the second week after the female spathe cracking produced the most favorable outcomes in terms of both fruit set percentage and average fruit size. Additional research is necessary to identify the optimal timing for delaying pollination in various cultivars and geographical regions. It is important to note that temperature requirements for pollen germination can vary among different plant species. Plants have evolved adaptive mechanisms to respond to changing environmental conditions, demonstrating flexibility in their reproductive strategies to ensure successful fertilization. However, in regions with challenging conditions such as the Figuig Oasis, precise knowledge of temperature requirements is imperative for successful crop cultivation.

5 Prospective future directions

1. Exploring different cultivars: One important avenue for future research is to investigate the effect of delaying pollination on various cultivars of the same plant species. Different cultivars may have varying responses to delayed pollination, and understanding these differences can provide valuable insights for cultivar selection in agriculture.
2. Geographical variability: Extending the study to different localities and climates is essential. Environmental conditions, including temperature, humidity, and sunlight, can vary significantly between regions. Conducting experiments in diverse geographic locations can help determine whether the optimal delay in pollination is consistent across different environments or if adjustments are needed based on local conditions.
3. Temperature thresholds: Further research should delve into the specific temperature requirements for pollen germination in the studied species. Investigating the temperature ranges and optima for pollen germination can lead to a more precise understanding of how temperature influences successful fertilization. This knowledge can be critical for optimizing cultivation practices in regions with varying temperature profiles.
4. Environmental stressors: Assessing the impact of environmental stressors, such as drought, extreme temperatures, or soil conditions, on delayed pollination and fruit set can be an intriguing avenue. Understanding how plants adapt to and cope with stressors during their reproductive phase can have practical implications for sustainable agriculture in challenging environments like the Figuig Oasis.
5. Molecular and genetic studies: Conducting molecular and genetic studies can help uncover the underlying mechanisms that enable plants to adjust their reproductive responses to changing environmental conditions. This could involve identifying specific genes or pathways involved in the regulation of delayed pollination and fruit set.
6. Conservation and sustainability: Applying the findings from these studies to practical agriculture and conservation efforts is crucial. Researchers should work alongside farmers and local communities to develop sustainable cultivation practices that maximize fruit set and yield while preserving the natural environment and biodiversity of the area.
7. Climate change adaptation: Given the ongoing changes in global climate patterns, it is essential to investigate how changing climates may affect the suitability of delayed pollination as a cultivation technique. This could involve

modeling the impact of future climate scenarios on fruit production and adapting agricultural practices accordingly.

In conclusion, while the current study has provided valuable insights into the benefits of delaying pollination, there are numerous exciting avenues for future research. By exploring different cultivars, varying environmental conditions, and the molecular mechanisms involved, we can refine our understanding of delayed pollination's potential and adapt it to address the challenges of modern agriculture, including climate change and sustainable cultivation in marginal areas like the Figuig Oasis.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

IZ: Conceptualization, Data curation, Investigation, Writing – original draft. FA: Methodology, Writing – review & editing. MA: Writing – review & editing. AA: Formal analysis, Writing – review & editing. ON: Formal analysis, Funding acquisition, Writing – review & editing. MP: Funding acquisition, Writing – review & editing. ME: Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abdelkrim, R., Ziane, L., Rima, B. H., Khaled, C., Sarra, C., and Ali, B. (2023). Molecular identification of genetic diversity in date palms (*Phoenix dactylifera* L.) from Algerian oases using simple sequence repeats (SSR) markers. *South African J. Bot.* 157, 438–446. doi: 10.1016/j.sajb.2023.04.017

Ahmed, Z. F. R., Alyafei, M. A. S., Al Dakheel, A., and Almoosa, M. (2022a). "Artificial pollination of date palm (*Phoenix dactylifera* L.) using a platform mounted robotic pollination system (drone)" in *Acta Horticulturae (International Society for Horticultural Science (ISHS))*, (Eds.) E. Ortega and E. Costes (Leuven, Belgium: ISHS Acta Horticuturae), 299–306. Available at: https://www.actahort.org/books/1342/1342_42.htm

Ahmed, Z. F. R., Kaur, N., and Hassan, F. E. (2022b). Ornamental date palm and Sidr trees: fruit elements composition and concerns regarding consumption. *Int. J. Fruit Sci.* 22, 17–34. doi: 10.1080/15538362.2021.1995570

Alam, M. Z., Al-Hamimi, S., Ayyash, M., Rosa, C. T., Yahia, E. M., Haris, S., et al. (2023). Contributing factors to quality of date (*Phoenix dactylifera* L.) fruit. *Sci. Hortic.* 321:112256. doi: 10.1016/j.scienta.2023.112256

Ali-Dinar, H., Mohammed, M., and Munir, M. (2021). Effects of pollination interventions, plant age and source on hormonal patterns and fruit set of date palm (*Phoenix dactylifera L.*). *Horticulturae* 7:427. doi: 10.3390/horticulturae7110427

Alla, F., Jdaini, K., M'Hamdi, H., Mechchate, H., AlZain, M. N., Alzamel, N. M., et al. (2022). Calibration of thermal dissipation probes for date palm (*Phoenix dactylifera* L.). *Horticulturae* 8:107. doi: 10.3390/horticulturae8020107

Askri, B., Ahmed, A. T., Abichou, T., and Bouhlila, R. (2014). Effects of shallow water table, salinity and frequency of irrigation water on the date palm water use. *J. Hydrol.* 513, 81–90. doi: 10.1016/j.jhydrol.2014.03.030

Awad, M. A. (2006). Water spray as a potential thinning agent for date palm flowers (*Phoenix dactylifera L.*) c.v. "Lulu.". *Sci. Hortic.* 111, 44–48. doi: 10.1016/j.scienta.2006.09.005

Awad, M. A., and Al-Qurashi, A. D. (2012). Partial fruit set failure phenomenon in 'Nabbut-Ali' and 'Sabbaka' date palm cultivars under hot arid climate as affected by pollinator type and pollination method. *Sci. Hortic.* 135, 157–163. doi: 10.1016/j.scienta.2011.12.028

Bouhlali, E. D. T., Ben-Amar, H., Meziani, R., and Essarioui, A. (2021). Development of a fungicide-based management strategy of inflorescence rot disease caused by Mauginiella scaettae Cavar on date palm (*Phoenix dactylifera L.*) in Morocco. *J. Saudi Soc. Agric. Sci.* 20, 173–179. doi: 10.1016/j.jssas.2021.01.003

Cerović, R., Ružić, D., and Mićić, N. (2000). Viability of plum ovules at different temperatures. *Ann. Appl. Biol.* 137, 53–59. doi: 10.1111/j.1744-7348.2000.tb00056.x

Chandrasekaran, M., and Bahkali, A. H. (2013). Valorization of date palm (*Phoenix dactylifera*) fruit processing by-products and wastes using bioprocess technology—review. *Saudi J. Biol. Sci.* 20, 105–120. doi: 10.1016/j.sjbs.2012.12.004

Chao, C. T., and Krueger, R. R. (2007). The date palm (*Phoenix dactylifera* L.): overview of biology, uses, and cultivation. *HortSci. Horts* 42, 1077–1082. doi: 10.21273/HORTSCI.42.5.1077

Cherif, H., Marasco, R., Rolli, E., Ferjani, R., Fusi, M., Soussi, A., et al. (2015). Oasis desert farming selects environment-specific date palm root endophytic communities and cultivable bacteria that promote resistance to drought. *Environ. Microbiol. Rep.* 7, 668–678. doi: 10.1111/1758-2229.12304

Cohen, Y., Slavkovic, F., Birger, D., Greenberg, A., Sadowsky, A., Ish-Shalom, M., et al. (2016). Fertilization and fruit setting in date palm: biological and technological challenges. *Acta Hortic.* 1130, 351–358. doi: 10.17660/ActaHortic.2016.1130.53

Dehghan-Shoar, Z., Hamidi-Esfahani, Z., and Abbasi, S. (2010). Effect of temperature and modified atmosphere on quality preservation of sayer date fruits (phoenix dactylifera l.). *J. Food Process. Preserv.* 34, 323–334. doi: 10.1111/j.1745-4549.2008.00349.x

Dowson, V. H. W.Food and Agriculture Organization of the United NationsHorticultural Crops Group (1982). Date production and protection: with special reference to North Africa and the near east. Food and agriculture Organization of the United Nations Available at: https://books.google.co.in/books?id=FYLWvwEACAAJ

Ghnimi, S., Umer, S., Karim, A., and Kamal-Eldin, A. (2017). Date fruit (*Phoenix dactylifera L.*): an underutilized food seeking industrial valorization. *NFS J.* 6, 1–10. doi: 10.1016/j.nfs.2016.12.001

Hedhly, A., Hormaza, J. I., and Herrero, M. (2003). The effect of temperature on stigmatic receptivity in sweet cherry (*Prunus avium L.*). *Plant Cell Environ.* 26, 1673–1680. doi: 10.1046/j.1365-3040.2003.01085.x

Hedhly, A., Hormaza, J. I., and Herrero, M. (2005). The effect of temperature on pollen germination, pollen tube growth, and stigmatic receptivity in peach. *Plant Biol.* 7, 476–483. doi: 10.1055/s-2005-865850

Iqbal, M., Ghafoor, A., and Rahman, S. (2004). Effect of pollination times on fruit characteristics and yield of date palm cv. *Int. J. Agric. Biol.* 6, 96–99.

Iqbal, M., Usman, K., Munir, M., and Khan, M. S. (2018). Quantitative and qualitative characteristics of date palm cv. Gulistan in response to pollination times. *Sarhad J. Agric.* 34, 40–46. doi: 10.17582/journal.sja/2018/34.1.40.46

Jacobsen, S. E., and Olszewski, N. E. (1993). Mutations at the SPINDLY locus of Arabidopsis alter gibberellin signal transduction. *Plant Cell* 5, 887–896. doi: 10.1105/tpc.5.8.887

Jdaini, K., Alla, F., M'Hamdi, H., Guerrouj, K., Parmar, A., and Elhoumaizi, M. A. (2022). Effect of harvesting and post-harvest practices on the microbiological quality of dates fruits (*Phoenix dactylifera L.*). *J. Saudi Soc. Agric. Sci.* 21, 552–559. doi: 10.1016/j.jssas.2022.04.001

Jilali, A. (2014). Impact of climate change on the Figuig aquifer using a numerical model: oasis of eastern Morocco. *J. Biol. Earth Sci.* 4, 16–24.

Kadri, K., Elsafy, M., Makhlouf, S., and Awad, M. A. (2022). Effect of pollination time, the hour of daytime, pollen storage temperature and duration on pollen viability, germinability, and fruit set of date palm (*Phoenix dactylifera* L.) cv "Deglet nour". *Saudi J. Biol. Sci.* 29, 1085–1091. doi: 10.1016/j.sjbs.2021.09.062

Karim, K., Awad, M. A., Manar, A., Monia, J., Karim, A., and Mohammed, E. (2022). Effect of flowering stage and storage conditions on pollen quality of six male date palm genotypes. *Saudi J. Biol. Sci.* 29, 2564–2572. doi: 10.1016/j.sjbs.2021.12.038

Maryam, , Jafar Jaskani, M., Fatima, B., Salman Haider, M., Naqvi, S. A., Nafees, M., et al. (2015). Evaluation of pollen viability in date palm cultivars under different storage temperatures. *Pak. J. Bot.* 47, 377–381.

Muralidharan, C. M., Panchal, C. N., Baidiyavadra, D. A., Sharma, K. M., and Verma, P. (2020). Pistillate receptivity of date palm (*Phoenix dactylifera* L.) cv. Barhee. *Sugar Tech.* 22, 1166–1169. doi: 10.1007/s12355-020-00859-2

Oladzad, S., Fallah, N., Mahboubi, A., Afsham, N., and Taherzadeh, M. J. (2021). Date fruit processing waste and approaches to its valorization: a review. *Bioresour. Technol.* 340:125625. doi: 10.1016/j.biortech.2021.125625

Pandolfini, T., Molesini, B., and Spena, A. (2018). Parthenocarpy in crop plants. *Annu. Plant Rev.* 38, 326–345. doi: 10.1002/9781119312994.apr0416

Postweiler, K., Stösser, R., and Anvari, S. F. (1985). The effect of different temperatures on the viability of ovules in cherries. *Sci. Hortic.* 25, 235–239. doi: 10.1016/0304-4238(85)90120-7

Rivera, D., Alcaraz, F., Rivera-Obón, D. J., and Obón, C. (2022). Phenotypic diversity in wild and cultivated date palm (*Phoenix*, *Arecaceae*): quantitative analysis using information theory. *Horticulturae* 8:287. doi: 10.3390/horticulturae8040287

Salomón-Torres, R., Krueger, R., García-Vázquez, J. P., Villa-Angulo, R., Villa-Angulo, C., Ortiz-Uribe, N., et al. (2021). Date palm pollen: features, production, extraction and pollination methods. *Agronomy* 11:504. doi: 10.3390/agronomy11030504

Sedra, M. H. (2015). "Date palm status and perspective in Morocco" in *Date Palm Genetic Resources and Utilization: Volume 1: Africa and the Americas*. eds. J. M. Al-Khayri, S. M. Jain and D. V. Johnson (Dordrecht: Springer Netherlands), 257–323.

Shafique, M., Khan, A. S., Malik, A. U., Shahid, M., Rajwana, I. A., Saleem, B. A., et al. (2011). Influence of pollen source and pollination frequency on fruit drop, yield and quality of date palm (*Phoenix dactylifera* L.) cv. Dhakki. *Pak. J. Bot.* 43, 831–839.

Shahid, M. A., Iqbal, M., and Niamatullah, M. (2017). Response of male pollinizers in fruit set, yield and quality of date palm (*Phoenix dactylifera L.*) Cv. Dhakki. *Sarhad J. Agric.* 33, 108–116. doi: 10.17582/journal.sja/2017.33.1.108.116

Sharma, K. M., Kumar, M., Muralidharan, C. M., and Salomón-Torres, R. (2023). Date palm pollination management. *Crop Prod. Sci. Hortic.* 209–240. doi: 10.1079/9781800620209.0007

Snider, J. L., and Oosterhuis, D. M. (2011). How does timing, duration and severity of heat stress influence pollen-pistil interactions in angiosperms? *Plant Signal. Behav.* 6, 930–933. doi: 10.4161/psb.6.7.15315

Vivian-Smith, A., and Koltunow, A. M. (1999). Genetic analysis of growth-regulator-induced parthenocarpy in Arabidopsis. *Plant Physiol.* 121, 437–452. doi: 10.1104/pp.121.2.437

Zulkarnain, Z., Eliyanti, E., and Swari, E. I. (2019). Pollen viability and stigma receptivity in Swainsona formosa (G.Don) J. Thompson (Fabaceae), an ornamental legume native to Australia. *Ornam. Hortic.* 25, 158–167. doi: 10.14295/oh.v25i2.2011