Iraqi Journal of Desert Studies 2025, 15 (2): 29-40 **Original Article**

The Effects of Pollen Sources, Pollination Methods, and Pollination Frequencies on the Yield Traits of Khastawi Date Palm *Phoenix dactylifera* L.

Zeena A. Aljanaby[1]*, R. M. Hamad[1], M. A. Ali[2]

[1] Department of Horticulture and Landscape Engineering, Agriculture College, University of Anbar, Anbar, Iraq.

[2] Faculty Agriculture, Mutah University, Jordan.

Abstract

Date palm cultivation is one of the fundamental crops in Iraq, due to its economic, nutritional, and strategic importance within the national food security system. Given that climate changes in Iraq have had negative effects, this study aimed to investigate the impact of pollination sources, pollination methods, and pollination frequency on the chemical and productive traits of this cultivar. The study also measured the anatomical characteristics of pollen grains by assessing shape, polarity, germination opening, wall thickness, and surface ornamentation, in addition to measuring the seed germination percentage of pollen in the laboratory for the three cultivars. The main factors included first, pollen source, consisting of Red Ghnamee, Green Ghnamee, and Khakri. Second, pollination method, consisting of: pollen suspension, dry pollination, and using four male catkins (stamens). Third, number of pollination repetitions, consisting of pollination one time and pollination twice. The experiment was conducted according to a randomized complete block design in a factorial arrangement with three replications. Across all pollen sources, fruit set generally increases as it moves from B1 to B3 and from C1 to C2, as in figure 1a. For instance, B3C2 tends to yield the highest fruit set, while B1C1 tends to yield the lowest. By pollen source (A1, A2, A3); A1 values rise from B1C1 (70.00) to B3C2 (77.08); A2 (Green Ghnamee): values rise from B1C1 (65.52) to B3C2 (69.40); A3 (Khakri): values rise from B1C1 (60.35) to B3C2 (65.14). Across pollination methods and repetitions, fruit drop percentages decline from B1C1 to B3C2; For A1 drop goes from 30.00% (B1C1) down to 22.91% (B3C2); For A2 drop goes from 34.48% (B1C1) down to 30.26% (B3C2); For A3 drop goes from 39.65% (B1C1) down to 34.85% (B3C2). There were also significant differences for the main factors and the two-way interactions among the study variables. The results showed that the pollen source type, pollination method, and pollination repetition have clear significant effects on the productive and chemical traits of the date palm cultivar Khastaawi. The use of the Red Ghnamee pollen with repeated pollination using the traditional method contributed to improved fruit set percentage and reduced fruit drop, positively affecting the weight of the spike and the overall palm yield. The pollination treatments also increased total sugars percentage and reducing sugars percentage in the fruits, indicating the possibility of using these treatments to improve the fruit's chemical quality.

Keyword: Khastaawi, Red Ghnamee, Fruit Set, number of pollinations

تأثير مصادر اللقاح وطرق التلقيح وتكرار التلقيح على صفات الإنتاج لنخيل الخستاوي *Phoenix dactylifera* L.

زينة عبد الله الجنابي[1]*، رسمي محمد حمد[1]، معاوية عايد العساسفة[2]

[1] قسم البستنة وهندسة الحدائق، كلية الزراعة، جامعة الأنبار، الأنبار، العراق.

[2] كلية الزراعة، جامعة مؤتة، الأردن.

المستخلص

تُعَدّ زراعة نخيل التمر من المحاصيل الأساسية في العراق لما لها من أهمية اقتصادية وغذائية واستراتيجية ضمن منظومة الأمن الغذائي الوطني. ونظراً لتأثيرات التغيرات المناخية السلبية في العراق، هدفت هذه الدراسة إلى تحليل تأثير مصادر اللقاح، وطرق التلقيح، وعدد مرات التلقيح في الصفات الكيميائية والإنتاجية لهذا الصنف. كما شملت الدراسة قياس الصفات التشريحية لحبوب اللقاح من حيث الشكل، والاستقطاب، وفتحة الإنبات، وسماكة الجدار، والزخرفة السطحية، إضافةً إلى قياس النسبة المئوية لإنبات حبوب اللقاح في المختبر للأصناف الثلاثة المدروسة. تضمنت العوامل الرئيسة ما يأتي: العامل الأول مصدر اللقاح: الغنامي الأحمر والغنامي الأخضر والخكري. أما العامل الثاني طريقة التلقيح: التلقيح السائل والتلقيح الجاف واستخدام أربع شماريخ ذكرية وتضمن العامل الثالث عدد مرات التلقيح: مرة واحدة ومرتين. نُفّذت التجربة وفق تصميم القطاعات العشوائية الكاملة بنظام عاملـــي وبثلاث مكررات، أظهرت النتائج أن نسبة عقد الثمار تزداد عموماً عند الانتقال من B1 إلى B3 ومن C1 إلى **C2**، كما هو موضح في الشكل (A1). اذ سجّل التداخل **B3C2** أعلى نسبة عقد للثمار بينما أظهر التداخل **B1C1** أدنى نسبة. وتم حساب معاملة مصدر اللقاح كما يلي: الغنامي الأحمر (A1) ارتفعت القيم من 70.00 في المعاملة **B1C1** إلى 77.08 في المعاملة B3C2 والغنامي الأخضر (A2) ارتفعت القيم من 65.52 في B1C1 إلى 69.40 في B3C2 والخكري (A**3**) ارتفعت القيم من 60.35 في B1C1 إلى 65.14 في B3C2. أما بالنسبة لنسبة

*Corresponding author.

Email: **zen22g5001@uoanbar.edu.iq**

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تساقط الثمار، فقد انخفضت تدريجياً من B1C1 إلى B3C2؛ إذ انخفضت في الغنامي الأحمر (A1) من 30.00% إلى 22.91%. أما الغنامي الأخضر (A2) من 34.48% إلى 30.26%. فيما انخفض الخكري (A3) من 39.65% إلى 34.85%. كما وُجدت فروق معنوية واضحة بين العوامل الرئيسة والتداخلات الثنائية بينها. أظهرت النتائج أن نوع مصدر اللقاح وطريقة التلقيح وعدد مرات التلقيح كان لها تأثير معنوي واضح في الصفات الإنتاجية والكيميائية لصنف التمر خستاوي. إن استخدام لقاح الغنامي الأحمر مع تكرار التلقيح بالطريقة التقليدية أسهم في تحسين نسبة عقد الثمار وتقليل نسبة تساقطها، مما انعكس إيجاباً على وزن العذق والحاصل الكلي للنخلة، كما أدت معاملات التلقيح إلى زيادة النسبة المئوية لكل من السكريات الكلية والسكريات المختزلة في الثمار، مما يشير إلى إمكانية استخدام هذه المعاملات لتحسين الجودة الكيميائية للثمار.

الكلمات المفتاحية: ....

Introduction

Date palm *Phoenix dactylifera* L. is one of the economically important and widely cultivated trees worldwide, especially in the Arab world, due to its historical, economic, nutritional, and industrial value. The Khastaawi cultivar is widely grown in Iraq because it is characterized by abundant production and acceptable fruit quality (Al-Bakr, 1972). Given this multi-dimensional importance, there is a need for continuous scientific studies aimed at improving economic yield and production quality of this vital crop (Zheng and Xia,2022).

Dates fruits contain a broad range of essential nutrients, making them highly nutritious and rich in antioxidants. Mature fruits largely contain sugars (about 80%) with lower amounts of protein, fiber, and trace elements, including boron, cobalt, copper, fluorine, magnesium, manganese, selenium, and zinc (Benchilo et al.,2024). The Khastaawi cultivar is a traditional variety with a strong market presence globally, providing a promising income source for local farmers (Aubied et al., 2023). The pollen source used for pollination in date palms directly and effectively influences many qualitative and chemical fruit traits, as fruit response varies according to pollen source in terms of fruit set percentage, growth rate, and ripening time, in addition to changes in chemical composition such as total sugars and reducing sugars, among others (Jaskani et al., 2023). Pollination of date palms is a highly important process that directly affects fruit set, quality, and prod uctivity (Kadri et al., 2019) (El-Rauof, 2021). Natural pollination by wind, bees, and other insects can lead to poor-quality fruits, uneven sizes, seedlessness, crowding in the inflorescence, shriveling, drying, and browning, resulting in fruit drop (Sharma et al., 2019) (Homed,2020). Therefore, both manual pollination and automated pollination are among the most efficient methods for delivering pollen directly to the pistils of the female flowers (Ahmed et al., 2022). These methods allow precise control over the amount and quality of the pollen used, in addition to timing pollination to suit the flower-opening stage, and this precision in application leads to increased fruit set and better distribution of fruits on the stalk, positively affecting the quality and quantity of production (Fayyad,2017). Additionally, the repetition of the pollination process has a significant impact on improving fruit quality traits, with studies showing that repeated pollination contributes effectively to enhancing the quality of the fruits and improving their marketability (Iqbal et al., 2018) (Ullah et al., 2018). Given the production and tolerance challenges faced by the Khastaawi date palm under adverse environmental conditions, this study aimed to explore ways to improve the productive and qualitative performance of this cultivar by studying the effects of different pollen sources, pollination methods, and pollination repetitions, with the goal of identifying the best treatments that enhance fruit set efficiency and improve fruit quality under local conditions.

Materials and Methods

This experiment was conducted during the 2024 growing season in a local date palm garden located in the village of Al-Jazira, about 25 km west of Ramadi city in the Anbar province, on the banks of the Euphrates River, from March until the end of September. The study aimed to assess the effect of pollen source, pollination method, and pollination frequency on the quantitative and qualitative traits of the date palm cv. Khastaawi. Fifty-four date palms, 15 years old, uniform in growth and free of disease and insect injuries, were selected and planted at equal spacings (8 × 8 m). These trees were irrigated with Euphrates River water, and ten inflorescences per palm were retained, distributed across the four directions to ensure uniform experimental units. The study included three main factors:

- Pollen source: Red Ghnamee (A1), Green Ghnamee (A2), Khakri (A3).
- Pollination method: suspension spray (B1), dry pollination (B2), traditional method (B3).
- Number of pollination repetitions: one pollination (C1) and two pollinations (C2).

Pollination was performed using the first method by dissolving pollen in a suspension (water) at a ratio of 1:3 g L^-1 (Ahmed et al., 2021), designated as B1. The second method mixes pollen with flour at a 2:1 ratio, designated as B2 (Alashaibi, 2023). The third method uses four catkins and is designated as B3 (Shaaban et al., 2019). The three methods were applied for each pollen source. Repetition of pollination was done once for part of the palms (C1) and twice for the other part (C2) seven days after the first pollination (Shakir and Abood, 2023).

Accompanying agricultural operations included insect control (control of red palm weevil and stem borer) and conditioning of all inflorescences for all experimental units, as well as removing inflorescences infected with the disease "Khiyas al- Tal" (note: transliteration; exact disease name may vary). A complete randomized block design (RCBD) with a factorial arrangement and three replications was used. Data were analyzed with GenStat statistical software, and means were compared using the Least Significant Difference (L.S.D) test at a 0.05 probability level (Al-Muhammadi and Al-Muhammadi, 2012).

Traits studied

Percentage of Fruit Set (%)

This trait was estimated five weeks after pollination. Five spathes were randomly selected from each bunch, and the fruit set percentage was calculated using the following formula, as described by (Hamood, 1984).

$$\text{Fruit Set} = \frac{\text{Number of set fruits}}{\text{Total Number of flowers}} \times 100$$

Percentage of Fruit Drop (%)

This parameter was determined after harvest time, by randomly selecting five spathes from each bunch and applying the formula described by (Al-Shujairi et al., 2015).

$$\text{Fruit Drop (\%)} = \frac{\text{Number of Drop}}{\text{Total Number of Set Fruits}} \times 100$$

Percentage of threshed fruit (%)

The percentage of threshed (husked) fruits is calculated when the fruits enter the date stage, five catkins were taken from each inflorescence, and the percentage of threshed fruits was computed (Al-Shujairi et al., 2015).

$$\text{Percentage of ripe fruits (\%)} = \frac{\text{Number of ripe fruits}}{\text{Number of ripe fruits} + \text{Number of unripe fruits}} \times 100$$

Total yield rate (kg.palm^{-1})

The total yield of each palm was obtained by summing the weight of every inflorescence and then computing the mean total weight per palm.

Weight of the fresh flesh of fruit (g)

The weight of the flesh of ten fruits randomly selected per experimental unit was measured. The seeds were removed from the fruit flesh, and the flesh weight per fruit was measured with a precise balance.

Weight of the seeds (g)

Ten samples were weighed per treatment with a precise balance, and the mean seed weight was obtained by dividing the total by the number of seeds.

Percentage of total sugars (%)

Sugars were estimated according to the method of (Joslyn, 1970).

Percentage of non-reducing sugars (sucrose) (%)

Calculated using the following formula (Joslyn, 1970).

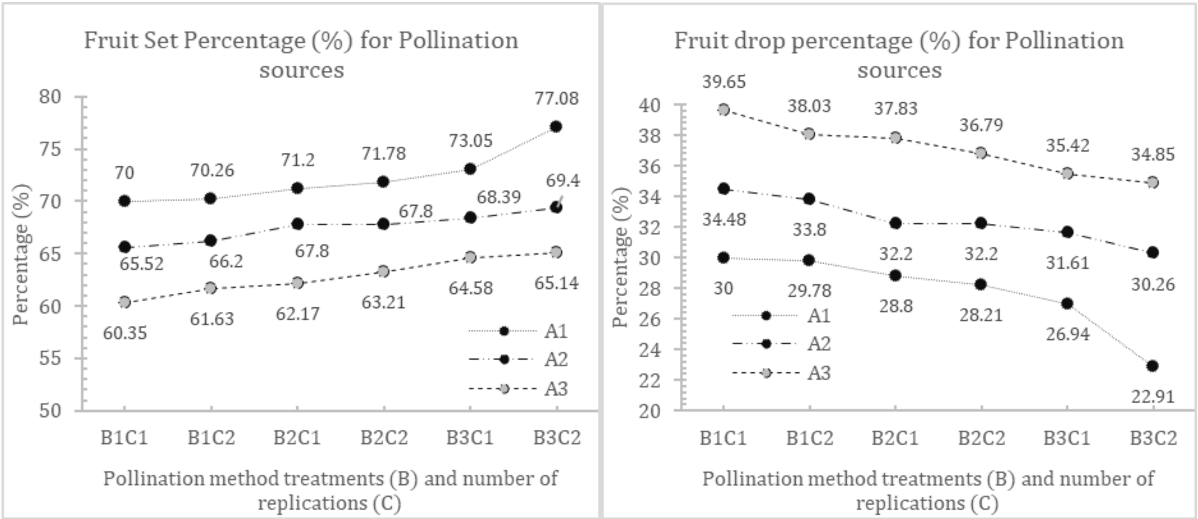
Non-reducing sugars (sucrose) = total sugars % – reducing sugars %

Results and Discussion

Across all pollen sources, fruit set generally increases as it moves from B1 to B3 and from C1 to C2, as in figure 1a. For instance, B3C2 tends to yield the highest fruit set, while B1C1 tends to yield the lowest. By pollen source (A1, A2, A3); A1 values rise from B1C1 (70.00) to B3C2 (77.08); A2 (Green Ghnamee): values rise from B1C1 (65.52) to B3C2 (69.40); A3 (Khakri): values rise from B1C1 (60.35) to B3C2 (65.14).

The pattern mirrors fruits set inversely as fruit set increases, fruit drop tends to decrease within each pollen source, as in figure 1b. Across pollination methods and repetitions, fruit drop percentages decline from B1C1 to B3C2; For A1 drop goes from 30.00% (B1C1) down to 22.91% (B3C2); For A2 drop goes from 34.48% (B1C1) down to 30.26% (B3C2); For A3 drop goes from 39.65% (B1C1) down to 34.85% (B3C2).

In general, C2 tends to yield modest gains in fruit set and modest reductions in fruit drop across all pollen sources. While Fruit set is highest for A1, especially under B3C2 (77.08%), and fruit drop is lowest for A1 under B3C2 (22.91%). Across pollen sources, the order is A1 > A2 > A3 for both higher fruit set and lower drop.



(a) **(b)**

Figure 1. Fruit set and fruit drop percentages for pollination sources in relation with pollination method treatment and number of replications.

In correspondence for Kimri, A1 shows a general decreasing trend from B1C2 (6.7) to B3C2 (5.333) with some fluctuations as in figure 2, while, A2 tends to cluster between ~5.0 and ~5.8 with a mild dip; A3 shows the strongest drop from higher values to lower.

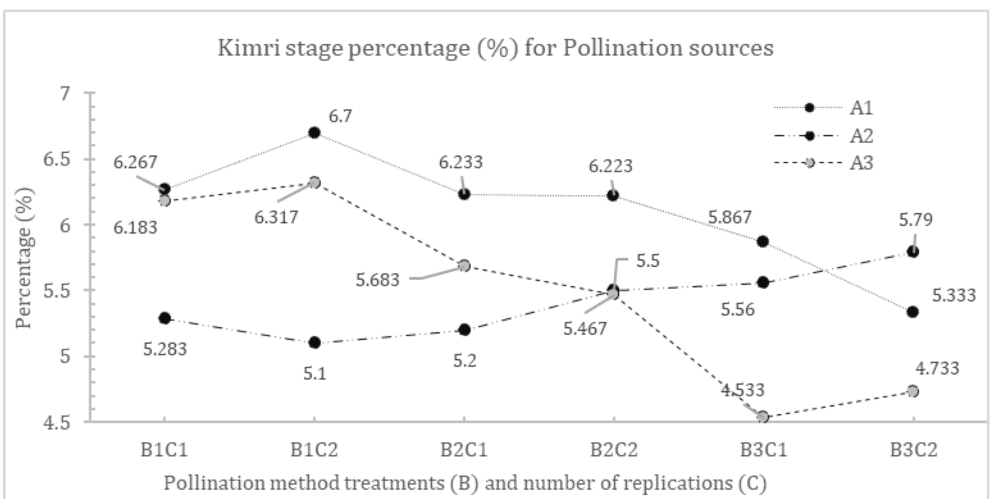


Figure 2. Kimri Stage Percentage for pollination sources in relation with pollination method treatment and number of replications.

As for Average total yield, A2 consistently yields the highest values across all combinations, with yields clustering around 189–194.5 kg palm^{-1} as in figure 3; while A1 yields are moderate, increasing gradually from 154 up to 187.5, showing a steady upward trend across combinations. Also, A3 yields are the lowest among the three sources, rising from 131 to 153.5, though the rate of increase is similar to A1.

Furthermore, the trend across pollination combinations (B1C1 → B3C2) increases as it moves from B1C1 to B3C2. This suggests that, regardless of pollen source, more intensive pollination combinations (moving toward B3C2) tend to produce higher yields, with A2 showing the smallest incremental gain.

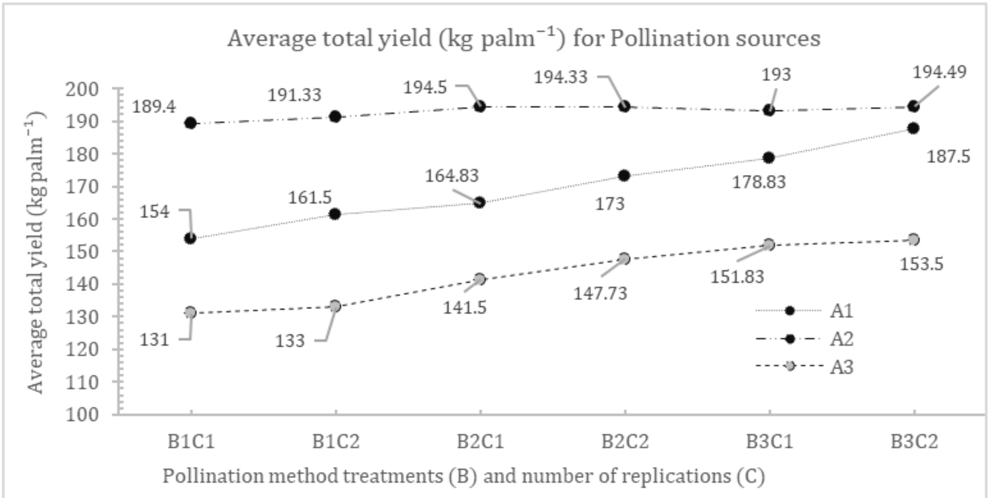
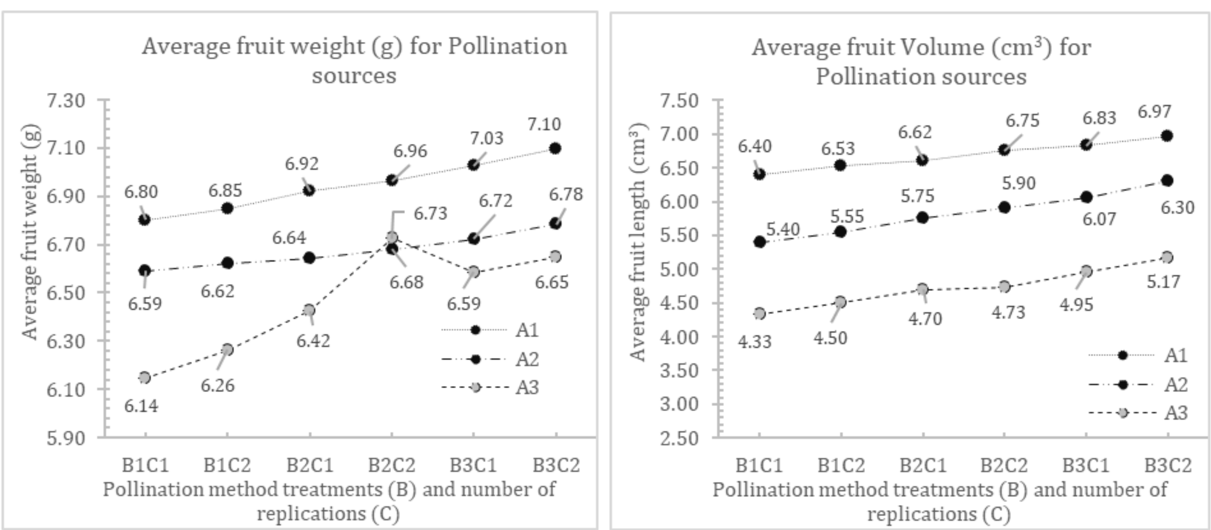


Figure 3. Average total yield in correspondence with pollination sources vs both pollination method treatment and number of replications.

Generally, the weight results show the following as in figure 4a; A1 yields the highest weights across all combinations, increasing from 6.80 to 7.10; A2 yields mid-range weights, increasing from 6.59 to 6.78; A3 yields the lowest weights overall, starting at 6.14 and ending at 6.65. For A3, there is a notable rise especially from B2C2 (6.73) to B3C2 (6.65) which is a slight decrease, but still increasing from B1C1 (6.14) to B3C2 (6.65). The gaps are relatively modest, with A1 typically ~0.2–0.5 g higher than A2, and A2 ~0.3–0.5 g higher than A3. For heavier fruit, A1 is the strongest pollen source, followed by A2 and A3. Increasing pollination intensity (toward B3C2) generally increases weight for A1 and A2; A3 shows a similar but slightly less pronounced pattern. However, as in figure 4b, A1 yields the highest volumes across all combinations, increasing from 6.40 to 6.97 as we move from B1C1 to B3C2; A2 yields mid-level volumes, increasing from 5.40 to 6.30; A3 yields the lowest volumes, increasing from 4.33 to 5.17. Within each pollen source, volumes generally increase from B1C1 to B3C2, showing a positive response to more intensive pollination combinations.



(a) (b)

Figure 4. Average fruit volume and weight for pollination sources in relation with pollination method treatment and number of replications.

Generally, for all pollen sources, the pulp-to-fruit ratio is quite high and gradually decreasing as it moves from B1C1 to B3C2, as shown in figure 5. A3 consistently has the highest pulp fraction, followed by A2, then A1. This suggests Khakri (A3) yields proportionally more pulp relative to total fruit, compared with the others. There is slight downward drift for all A, meaning proportion of pulp relative to total fruit is decreasing as pollination intensity increases.
While the pit-to-fruit ratio increases with later combinations (weak upward trend), with A1 generally the highest, A3 the lowest. A1 has the highest pit fraction, then A2, then A3. There is an upward drift for all A, meaning more seeds per fruit relative to total fruit as pollination intensity increases.
Furthermore, Across combinations, moving toward B3C2 (the most intensive pollination) tends to increase both pulp fraction and seed fraction slightly for each pollen source, though the pulp-to-fruit ratio shows a small downward drift.

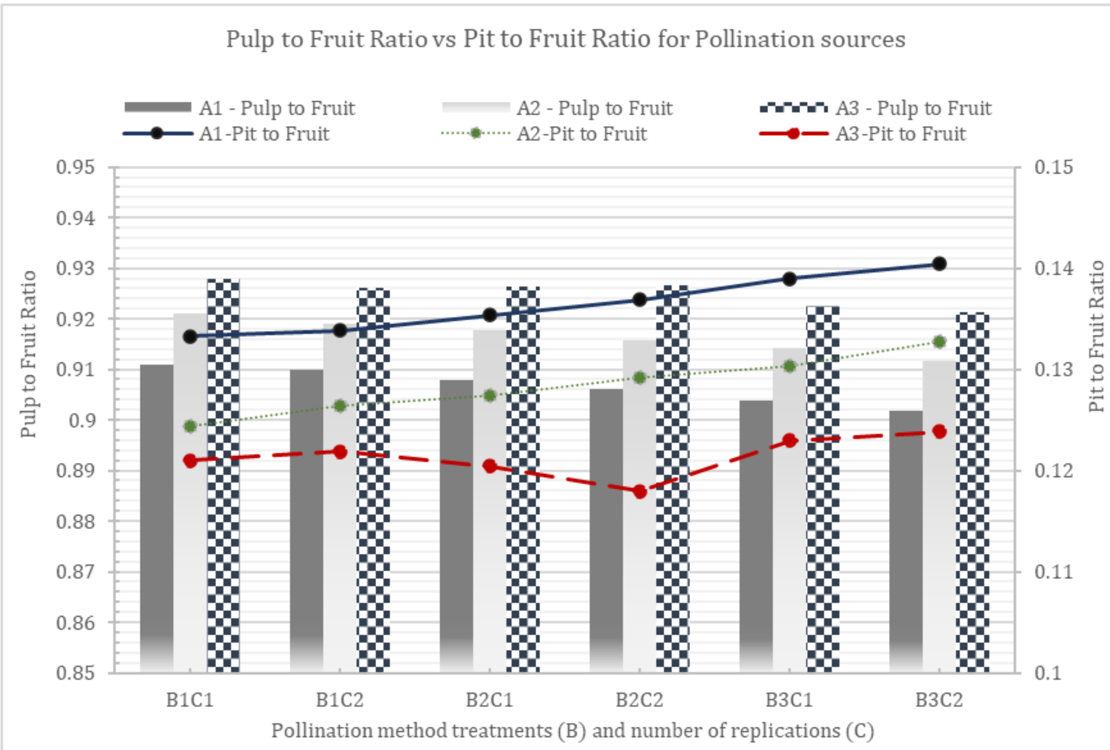


Figure 5. Pulp to fruit ratio and Pit to fruit ration for pollination sources in relation with pollination method treatment and number of replications.

In the aspect of Total Soluble Solids (TSS), as in figure 6, A1 consistently yields the highest TSS across all combinations; A2 yields intermediate TSS values; A3 yields the lowest TSS, with one notable dip at B1C2 (58.33). TSS generally increases as combinations become more intensive (toward B3C2); B3C2 often yields the highest TSS for A1 and A3, while A2 peaks at or near B3C1 or B3C2. However, in the aspect of moisture content, A1 shows high moisture in several combos (notably B1C1 and B3C2), but also some low values (B1C2 around 24.65). A2 generally exhibits lower moisture in early combos but peaks at B3C1 (33.27), indicating more variability. A3 tends to be moderate, with values typically in the high 20s and approaching 30% in B3C2 (30.35). In many combos, A2 achieves higher moisture than A1 and A3 (e.g., B3C1: A2 = 33.27 vs A1 = 28.10, A3 = 28.71). A1 often has the highest moisture in B1C1, but this is not uniform across all combos.
Generally, for pollen sources, A1 yields the highest total sugar percentages across all combinations; A2 yields intermediate values, generally 60–64%; A3 yields the lowest values, ranging from mid-50s to 60, as it noticed in figure 7. For each pollen source, total sugar tends to increase as we move toward B3C2, though A3 shows a dip at B2C2 (58) before rising again.
A3 often has the highest non-reducing sugar in several combos (notably B2C2: 6.63, B3C2: 6.83). A1 tends to be moderate, around 5.67–6.17, with a few higher points (6.17 at B1C2, B3C1/B3C2). A2 is more variable and sometimes lower (e.g., B1C2: 5.20; B3C2: 6.43). Non-reducing sugar values for A3 show an upward trend toward B3C2 (6.83 at B3C2 is the highest in the table). A1 shows relatively stable values with minor fluctuations around 5.6 – 6.2.

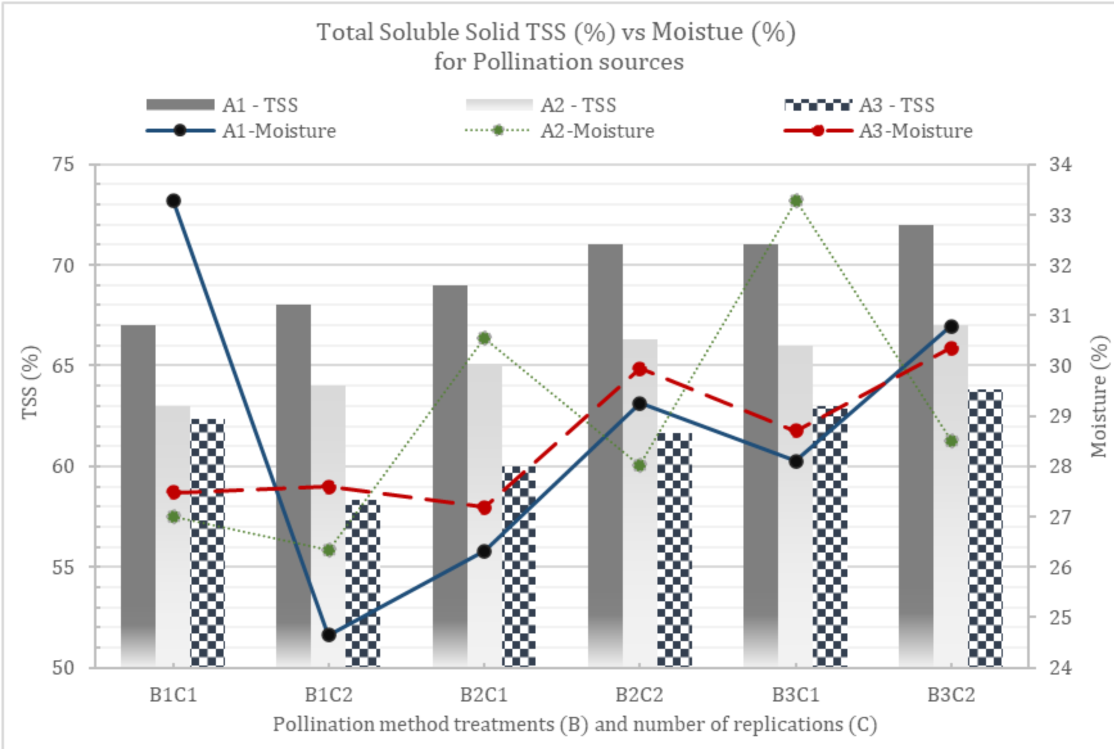


Figure 6. Total soluble solids TSS and Moisture content for pollination sources in relation with pollination method treatment and number of replications.

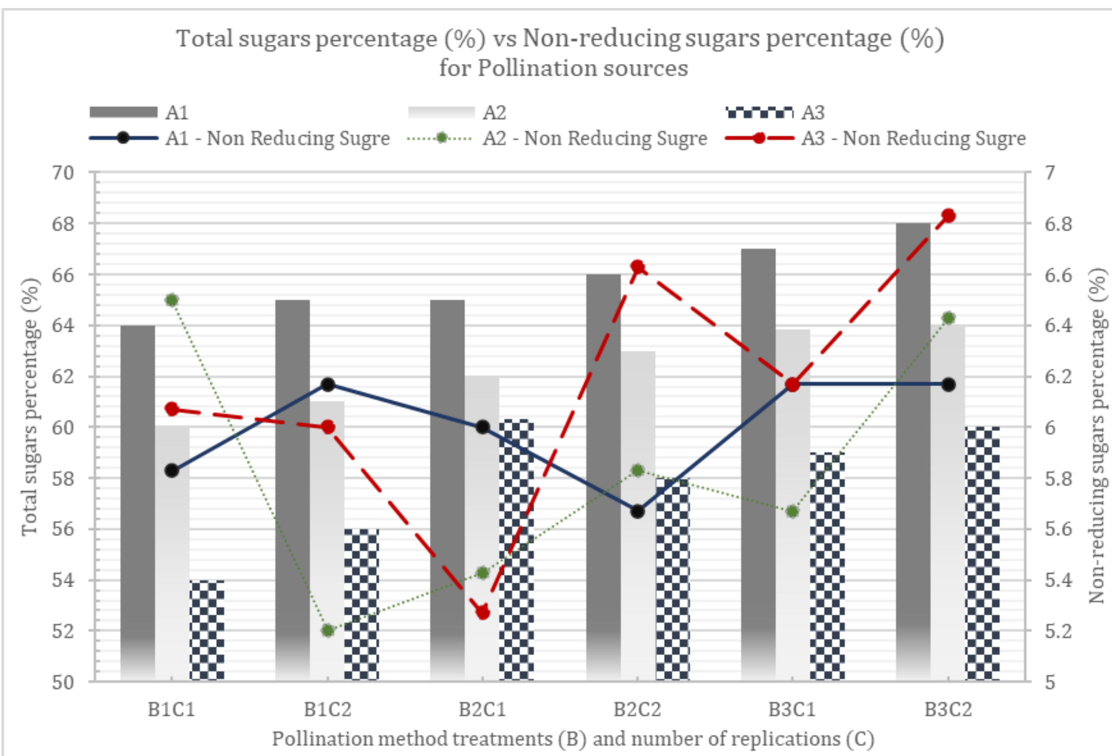


Figure 7: Total Sugar and Non-reducing sugar percentages for pollination sources in relation with pollination method treatment and number of replications

Figure (8) contains Taguchi analysis plots (Main Effects and Interaction plots) for two different metrics when larger is better for the responses, Fruit Set, volume and weight of fruit, pulp to fruit ratio, total sugar and total yield. The top two plots are for Means while the bottom two plots are Signal-to-Noise (S/N) Ratios.

Interaction plot for means shows interactions between factors A, B, and C. Each sub-plot corresponds to interaction between two factors while the third is kept constant. Where A-B interaction has significant interaction lines are not parallel, especially for factor A at level 2. However, A-C interaction has lines cross, indicating strong interaction. But, B-C interaction lines are nearly parallel refers to weak interaction.

Main effects plot for means displays effect of each factor (A, B, C) on the mean response. The A1 has the largest effect; Level 2 gives the highest mean, Level 3 the lowest. While C is almost flat refers to a negligible effect on mean response.

Interaction Plot for S/N Ratios shows A-B interaction lines is diverge significantly indicating strong interaction. While B-C interaction is nearly parallel indicating weak interaction. Furthermore, main effects plot for S/N Ratios shows the (A) has strong positive effect higher level improves robustness significantly. The B-factor has Small negative trend. While C has almost negligible impact.

Figure (9) contains Taguchi analysis plots when smaller is better for the responses, Fruit drop, Kimri and pit to fruit ratio. The top two plots are for Means while the bottom two plots are Signal-to-Noise (S/N) Ratios.

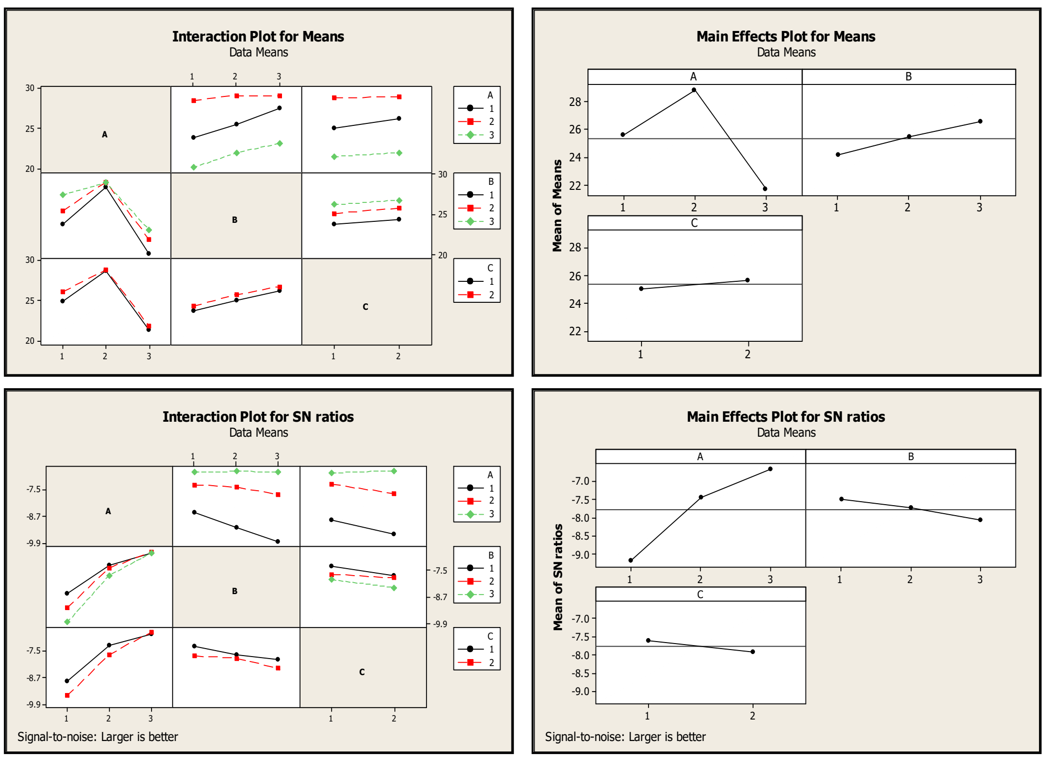


Figure 8. Taguchi analysis when larger is better; Main Effects and Interaction plots for Means in the top and for S/N ratio in the two bottoms

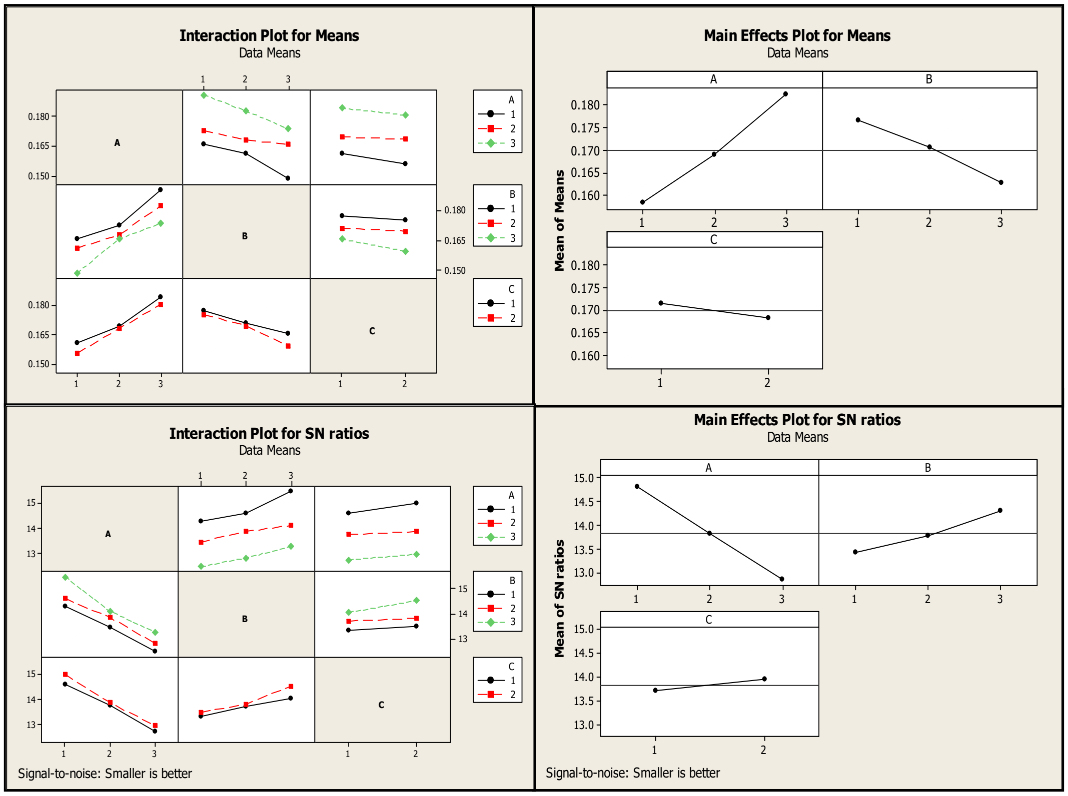


Figure 9. Taguchi analysis when smaller is better; Main Effects and Interaction plots for Means in the top and for S/N ratio in the two bottoms

The A-B interaction lines are not parallel indicating moderate interaction. While both A-C and B-C interaction lines are almost parallel refer to weak interaction. For means the lower means are better for that reason the best performance in A1, B3, C2 (because A1 and B3 minimize the mean). However, for lowest S/N ratio, the A3, B1, C1 is better at robustness.
Figure (10) contains Taguchi analysis plots when nominal is better for the responses, non-reducing sugar and moisture content. The top two plots are for Means while the bottom two plots are Signal-to-Noise (S/N) Ratios

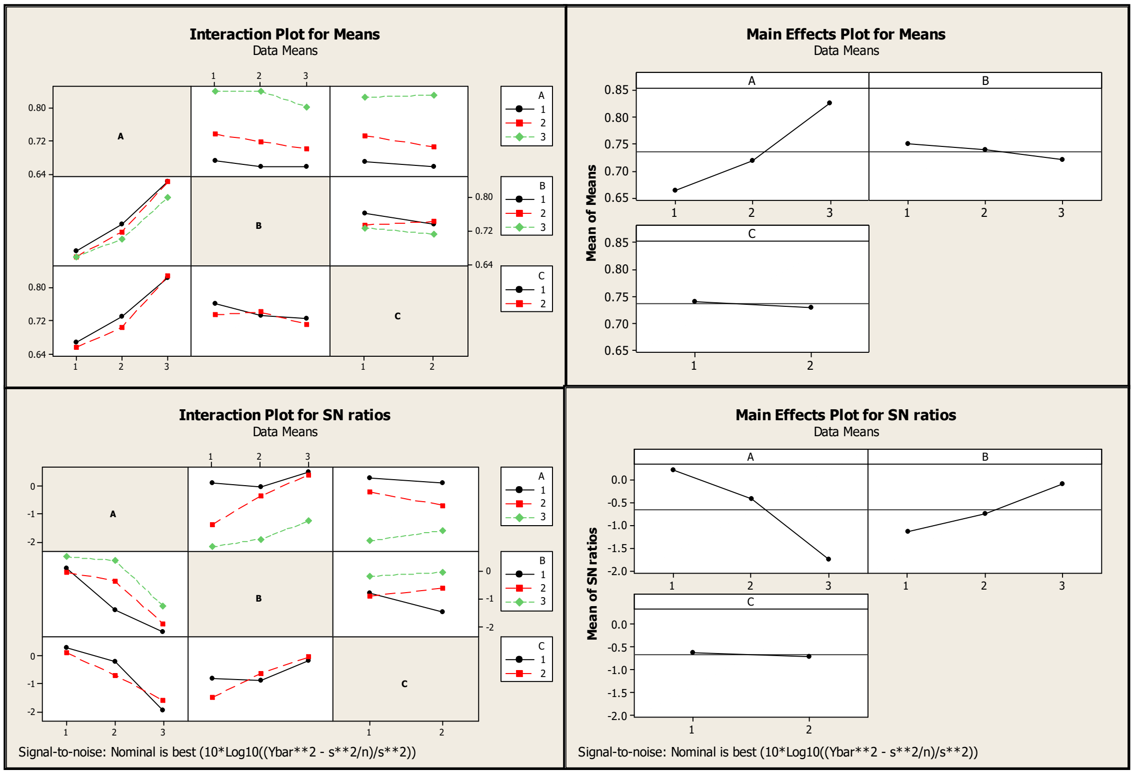


Figure 10. Taguchi analysis when nominal is better; Main Effects and Interaction plots for Means in the top and for S/N ratio in the two bottoms

The (A) factor has large positive slope and A3 has the highest mean (0.83), while A1 is the lowest (0.67). Factor B has negative slope and B1 has the highest (0.75) and B3 is lowest (0.72). Factor C is almost flat which has very little effect on the mean.
A-B interaction clearly has lines diverge strongly. While A-C has small effect and B-C is almost flat. Factor A strongly influences both means and S/N ratio, but in opposite ways; means trend upward (Level 3 highest), but S/N ratio trend downward (Level 1 best). Factor B has small effect on means, noticeable on S/N (Level 3 better). Factor C has negligible effect.

Based on the results of Figures (1, 2, 3, 4, 5, 6, 7, 8, 9 and 10) significant differences were observed when pollinating date palms with Red Ghannami pollen. This effect can be attributed to the ability of this pollen source to improve the qualitative and chemical traits of the Khastawi cultivar, as it increased the fruit set percentage, which in turn enhances the yield per palm (Aubied and Hamzah, 2019). The growth, development, and improvement of fruit characteristics are positively reflected in increasing productivity and farmers' income (Zubaidy and Al Mousawi, 2022). Therefore, selecting pollen sources that provide abundant pollen grains, such as the Red Ghannami cultivar, which exhibit high viability and efficiency in fertilization and fruit set, is crucial due to their impact on fruit quality traits, Such care should be given equal importance as that of female palms, considering the vital role of pollen grains in influencing both seeds and fruits of the date palm (Khierallah et al., 2017; Salomón-Torres et al., 2021). The significant impact of the traditional hand pollination method using male spadices lies in ensuring full distribution of pollen grains across the female inflorescence by the farmer, which consequently increases fruit set, reduces fruit drop, and leads to significant improvements in both quality and productivity. This superiority is most likely attributed to the distinctive biological and physiological characteristics of the Red Ghanami pollen grains, which may include higher pollen viability and greater germination capacity, in addition to their sexual compatibility with the female cultivar used in the experiment, as well as the metaxenia effect (Soliman et al., 2017 ; Abu-Zahra and Shatnawi, 2019). From a physiological perspective, the rapidly growing pollen tube secretes enzymes such as pectinase and cellulase, which facilitate the penetration of stigma tissues and enable more efficient access to the embryo sac, This process reduces the loss of unfertilized flowers and leads to the formation of strong embryos and well-developed seeds, which constitute the physiological basis for continued fruit growth without abscission (Zarei et al., 2013). Repeated pollination further guarantees the complete coverage of all female flowers of the spadix, thereby ensuring increased production through higher fruit set and reduced fruit drop (Iqbal et al., 2018). The traditional pollination method is characterized by providing sufficient and uniform quantities of pollen that are distributed directly among the flowers of the female spathe. Each male strand contains a large number of flowers and pollen grains, ensuring wider coverage of the receptive stigmatic surface. This reduces the likelihood of unpollinated flowers and increases the chances of complete fertilization. When the stigmas are exposed to abundant fresh pollen, pollen germination percentage becomes very high, pollen tubes rapidly reach the embryo sac, and the number of fertilized flowers increases, which is reflected in a higher fruit set percentage (Ali-Dinar et al., 2021). The benefits of integrating these three factors selection of the most suitable pollen source, appropriate pollination method, and repetition of pollination—lie in their effective role in enhancing the efficiency of pollination in Khastawi date palms. This leads to achieving the highest quality fruits (Al-Janaby, 2018). Repeating the pollination process twice instead of once contributed significantly to increasing the fruit set percentage and reducing fruit drop. This confirms the importance of proper pollination timing and consideration of the maturity stage of female flowers, as flowers within the inflorescence do not all mature simultaneously. Consequently, repeated pollination ensures wider coverage of mature flowers at an appropriate time for fertilization. In addition, some pollen grains may not remain viable for extended periods; therefore, repeated pollination compensates for potential losses or damage that may occur during the first pollination application. Moreover, repetition helps offset the loss of pollen viability during the initial pollination due to adverse environmental conditions such as high temperature or humidity (Shakir and Abood, 2023) The findings of this study are in agreement with those reported by (Jameela and Alagirisamy, 2021), (Ashmawy, 2023), (Abed and Abed-Alazeez, 2020) and (Shafique et al., 2011).

Conclusion

Pollen source is the dominant influence on outcomes where it consistently shows the largest impact on both means and S/N ratios. In practical terms, prioritizing the level of (A) will yield the biggest gains (or losses) in the measured quality characteristics, regardless of whether you are optimizing for larger-is-better, smaller-is-better, or nominal-is-best objectives. Pollination treatment method has a noticeable but smaller effect and the replication number is the least influential. This suggests a design focus on pollen source (primary) with pollination treatment method as a secondary tuning factor, while replication number can be given lower priority or fixed at a level that simplifies experimentation. Significant interactions between pollen source and Pollination treatment method, and between pollen source and replication number. Optimization cannot consider A in isolation; the best level for pollen source depends on the level chosen for pollination treatment method (and to a lesser extent replication number).

References

Abed, U. H. K., & Abed-Alazeez, A. A. (2020). The effect of pollen type on some fruit traits and production quantity of date palm trees (*Phoenix dactylifera* L.) cultivar Al-Ibrahimi. *Indian Journal of Forensic Medicine and Toxicology, 14*(4), 1551–1555.

Abu-Zahra, T. R., & Shatnawi, M. A. (2019). New pollination technique in date palm (*Phoenix dactylifera* L.) cvs. Barhee and Medjool under Jordan Valley conditions. *American-Eurasian Journal of Agricultural & Environmental Sciences, 19*, 37–42.

Ahmed, A. A., Badran, M. A. F., & Gaber, S. H. (2021). Impact of different times and methods of pollination on fruit set and productivity of Barhi date palm. *Assiut Journal of Agricultural Sciences, 52*(5), 104–112.

Ahmed, Z. F. R., Alyafei, M. A. S., Al Dakheel, A., & Almoosa, M. (2022). Artificial pollination of date palm (*Phoenix dactylifera* L.) using a platform-mounted robotic pollination system (drone). In E. Ortega & E. Costes (Eds.), *Acta Horticulturae* (pp. 299–306). International Society for Horticultural Science.

Alashaibi, N. (2023). Comparative study between natural and manual pollination of date palm (*Phoenix dactylifera* L.): An applied practical lesson using technology to improve education quality. *International Journal of Educational Sciences and Arts, 2*(9).

Al-Bakr, A. J. (1972). *The date palm: Its past, present, and new developments in its cultivation, industry, and trade*. Al-Ani Press.

Al-Janaby, Z. A. B. (2018). *Effect of number of male spadices, time, and frequency of pollination on productivity of date palm cv. Khayara* (Master's thesis). College of Agriculture, University of Anbar, Iraq.

Ali-Dinar, H., Mohammed, M., & Munir, M. (2021). Effects of pollination interventions, plant age, and pollen source on hormonal patterns and fruit set of date palm (*Phoenix dactylifera* L.). *Horticulturae, 7*(11), 427. https://doi.org/10.3390/horticulturae7110427

Al-Muhammadi, S. M., & Al-Muhammadi, F. M. (2012). *Statistics and experimental design*. Osama Publishing and Distribution House.

Al-Shujairi, T. A., Rawdan, S. A., Salman, M. R., & Hammoudi, H. N. (2015). Comparison between hand and mechanical pollination methods and effect of pollen source on fruit traits of date palm cv. Khastawi. *Iraqi Journal of Agricultural Sciences, 46*(6), 1069–1075.

Ashmawy, E. M. (2023). Effect of pollination time and daytime hours on fruit set and production of Seewy date palm cultivar. *New Valley Journal of Agricultural Science, 3*(10).

Aubied, I. A., Al-Janabi, A. M. I., & Alkhafaji, Z. A. H. (2023). Effect of NPK fertilization and leaf/bunch ratio on fruit yield and quality of Khastawi date palm. *SABRAO Journal of Breeding and Genetics, 55*(4), 1443–1450. https://doi.org/10.54910/sabrao2023.55.4.18

Aubied, I. A., & Hamzah, H. A. (2019). Effect of pollen grains and growth regulator NAA on fruit characteristics of date palm (*Phoenix dactylifera* L.) cv. Sultani. *Al-Qadisiyah Journal for Agriculture Sciences, 9*(1), 136–142.

Benchilo, B., Roja, K., & Agastian, P. (2024). A review on phytochemistry of *Phoenix dactylifera* L. fruits and seeds. *World News of Natural Sciences, 52*, 23–33.

El-Rauof, F. A. (2021). Effect of different pollination techniques on fruit set, fruit quality, and yield of Barhi date palm cultivar. *Egyptian International Journal of Palms, 1*(2), 34–42.

Fayyad, A. (2017). A new technology for date palm pollinators in Qatari farms. *Publications of the Plant Research Department*, Al-Watan Newspaper. http://www.al-watan.com

Hamood, H. H. (1984). *Effect of different insemination methods on fruit set and retention of date palm cv. Zuhdi* (Master's thesis). College of Agriculture, University of Baghdad, Iraq. (In Arabic)

Homed, A. T. (2020). Effect of pollen source on some chemical characteristics of date palm (*Phoenix dactylifera* L.) cv. Al-Maktoum. *Plant Archives, 20*(1), 270–273.

Iqbal, M., Usman, K., Munir, M., & Khan, M. S. (2018). Quantitative and qualitative characteristics of date palm cv. Gulistan in response to pollination times. *Sarhad Journal of Agriculture, 34*(1), 40–46. https://doi.org/10.17582/journal.sja/2018/34.1.40.46

Jameela, R. V., & Alagirisamy, M. (2021). Effect of mechanical (dry and wet) pollination of date palms on cultivar Naghal in Oman. In *2021 International Conference on Information and Communication Technology Convergence (ICTC)* (pp. 967–972). IEEE. https://doi.org/10.1109/ICTC52510.2021.9621025

Jaskani, M. J., Ahmad, I., Nafees, M., Alafari, H. A., Fiaz, S., Fatima, S., & Uzair, M. (2023). Effects of hybridization and metaxenia on biochemical and molecular attributes of date palm (*Phoenix dactylifera* L.) cv. Hillawi. *Turkish Journal of Agriculture and Forestry, 47*(4). https://doi.org/10.55730/1300-011X.3073

Joslyn, M. A. (1970). *Methods in food analysis: Physical, chemical and instrumental methods* (2nd ed.). Academic Press.

Kadri, K., Ahmed, O., Souhaila, M., Mohamed, S. C., Abdelhamid, C., & Amani, T. (2019). Effect of pollination mode on fruit set and yield of date palm (*Phoenix dactylifera* L.) in Tozeur oases, Tunisia. *International Journal of Agricultural Innovation and Research, 7*, 533–537.

Khierallah, H. S. M., Abood, M. R., & Al-Rawi, T. K. (2017). Sex identification of date palm using DNA molecular markers. *Iraqi Journal of Agricultural Sciences, 48*(5), 1197–1205.

Salomón-Torres, R., Krueger, R., Garcia-Vazquez, J. P., Villa-Angulo, R., Villa-Angulo, C., Ortiz-Uribe, N., & Samaniego-Sandoval, L. (2021). Date palm pollen: Features, production, extraction, and pollination methods. *Agronomy, 11*(3), 504. https://doi.org/10.3390/agronomy11030504

Shaaban, M. M., Ahmed, E. F. S., & El-Akkad, M. M. (2019). Improvement of date palm productivity using different pollination methods and fruit thinning levels. *Journal of Plant Production, 10*(4), 373–377. https://doi.org/10.21608/jpp.2019.38646

Shafique, M. U., Khan, A. S., Malik, A. U., Shahid, M. U., Rajwana, I. A., Saleem, B. A., & Ahmad, I. (2011). Influence of pollen source and pollination frequency on fruit drop, yield, and quality of date palm (*Phoenix dactylifera* L.) cv. Dhakki. *Pakistan Journal of Botany, 43*(2), 831–839.

Shakir, M. A., & Abood, M. R. (2023). Effect of pollinator, number of pollination times, and organic fertilizer on leaf mineral content and yield of Barhi date palm. *IOP Conference Series: Earth and Environmental Science, 1262*(4), 042039. https://doi.org/10.1088/1755-1315/1262/4/042039

Sharma, K. M., Muralidharan, C. M., Baidiyavadra, D. A., & Panchal, C. N. (2019). Effect of different pollination times on date palm (*Phoenix dactylifera* L.) cv. Barhee. *(Conference proceedings)*, 1568–1570.

Soliman, S. S., Alebidi, A. I., Al-Saif, A. M., Al-Obeed, R. S., & Al-Bahelly, A. N. (2017). Impact of pollination by pollen-grain-water suspension spray on yield and fruit quality of Segea date palm (*Phoenix dactylifera* L.). *Pakistan Journal of Botany, 49*, 119–123.

Ullah, M., Ahmad, F., Iqbal, J., Imtiaz, M., & Raza, M. K. (2018). Effects of different pollination methods on fruit quality and yield of date palm candidate line Hillawi. *Journal of Environmental and Agricultural Sciences, 17*, 55–62.

Zarei, M., Safari, H., & Rad, B. (2013). Influence of pollen source on fruit production of date palm (*Phoenix dactylifera* L.) cv. Barhi in humid coastal regions of southern Iran. *Scientia Horticulturae, 160*, 182–188. https://doi.org/10.1016/j.scienta.2013.06.014

Zheng, J., & Xia, R. (2022). Flower development and sex determination in horticultural crops. *Fruit Research, 2*(1), 1–9. https://doi.org/10.48130/FR-2022-0001

Zubaidy, B. H. F. A., & Al-Mousawi, S. J. K. (2022). Effect of Gorogreen five fructus and pollen cultivar on physical and chemical properties of date palm fruits (*Phoenix dactylifera* L.) cv. Barhi derived from tissue culture. *University of Thi-Qar Journal of Agricultural Research, 11*(1), 102–110.