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RESEARCH PAPER

Influence of pollination in liquid suspension on the date palm (*Phoenix dactylifera* L.) Mejhoul cultivar in the Mexicali valley, Mexico

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Abstract

The pollination process is one of the most important contributors to a successful date production since the yield and quality of the fruit depends on its correct successful. Liquid pollination in the date palm production is a recently used technique that seeks to obtain acceptable fruit set percentages (FSP) with lower pollen consumption. In this study, during the 2021 and 2022 growing seasons, the effect of pollination with pollen grains in liquid suspension on the FSP in the date palm cultivar 'Mejhoul' was evaluated in the Mexicali Valley, Mexico. The applications were in various proportions of pollen in liquid suspension (1, 2, 3 and 4 g/L), with approximately 40 mL on each inflorescence. The results revealed that the best treatment was 4 g/L with an average FSP of 67.89 and 68.69% for the years 2021 and 2022 respectively, while the control treatment obtained 54.94 and 57.75%, for the same years. Likewise, this method did not affect the physical and chemical properties and yields. Finally, this study suggests that in addition to consuming a smaller amount of pollen, this method has better pollination efficiency.

Keywords

Artificial pollination, Date palm pollen, Fruit set, Liquid suspension pollen, Liquid pollination, *Phoenix dactylifera* L.

Introduction

Pollen from any male date palm (*Phoenix dactylifera* L.) can germinate in any recipient female date palm cultivar (Salomón-Torres et al. 2022). This is very important in the pollination process, since pollen viability and pollination method influences the quality, development, and yield of the fruit (Awad 2010b).

Pollination in the date palm occurs naturally due to the action of the wind, but for commercial date production, it is necessary to carry it out artificially (Abu-Zahra and Shatnawi 2019). Artificial pollination allows more precise and controlled pollination, promoting high fruit set percentages. Over the centuries, artificial pollination methods have evolved from manual application to the use of different types of tools to automation, using drones and robotic pollinator arms (Salomón-Torres et al. 2021).

The oldest method of manual pollination is to place strands of male inflorescences between the strands of female inflorescences (Zaid and Arias-Jimenez 2002).

This method is highly effective; however, it requires more work, since it depends on the worker's skills and consumes a greater amount of pollen than other methods. Some manual pollination methods are based on the use of a squeeze bulb (Ortiz-Uribe et al. 2019), plastic bottles (Salomón-Torres et al. 2021), small insecticide dusters (Nixon 1966), cloth bags (Food and Tools 2016), cotton pieces (Zaid and Arias-Jimenez 2002), and sponge strips (Abdallah et al. 2014).

Among the devices used for date palm pollination, mechanical, motorized, and even electric sprinklers have been developed (El-Mardi et al. 1995; Hajian 2005; Mostaan et al. 2010; Al-Wusaibai et al. 2012; Ullah et al. 2018; AGROM 2023). These devices generate air pressure inside through a mechanical action, expelling the pollen from its container through a tube or a small hose. For a time, aircraft were used for pollination in the USA, but they stopped being used due to their high operating cost and excessive quantities of pollen being necessary (Zaid and Arias-Jimenez 2002). Finally, a robotic arm controlled by artificial intelligence has been developed for pollination with dry pollen, which uses a camera to identify the inflorescence size and calculate the amount of pollen to use (Shapiro et al. 2008).

All these artificial pollination methods seek greater efficiency and optimization of the consumption of dry pollen, which depending on the date palm cultivar to be pollinated, is commonly diluted in various proportions with wheat flour, talc, and remains of ground bunches of dates, or other inert filler agents (Hajian 2005; Ullah et al. 2018). Mixing proportions may vary according to the convenience and technique applied by the farmer (Salomón-Torres et al. 2021).

Recently, pollination with pollen grains in liquid suspension has been widely promoted due it resulting in higher fruit set percentage, higher yields and fruit quality in the fruit, while using less pollen compared to traditional pollination methods (Kumawat et al. 2022). This can be applied with a manual sprayer or through a pressurized water suspension mechanism. Likewise, liquid pollination using fumigating drones on various cultivars such as 'Barhi', 'Lulu', and 'Khesab', are currently being developed in United Arab Emirates with excellent results (Alyafei et al. 2022). The proportion of pollen to water can vary from 0.5 to 4 g of pollen per L of water and up to 100 mL of liquid sprayed, can be applied to each inflorescence depending on its size (Awad 2010b; Abu-Zahra and Shatnawi 2019). Likewise, in order to contribute to a better fruit set percentage, the liquid suspension can be supplemented with other elements, such as 10% sucrose or 20 ppm GA_3, among others (Iqbal et al. 2010).

In Mexico, the main cultivated date palm cultivar is the 'Mejhoul' date (94%), with a production of 19,128 tons in 2021. Mexican farmers mostly pollinate the date palm with dry pollen manually using a squeeze bulb, mixing the pollen with wheat flour in various proportions (Ortiz-Uribe et al. 2019). The objective of this study was to identify the effect of the proportion of pollen in liquid suspension on percentage of fruit set, the physical characteristics of the fruit, and yield on the 'Mejhoul' cultivar, grown under the agroclimatic conditions of the Mexicali Valley, Mexico.

Materials and methods

Characterization of the experimental area

The present study was carried out in a date plantation located in the Jiquilpan Ejido (32°31'17"N, 115°4'17"W (DMS)), in the Mexicali Valley, in Northwestern Mexico (Fig. 1). The orchard has organic certification in a planted area of 35 ha, with the soil being predominantly clay with a small sandy area. The palms were planted with 8 × 8 m spacing between and within rows. Irrigation is by gravity, distributed in eight cycles of 15 cm each during the year.

Plant materials, treatments and pollination

The pollen used for this study was extracted from vigorous 20-year-old male palms growing in the local area. All spathes were removed from each tree as they matured,

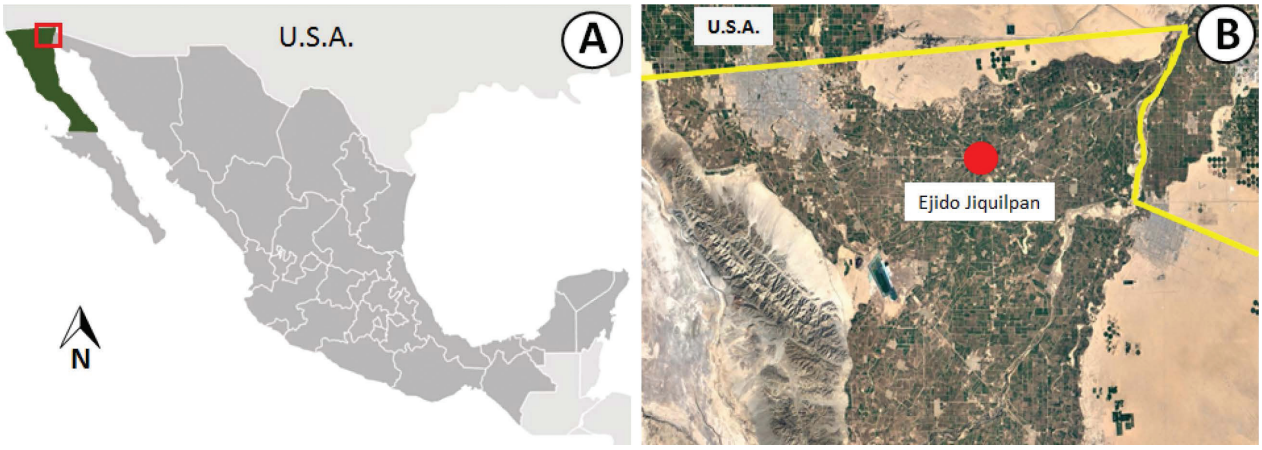

Figure 1. Main date production area in Mexico. **A)** The Mexicali Valley, one of the largest date producing areas in Mexico. **B)** Geographic location of the Jiquilpan Ejido, in the Mexicali Valley (Map data 2023 © Google).

and then transported to a drying area free of moisture, where the spathes were separated from the inflorescences. Each inflorescence was placed on a bed of paper in a plastic tray for final drying and release of pollen grains. Once the inflorescence was completely dry, it was shaken over a container, and all the flowers were separated manually. Finally, the contents of the container, together with the pollen released on the paper bed, were manually passed through a fine mesh, to obtain completely clean and pure pollen, which was stored at 4 °C until its use (Salomón-Torres et al. 2022).

During the 2021 and 2022 agricultural cycles, ten 21-year-old female 'Mejhoul' date palms were randomly selected. Twelve inflorescences on each palm were selected to be pollinated individually only once, with one treatment applied to all inflorescences on an individual palm. After the natural cracking of the female spathes, each was manually opened and covered with paper bags before and after pollination to avoid contamination with other pollen sources. The pollination process was carried out between the 3rd and 5th days after the spathes were opened.

Five treatments were applied (Table 1). Four of them consisted of the pollen-water suspension in proportions of 1, 2, 3 and 4 g pollen/L of well water (liquid pollination). The last treatment consisted of the traditional farmer's pollination method, which mixes the fresh pollen source in a 1:1 ratio with commercial wheat flour (dry pollination) (Salomón-Torres et al. 2020). Each of the five treatments was applied to all 12 inflorescences of two palms.

Table 1. Description of the five treatments used in this study.

Palm	Treatment	Description
P1, P2	T1	1 g pollen + 1 L water
P3, P4	T2	2 g pollen + 1 L water
P5, P6	T3	3 g pollen + 1 L water
P7, P8	T4	4 g pollen + 1 L water
P9, P10	T5	65 g dry pollen + 65 g wheat flour

For liquid pollination (P1–P8), pollen grains were suspended in water directly before starting the process. The spraying on the inflorescences was carried out using a manual hand sprayer with a capacity of one liter, which was shaken each time to maintain the pollen suspended in the water (Fig. 2A). Each pollinated inflorescence received approximately 40 mL of the suspension, ensuring that the entire inflorescence was completely covered with the liquid mixture (Fig. 2B).

Dry pollination (P9–P10) was carried out manually using a squeeze bulb, which is commonly filled with 65 g of dry pollen and 65 g of wheat flour (Salomón-Torres et al. 2021). Depending on the size of the inflorescence, it received two to three sprays of the dry pollen mixture, resulting in an average of 1.3 g of pollen per inflorescence being applied. Inflorescences pollinated by this method were not covered with paper bags, in accordance with the traditional local method. The pollinations extended for four weeks, according to the maturation of the female inflorescences.

Assessment of some parameters in the water

In order to identify the characteristics of the well water used for pollination, some parameters were characterized, such as minerals dissolved in the water (ppm), temperature (°C), electrical conductivity (dS/m), and pH. For this, a Multi-Parameter Pocket Tester (Apera Instruments PC60 Premium 5-in-1Waterproof) was used, which was calibrated for use according to the manufacturer's instructions. (APERA-Instruments 2023).

Fruit set percentage measurements

Six weeks after pollination, ten strands from each bunch on each palm were selected. The total number of fruit positions and the total number of set fruit were counted in each strand. The fruit set percentage (FSP) was calculated using the following equation:

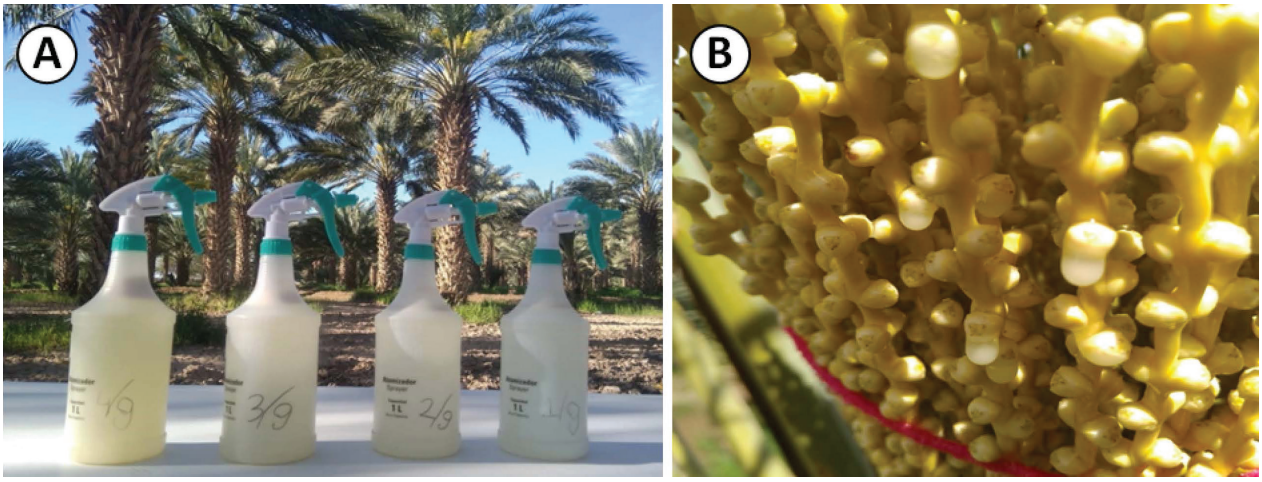

Figure 2. Liquid pollination. **A)** Manual sprayers with each of the treatments used. **B)** Appearance of the female 'Mejhoul' inflorescence after spraying pollen in liquid suspension.

$$FSP = \frac{total\ fruit\ set}{total\ fruit\ positions}\ x\ 100$$

After calculating the FSP, an average of 70 strands were left on each bunch, with 12 to 14 dates per strand. All trees received the same agricultural management according to the farmer's practices.

Fruit and bunch weight and yield per palm

The harvest of fruits for each year was carried out in two rounds during the tamar stage. From the first harvest, ten fruits were taken from each bunch to measure their weight (g) and dimensions (cm), using electronic scales for the weight. The total yield per palm (kg/palm) was calculated by the total sum of the weight of each bunch, while the yield per bunch (kg/bunch) was the average weight of the twelve bunches in each palm.

Statistical design and analysis

For each parameter, the collected data were statistically analyzed in a balanced design using a one-way ANOVA test. A completely randomized design was used. The analysis of variance was calculated with R Statistical Software version 4.2.0 (R Core Team) (R Core Team 2019). In order to avoid a type I error, a multiple comparison of means was carried out using the least significant differences (LSD), which provides a test of differences in pairs of data between groups of means, where a level of 5% significance was used (Steel and Torrie 1980).

Results and discussion

Characterization of the water used

Dissolved mineral concentrations, temperature, and electrical conductivity increased significantly when date pollen was suspended in well water. This could be due to the properties of the pollen, such as its mineral content that increased the ppm in the water and increased its electrical conductivity. Likewise, the temperature of the water increased, because the well was cool and the pollen was stored at room temperature. However, the pH remained stable after adding the pollen to the water (Table 2).

Table 2. Characterization of well water used for liquid pollination before and after mixing with fresh date pollen (pooled data from the 2021 and 2022 pollination seasons).

Solution	Minerals dissolved in water (ppm)	Temperature (°C)	Electric Conductivity (dS/m)	pH
Water	234.00 ± 58.51	17.4 ± 6.29	481.6 ± 88.42	7.07 ± 0.50
Water with pollen	337.20 ± 42.83	24.04 ± 5.33	650 ± 100.33	7.00 ± 0.29

Values are averages ± SD of 30 measurements for each solution.

Fruit set percentage

Table 3 shows that for the 2021 harvest season, the pollen in liquid suspension at a concentration of 4 g/L (T4) represented the highest statistically significant FSP with 65.69 and 70.10% for P7 and P8, respectively, with average of 67.89%. Likewise, the lowest FSP was obtained by applying 1 g/L (T1) with 39.98 and 44.58% for P1 and P2 respectively, with an average of 42.28%. Regarding the control treatment (T5), the result does not differ statistically from that of T3.

Results were similar for the 2022 harvest season. The liquid suspension of pollen grains in water in a proportion of 4 g/L (T4) resulted the highest statistically significant FSP with 69.50 and 67.89% for P7 and P8, respectively, with average of 68.69%. The lowest FSP was obtained for T1 with 46.74 and 43.65% for P1 and P2, respectively, with an average of 45.19%. Regarding the control treatment (T5), the result does not differ statistically from that of T3.

Table 3. Results obtained from liquid pollination in two recipient 'Mejhoul' date palms for each treatment in the 2021 and 2022 seasons.

Treatment	Palm	Fruit Set Percentage			
		2021	Average	2022	Average
T1	P1	39.98 ± 12.71f	42.28%	46.74 ± 10.47cd	45.19%
	P2	44.58 ± 14.69ef		43.65 ± 9.56d	
T2	P3	55.52 ± 11.15d	51.52%	54.10 ± 12.16bc	52.25%
	P4	47.53 ± 12.42e		50.41 ± 9.11cd	
T3	P5	62.46 ± 10.51bc	60.22%	58.17 ± 9.28b	58.36%
	P6	57.99 ± 16.10cd		58.55 ± 13.31b	
T4	P7	65.69 ± 9.77ab	67.89%	69.50 ± 10.97a	68.69%
	P8	70.10 ± 5.02a		67.89 ± 9.20a	
T5	P9	57.52 ± 14.24cd	54.94%	58.74 ± 10.55b	57.75%
	P10	52.37 ± 12.45d		56.77 ± 12.05b	

Values are averages ± SD of 120 measurements for each treatment per year. The averages with the same letter indicate no significant difference between treatments, with a probability level of 0.05.

Fig. 3 shows the average results of the FSP, with their respective comparison of means among the five treatments (ANOVA), for the 2021 and 2022 growing seasons. The least significant differences (LSD) adjustment test revealed that T4 resulted in the highest and most statistically significant average compared to the rest of the treatments. Likewise, T1 resulted in the lowest average FSP, which was statistically significantly lower than all the rest of the treatments. Finally, the control treatment (T5) was statistically equal to T3. This last suggests that they could replace the traditional pollination treatment of dry pollen mixed with flour. Our findings indicated that a high FSP is associated with the highest pollen concentration in liquid suspension.

Similar studies to this work have reported an average FSP for two years of 74.67 and 72.5% (1 g pollen/L), 79.67

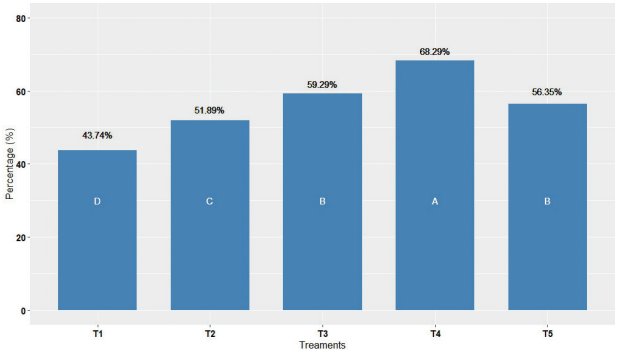

Figure 3. Results of the ANOVA test with a multiple comparison of means (LSD), on the fruit set percentage (FSP) obtained from the treatments with liquid pollination and the control treatment. Values are averages of 240 measurements for each treatment. The averages with the same letter present no significant difference between treatments, with a probability level of 0.05.

and 81.00% (2 g pollen/L), 84.5 and 81% (3 g pollen/L), and 86 and 91.5% (4 g pollen/L) using 100 mL of suspension for each bunch (Abu-Zahra and Shatnawi 2019; Munir 2020). In our study, averaged over two years, 43.74% (1 g pollen/L), 51.89% (2 g pollen/L), 59.29% (3 g pollen/L) and 68.29% (4 g pollen/L) were obtained, with FSP being lower than those reported previously (Abu-Zahra and Shatnawi 2019; Munir 2020). This may have been because the amount of suspension used in this study to pollinate date palms was only 40 mL for each bunch. However, the FSP obtained are very acceptable for the 'Mejhoul' cultivar, because any of the four treatments will require bunch thinning. Likewise, T4 turned out to be superior statistically significantly to the control treatment (T5), having a higher FSP while using a smaller amount of pollen for each bunch.

One of the characteristics of the cultivation of the 'Mejhoul' date cultivar, is that bunch thinning must be carried out to increase the size and weight of the fruit, depending on the level of FSP. This process consists of leaving 50 to 70 strands per bunch and 8 to 14 dates per strand, depending on the size of the bunch and the length of the strands (Zaid and Oihabi 2022). Having FSP above 60% in 'Mejhoul' is very acceptable, but represents a lot of additional work for farmers when investing in labor for bunch thinning. Likewise, the bunch thinning process could be replaced by identifying the appropriate reduction in pollen concentration in the suspension (Al-Wasfy 2014). The farmer's selection of a proportion such as T1 or T2 could save labor costs for bunch thinning in cultivars such as 'Mejhoul'. Therefore, the treatment providing the best FSP is not necessarily the most appropriate for the date producers mainly those dealing with 'Mejhoul' cultivar.

Some physical properties of the fruit and yields

The physical properties of the date cultivar 'Mejhoul' associated with the pollination treatments are shown in Table 4. The results reveal that statistically significant differences were only obtained for T4 in 2021 for weight and length. However, the significant differences are not large in absolute terms. The parameters evaluated for the rest of the treatments in 2021 and 2022 did not have statistically significant differences. This suggests that the liquid pollination method, does not negatively affect fruit growth and achieves similar physical characteristics to the traditional pollination method (T5). This may be explained by the fact that the fruit quality, depends essentially of the agricultural practices implemented by farmers during the date production cycle.

Likewise, other studies have reported that liquid pollination in the date palm does not have secondary effects on the physical quality characteristics of the fruit, nor does it decrease the concentrations of its chemical constituents (Awad 2010b; Al-Wasfy 2014; Radwan et al. 2022). Others have confirmed that the addition of some components to the pollen-water mixture, such as ascorbic acid or sugar, increased the yield and improved the physical and chemical properties of the fruit (Samouni et al. 2016; El-Sharabasy et al. 2020; El-Salhy et al. 2021; Radwan et al. 2022).

The influence of pollination with pollen grains in liquid suspension compared to dry pollen mixed with wheat flour, on yield per bunch and yield per palm are shown in Table 5. The results reveal that there were no statistically significant differences between the treatments on yield per bunch and yield per palm. The results show there was only a statistically significant difference, for the yield per bunch for T1 as the lowest and for T2 as the highest, for the year 2022. For the data corresponding to yield per palm, only the averages are shown without ANOVA test due to the low number of individuals, T2 being the treatment that

Table 4. Effects obtained from liquid pollination for each treatment in some physical properties of the 'Mejhoul' fruit for the 2021 and 2022 harvest seasons.

Treatment	Weight		Length		Diameter	
	2021	2022	2021	2022	2021	2022
T1	20.14 ± 3.63b	19.06 ± 3.94a	4.41 ± 0.39b	4.19 ± 0.48b	2.51 ± 0.21ab	2.53 ± 0.31ab
T2	19.45 ± 3.12b	20.35 ± 3.95a	4.37 ± 0.43b	4.46 ± 0.40a	2.62 ± 0.26a	2.63 ± 0.23a
T3	20.96 ± 3.49ab	18.47 ± 3.37a	4.42 ± 0.34b	4.31 ± 0.28ab	2.44 ± 0.24b	2.43 ± 0.24b
T4	22.47 ± 2.73a	20.35 ± 3.71a	4.77 ± 0.30a	4.46 ± 0.22a	2.65 ± 0.23a	2.51 ± 0.13ab
T5	19.45 ± 2.66b	20.01 ± 3.14a	4.26 ± 0.26b	4.49 ± 0.37a	2.65 ± 0.28a	2.59 ± 0.28a

Values are averages ± SD of 240 measurements for each treatment. The averages with the same letter present no significant difference between treatments, with a probability level of 0.05.

presented the highest yields. This suggests that the liquid pollination method does not negatively affect fruit production, as it has similar production characteristics as the traditional pollination method (T5).

Table 5. Effects obtained from liquid pollination for each treatment in relation to the average yield per bunch and per palm for the 2021 and 2022 harvest seasons.

Treatment	Yield/Bunch		Yield/Palm	
	2021	2022	2021	2022
T1	8.95 ± 2.26a	7.51 ± 1.15b	127.04 ± 9.25	125.06 ± 12.64
T2	9.50 ± 2.49a	12.74 ± 3.46a	131.54 ± 10.62	129.38 ± 14.06
T3	11.82 ± 1.38a	10.70 ± 2.56ab	95.73 ± 8.97	111.05 ± 10.23
T4	11.73 ± 0.65a	11.58 ± 1.61ab	131.08 ± 9.75	103.63 ± 10.09
T5	10.31 ± 2.73a	11.91 ± 3.96ab	96.40 ± 8.55	126.44 ± 13.49

Values in yield/bunch are averages ± SD of six measurements for each treatment. The averages with the same letter present no significant difference between treatments, with a probability level of 0.05.

Pollination using a suspension of pollen grains or liquid pollination, using a manual sprinkler, has demonstrated its effectiveness under the agroclimatic conditions of Egypt, Saudi Arabia, Pakistan, and Jordan in cultivars such as 'Barhi', 'Mejhoul', 'Khadrawy', 'Zahidi', 'Khenazy', 'Khalas' and 'Zaghloul' (Awad 2010a; Abbès et al. 2011; Abdalla et al. 2011; Adeosun et al. 2016; Adenekan et al. 2018). Recently, a study evaluated the effectiveness liquid pollination using a fumigator drone adapted for this purpose on the date cultivars 'Barhi', 'Lulu' and 'Khesab' (Alyafei et al. 2022). The results revealed that the FSP and fruit retention were slightly superior to traditional pollination methods and were commercially acceptable, so this modern method could become a potential pollination alternative.

One of the great advantages of adopting the liquid pollination method is the large amount of pollen saved. For this experiment each squeeze bulb contains 65 g of dry pollen, diluted in a 1:1 ratio with 65g of commercial wheat flour. Each squeeze bulb can pollinate up to 50 inflorescences, for an average pollen consumption of 1.3 g per inflorescence. Under this method, pollen production from 1.5 male palms is required to pollinate up to 50 'Mejhoul' female palms, if each has 18 inflorescences per palm. This represents a consumption of 1.17 kg of pollen, while with the liquid suspension method with a proportion of 4 g of pollen per L of water, it represents a consumption of only 360 g (Salomón-Torres et al. 2021).

Conclusions

The present study evaluated the effect of liquid pollination on the date palm cultivar 'Mejhoul' under the agroclimatic conditions of northwest Mexico. The results suggest that liquid pollination consumes a lower amount of pollen, it does not decrease the quality parameters of the fruit, such as weight and size. Additionally, no changes in color or excessive peeling of the skin were observed in the fruit, so it does not present any negative effect on the fruit. For these reasons, its use could be more effective than the traditional pollination method. Finally, the proportion of pollen in the liquid suspension must be selected by each farmer, depending on their bunch thinning needs and the age of the plant.

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Authors' contributions

Salomón-Torres, R: Conducted the research work and manuscript writing; Acosta-Perez, J.A: Carry out the field work. Krueger, R.R: Writing, review and editing of the manuscript. Gutiérrez-Pacheco, M.M: Writing, review and editing of the manuscript. Ruisanchez-Ortega, Y: Carry out the field work. Oihabi, A: Guidance and evaluation of the manuscript Abul-Soad, A.A: Guidance and correction of the manuscript. Zaid, A: Guidance and correction of the manuscript. All authors have read and agreed to the published version of the manuscript.

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Competing interests

The authors have declared that no competing interests exist.

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