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Evaluation of Pollen Production of Common Male Date Palms Grown in the Mexicali Valley, Mexico

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Abstract: The aim of this study was the evaluation of date palm (*Phoenix dactylifera* L.) pollen production during the 2021 and 2022 seasons in the Mexicali Valley, Mexico. Twelve seed-propagated male palms of 20 years of age and similar vigor were selected and grouped into four groups with phenotypic characteristics of the common female cultivars in the area (Medjool, Deglet Noor, Khadrawy, and Zahidi). The pollen was extracted manually, with average production among all individuals of 780.94 and 777.11 g, in 26 and 24 inflorescences, respectively, for each year. Likewise, the flowering period on average was 47 and 41 days for each year. The pollen extracted from the earliest four inflorescences averaged 38.7 and 32.55 g, while that of the latest one produced 10.70 g and 18.28 g for each year, respectively. Seedling male palms with a phenotype similar to the Deglet Noor cultivar produced the greatest amount of pollen with 1250.98 and 1114.26 g on average for each year, produced during a late, short flowering period. Likewise, those palms with phenotypes similar to the Medjool cultivar produced the second-highest amount of pollen with 851.28 and 866.43 g on average for each year, produced during an early, long flowering period. Finally, an in vivo viability test through the fruit set percentage, revealed that the use of any of these four pollen sources would be suitable for the pollination of the recipient female cultivar Medjool, the most widely cultivated variety in Mexico. These results will allow date producers to select and propagate better pollen-producing male palms.

Keywords: date palm pollen; pollen production; pollen extraction; in vivo; spathes; flowering period

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1. Introduction

The date palm (*Phoenix dactylifera* L.) is a dioecious species, which means that separate trees are males (staminate) or females (pistillate), the first being the one that produces pollen, and the second, the one that produces the ovary and consequently the fruit [1]. In the Northern Hemisphere, male date palms normally have their flowering period between February and March. Female date palms flower slightly later in March and April [2]. The pollination period is approximately 40 days on average [3], commonly taking place between the months of March and April. However, these periods can be advanced or delayed due to the climatic conditions of each year [4].

Both male and female inflorescences grow inside a hard, fibrous sheath called a spathe. Male spathes are usually shorter and wider than female spathes, which are long and slender. The spathes grow in the tree's crown, at the axils of the new leaves developed during the previous year [5]. There are usually three whorls distinct of spathes, with the upper ones being larger and developing earlier and the lower ones developing later and usually being

smaller. The inflorescence has a main rachis that extends from the leaf axis and is composed of several dozen strands. Each strand of a male inflorescence has 50–100 male flowers. The male flowers are waxy white and consist of three sepals, three petals, six stamens (each stamen containing two small pollen sacs), and three completely degenerate carpels [6].

A sign of the maturation of the male inflorescence is when the spathe naturally cracks [7], exposing the inflorescence and beginning anthesis. It is at this time that the male inflorescence is removed from the tree for artificial pollination, this being standard practice in date cultivation. When the inflorescence of the palm is cut and removed, it is necessary to place it in dry conditions so it dehydrates and the two small pollen sacs in the anthers open. The pollen grains can then be extracted manually or mechanically.

The pollen from any male palm is able to pollinate any cultivar of female palm [2]. However, Nixon (1956) [8] mentions that pollen influences not only the size and shape of the seeds (xenia), but also the size, shape, weight, and rate of ripening of the fruit (metaxenia), and that pollen of specific sources may result in larger fruit or earlier ripening.

When not cultivated, the number of male and female trees is similar, enabling sufficient natural wind pollination. However, in commercial orchards, the pollen is extracted from the male inflorescences and artificially applied by different techniques to the females. In the establishment of a new date palm plantation, the farmer commonly plants the maximum number of female palms and a minimum number of male individuals for pollination. It is estimated that the pollen production of a healthy adult male palm is sufficient to pollinate up to 50 female palms, varying according to the application method [2,7].

Male date palms commonly produce their inflorescences over a long period, which can extend to more than a month depending on climatic conditions [9]. Some male palms regularly flower early, while others tend to come late [10]. Normally the first spathes to emerge are the ones that reach the largest sizes and thus produce the most pollen. The early inflorescences emerge from the youngest leaves developed in the previous year, and the later ones emerge from older leaves developed at the beginning of the previous year. Thus, the order of appearance of the first spathes and their larger size could be related to the highest photosynthetic capacity of the canopy being found in the youngest leaves of the palm.

The main date-producing regions in Mexico are located in the valleys of San Luis Rio Colorado, Sonora, and Mexicali, Baja California, where the area producing dates is constantly expanding [11]. Small date farmers commonly do not consider the inclusion of male palms in their plantations, due to the lack of technical advice for good agricultural management. For this reason, they rely on buying pollen, which can reach prices of up to 450 USD per gallon (approximately 2 kg). Some of the purchased pollen is not of the desired quality [2].

Due to the fact that the most recent studies on date palms in Mexico have been oriented towards female palms [12,13], the pollen production potential of male palms under the soil and climatic conditions of the region has not been explored. The aim of this study was to evaluate the pollen production of male date palms in Northwestern Mexico and the in vivo viability of the pollen produced in order to identify the trees producing the most pollen. With this information, farmers can consider the inclusion and selection of superior male palms, which will provide a greater amount of viable pollen and could be candidates for their propagation by offshoots or tissue culture.

2. Materials and Methods

2.1. Characterization of the Experimental Area

The study was conducted during the 2021 and 2022 growing seasons in a 15 ha date orchard with organic certification located in Ejido Jiquilpan (32°31′17″ N, 115°4′17″ W), in the Mexicali Valley, Northwest Mexico (Figure 1). The palms are planted at 8 × 8 m spacing. The soil is classified as alluvial from the dry bed of the Colorado River. Irrigation is by flooding, distributed in eight cycles of 15 cm each during the year. The field is organically fertilized, with a formulation in the liquid state of macro- and micro-nutrients, amino acids,

humic acids, rock dust, bone meal, phosphoric rock, and calcium polysulfide developed for date palm by the company Fertiorganicos SuperCosecha®.

Figure 1. Geographical location of Ejido Jiquilpan, in Northwestern Mexico, where pollen production was characterized.

2.2. Plant Material, Phenotypic Characterization of Male Trees and Pollen Extraction

In January and February 2021, the standard descriptors that define the vegetative phenotype of the date palm [14–16] were taken for the most common cultivars in the area (Medjool, Deglet Noor, Khadrawy, and Zahidi). Ten female palms of each cultivar were randomly selected. For their morphological characterization, three measurements of nine vegetative characters were collected from each palm and described in Table 1 (the length and width of the leaves, of the middle leaflet, of the middle spine, the length of the basal spiny portion, and the number of leaves and total spines per leaf).

Table 1. Value ranges of the morphological characterization of four date palm cultivars grown in Mexico.

Cultivar	Leaf Length (cm)	Leaf Width (cm)	Middle Leaflet Length (cm)	Middle Leaflet Width (cm)	Middle Spine Length (cm)	Middle Spine Width (cm)	Spined Portion Length (cm)	Leaflet Number	Spine Number
Medjool	304–376	65–82	50–64	2.8–3.4	11–16.5	0.5–0.8	57–88	143–156	20–30
Deglet Noor	327–400	63–74	49–53	2.9–3.7	8.1–13.5	0.6–0.8	103–122	117–182	36–44
Khadrawy	316–329	71–89	47–57	3.6–4.5	9.8–13.2	0.5–0.6	57–64	130–143	20–22
Zahidi	443–468	57–64	46–52	2.7–3.7	5.2–7.6	0.6–0.7	90–120	117–133	28–32

After characterizing each cultivar, twelve male palms with phenotypic characteristics similar to the four cultivars described above were selected and grouped into four groups according to the above phenotypic description (Table 2). The male date palms had been propagated from seeds and were at least 20 years of age and free of diseases.

Table 2. Seedling date palm males with similar phenotypic characteristics to four cultivars, which were selected for pollen extraction during the 2021 and 2022 seasons.

Palm	Group	Phenotypic	Leaf Length (cm)	Leaf Width (cm)	Middle Leaflet Length (cm)	Middle Leaflet Width (cm)	Middle Spine Length (cm)	Middle Spine Width (cm)	Spined Portion Length (cm)	Leaflet Number	Spine Number
P1	G1	Medjool	308	72	52	3.4	13.7	0.7	61	147	24
P2	G1	Medjool	348	71	55	3.2	12.4	0.5	73	156	26
P3	G1	Medjool	354	80	63	3.2	12.3	0.5	66	152	21
P4	G1	Medjool	337	76	57	3.3	12.8	0.6	69	150	29
P5	G2	Deglet Noor	330	66	49	3.1	10.3	0.6	104	169	42
P6	G2	Deglet Noor	397	69	50	3.1	9.1	0.7	105	180	37
P7	G2	Deglet Noor	385	71	53	3.5	12.1	0.7	112	155	38
P8	G3	Khadrawy	323	82	51	4.0	11.2	0.5	62	137	21
P9	G3	Khadrawy	321	79	56	3.7	11.9	0.6	60	140	20
P10	G3	Khadrawy	326	87	47	4.2	10.2	0.5	63	130	22
P11	G4	Zahidi	450	61	48	3.1	6.7	0.6	108	120	30
P12	G4	Zahidi	447	60	46	2.9	7.5	0.6	115	127	32

The pollen extraction method was the technique used by the farmer, as is described below. All spathes were removed from each tree sequentially as they matured. Once a spathe naturally cracked, twine was wrapped around it while it was still attached to the tree. This was performed to prevent pollen dispersal but still allow moisture loss from the inflorescence (Figure 2A). Two or three days later, the spathe was cut from the palm, noting the date of its removal. The spathes were then taken to a shady outdoor drying area, where they were removed from around the inflorescences (Figure 2B). Each inflorescence was placed on paper on a plastic tray to dry and release the pollen grains (Figure 2C).

Figure 2. Drying of male date palm inflorescences for pollen extraction. (**A**) Inflorescence ready to be cut from the palm and tied to prevent pollen dispersal. (**B**) Manual opening of the inflorescences. (**C**) Drying area. (**D**) Group of three inflorescences covered with a fine mesh screen on a layer of paper, in the process of drying in the open air.

The trays were covered with a fine mesh plastic screen that allowed the passage of air and natural light to prevent contamination and protect the inflorescences from bees. The inflorescences were maintained under these conditions for a period of one to two weeks. To achieve uniform drying, one side of the inflorescence was exposed to natural light. Once

the petals acquired a dark brown hue, the inflorescence was turned to expose its other side to the light. The first four mature inflorescences and the last removed from each palm were put separately in different trays, in order to quantify the weight of their extracted pollen individually. The remaining inflorescences were placed in separate trays in groups of three to six from the same male palm (Figure 2D).

For this study, the pollen was manually extracted. First, the pollen released by the inflorescences on the paper bed was poured into a plastic container, and all the loose pollen on the dry inflorescence was shaken off (Figure 3A). Then, all the flowers were manually separated from the inflorescence and deposited in that same container (Figure 3B). Finally, the entire content of the container was manually passed through a fine mesh (Figure 3C), to obtain completely clean and pure pollen (Figure 3D).

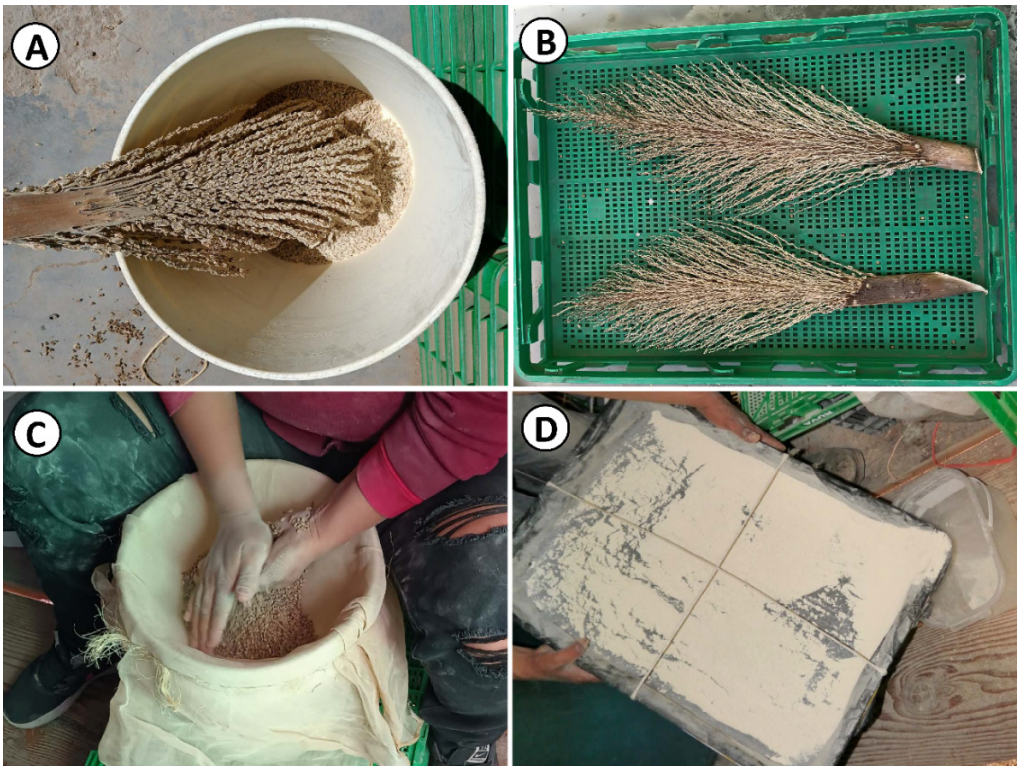

Figure 3. Date palm pollen extraction process. (**A**) Shaking the inflorescence in a plastic container. (**B**) Leaving only dry strands after all their flowers were manually removed. (**C**) Manual process of pollen extraction and filtering. (**D**) Final collection of filtered fresh pollen, ready to use.

An analytical balance was used to weigh the extracted pollen. The weights of the first four inflorescences and the last inflorescence removed from each palm were weighed individually. Pollen from the rest of the inflorescences of the same palm were all weighed together. The sum of the weight of the pollen extracted from all the inflorescences determined the total production of each palm.

2.3. Pollen Fresh Viability

Through the fruit set percentage, an in vivo pollen viability test was performed [17]. For this purpose, 12 female palms of the Medjool cultivar were selected to be pollinated by each group of male palms (3 female palms per group). After the natural cracking of their spathes, each spathe was manually opened and covered with paper bags. Pollination was carried out manually using a plastic squeeze bottle, between the third and seventh days after the spathes opened. In order to improve the efficiency of its consumption and management, fresh pollen from all sources was diluted with wheat flour at a ratio of 1:1 [2,13], and approximately 1.3 g of pollen was used per inflorescence. Between twelve

and eighteen bunches on each female palm were pollinated and were then re-covered with paper to avoid any contamination from other sources of pollen.

All the inflorescences on all female trees were pollinated in a period of four weeks, as they emerged and matured. The covering bags were removed two weeks after pollination. Six weeks after pollination, ten strands from 12 bunches of each palm were selected. The total number of fruit positions and the total number of fruit set in each strand were calculated. The fruit set percentage (FSP) was calculated using the following Equation:

$$\text{FSP} = \frac{\text{total fruit set}}{\text{total fruit positions}} \times 100 \quad (1)$$

2.4. Statistical Analysis

Statistical analysis was performed for the average pollen production of all palms, the first four inflorescences, the last inflorescence, and FSP, using a balanced design one-way ANOVA. In order to avoid type I error, a multiple comparison of means according to the least significant differences (LSD) was used, where the significance level was 5%. The variance analysis and the graphs were developed using version 4.2.0 of the statistical software R (R Core Team) [18]. The results of the average values were calculated for each year of production using Microsoft Excel software.

3. Results and Discussion

The pollen production of 12 selected male palms, which were studied for their pollen production during the 2021 and 2022 growing seasons, is presented in Table 3. For each of these male trees, the annual number of inflorescences, the pollen produced by each palm, the average per inflorescence, and the flowering period (from the opening of the first and last inflorescence) were quantified.

Table 3. Number of inflorescences, pollen production, average per inflorescence, and flowering period of the twelve seedling date palm males, selected for pollen extraction.

Palm	Inflorescences		Production Weight		Average per Inflorescence Weight		Flowering Period	
	(Number)		(g)		(g)		(days)	
	2021	2022	2021	2022	2021	2022	2021	2022
P1	29	21	661.56	632.26	22.81	30.11	64	55
P2	25	22	870.11	832.06	34.8	37.82	50	65
P3	24	26	966.76	1049.89	40.28	40.38	56	69
P4	32	31	906.7	951.52	28.33	30.69	54	26
Average G1	27.5 ± 3.70 a	25.0 ± 4.55 a	851.28 ± 132.61 b	866.43 ± 179.74 ab	31.55 ± 7.61 ab	34.75 ± 5.14 a	56 ± 5.89 a	54 ± 19.41 a
P5	36	35	1353.27	1262.52	37.59	36.07	51	37
P6	31	26	1026.68	994.95	33.12	38.27	45	25
P7	27	25	1373	1085.32	50.85	43.41	46	33
Average G2	31.3 ± 4.51 a	28.6 ± 5.51 a	1250.98 ± 194.50 a	1114.26 ± 136.11 a	40.52 ± 9.22 a	39.25 ± 3.77 a	47 ± 3.21 a	32 ± 6.11 a
P8	21	19	278.11	322.18	13.24	16.96	34	27
P9	16	22	395	325.98	24.69	14.82	33	21
P10	16	23	217.78	382.52	13.61	16.63	20	42
Average G3	17.6 ± 2.89 b	21.3 ± 2.08 a	296.96 ± 90.1 c	343.56 ± 33.79 c	17.18 ± 6.51 b	16.13 ± 1.15 b	29 ± 7.81 b	30 ± 10.82 a
P11	26	17	484.89	546.1	18.65	32.12	59	35
P12	24	26	837.5	940.13	34.9	36.16	56	64
Average G4	25 ± 1.41 ab	21.5 ± 6.36 a	661.2 ± 249.33 b	743.11 ± 278.62 b	26.77 ± 11.49 ab	34.14 ± 2.86 a	57 ± 2.12 a	49 ± 20.51 a
Total	307	293	9371.36	9325.43				
Average	26	24	780.94	777.11	29.41	31.12	47	41

Values are mean ± SD for each group. Means followed by the same letter(s) in a column do not differ significantly at the 0.05 probability level.

The total and average number of inflorescences produced by the 12 male palms, as well as the total amount of pollen produced, were similar for the two years. Likewise, the length of the flowering season on average was also similar, with a difference of 6 days for the cultivation period between one year and the next.

Some studies have reported that a seedling male date palm has the capacity to produce 500 g of pollen on average per year, but depending on its origin and with good agricultural management, it can produce more than double [7,19]. Wertheimer (1957) [3] reports an average pollen production of 756.905 and 1115 g in twelve palms, in three different seasons. In our study, an average production of 780.94 and 777.11 g is reported for 2020 and 2021, respectively, among the various groups of seedling date palms studied (Table 3).

The yield in pollen production is highly variable among seedling male palms because they differ greatly in the characteristics of the spathe, flowering time, vigor, and growth, among other aspects [20–23]. Studies carried out for three consecutive years on 12 and 50 male palms [3,22], without specifying their age, reported that the pollen production per male palm ranged from 248 to 2133 g and from 24.26 to 1568 g, respectively. In our study with 12 individuals of at least 20 years of age, in two consecutive years, a pollen production per palm from 217.78 to 1373 g is reported (Table 3).

The number of inflorescences on each palm varies from none to more than 25, depending on the age and vigor of the tree [7], as well as the environmental conditions and horticultural practices. Studies carried out in Algeria and Egypt reported an average production of 19 and 17 inflorescences in three consecutive seasons, with a maximum of 36 and 33, and a minimum of 11 and 9 inflorescences, respectively [3,22]. In this study carried out in Mexico, an average production of 25 inflorescences in two consecutive seasons is reported, with a maximum of 36 and a minimum of 16 inflorescences. The flowering period in this study was 47 and 41 days on average, for 2021 and 2022, respectively. Likewise, a range of flowering between 20–69 days is reported, while other studies reported flowering ranges between 31–43, 26–44, and 34–57 days, respectively [3,9,23].

Regarding the significant differences found among the four groups of seedling male palms studied, we found that G2 (phenotypically similar to the Deglet Noor cultivar), produced on average the greatest number of inflorescences (31 and 29) for the years 2021 and 2022, respectively; however, this was not statistically significant compared to the rest of the groups. The average pollen production of G2 was 1251 and 1114 g, for the years 2021 and 2022, respectively, being the highest significant average weight among the four groups for the two years. The highest average pollen production per inflorescence (40 and 39 g), was determined by G2 for the same two years but was not significant with respect to the rest of the four groups. Likewise, the highest average flowering period was for G4 (57 days) in 2021 and G1 (54 days) for 2022, but this was not statistically significant with respect to the rest of the groups.

G1 (phenotypically similar to the Medjool cultivar) was the group that produced the second-highest amount of pollen, inflorescences, and average pollen production per inflorescence. G3, phenotypically similar to the Khadrawy cultivar, reported an average of 17 and 21 inflorescences, with a pollen production of 296.96 and 343.56 g, for 2021 and 2022, respectively, being the group with the least significant amount of pollen and the least number of inflorescences produced. This was followed by G4, phenotypically similar to the Zahidi cultivar. Likewise, these two groups have the lowest average pollen production per inflorescence. Finally, G1 and G4 showed the longest flowering period from 49 to 57 days, with G1 showing higher pollen production than G4. G2 and G3 had the shortest flowering period of 29 to 47 days, where G2 presented a high pollen production, compared to G3 (Table 3).

A determining factor for the total production of pollen is given by the number of inflorescences produced in each palm or by the amount of pollen produced by each inflorescence. In this study, the total pollen production of groups G1 and G3 was determined by the average pollen produced by each inflorescence. However, for groups G2 and G4, total pollen production was determined by the average number of inflorescences produced per palm.

The average pollen production of the first four inflorescences in each palm, as well as the first harvest date and corresponding day of the year, are presented in Table 4. The overall average of the twelve palms for 2021 was 38.7 g, while for 2022 it was 32.55 g. The greatest averages of the first four inflorescences were 47.05 and 39.94 g (both G1), being significantly greater than the pollen production of G3 with 19.54 and 21.39 g for 2021 and 2022, respectively. The greatest individual pollen production from the first inflorescence was 71.64 (P3) and 74.1 g (P2) from G1. The lowest productions were 10.63 and 11.83 g (both P9) for 2021 and 2022, respectively (data not shown in Table 4).

Table 4. Average pollen production of the first four male inflorescences that appeared on each seedling date palm male.

Palm	Weight (g)		First Harvest Date—Day Number	
	2021	2022	2021	2022
P1	33.19	34.68	February 21–52	January 29–29
P2	54.83	54.59	March 3–62	February 10–41
P3	59.21	40.94	February 25–56	February 5–36
P4	40.97	29.58	March 3–62	March 16–75
Average G1	47.05 ± 14.7 a	39.94 ± 14.44 a	58 ± 4.9c	45 ± 20.43 b
P5	50.11	35.99	March 3–62	March 10–69
P6	40.29	32.81	March 9–68	March 20–79
P7	46.77	33.03	March 7–66	March 15–74
Average G2	45.72 ± 11.82 a	33.94 ± 9.64 a	65 ± 3.06 b	74 ± 5 a
P8	20.61	20.29	March 19–78	March 21–80
P9	16.99	18.45	March 20–79	March 25–84
P10	21.03	25.45	March 25–84	March 2–61
Average G3	19.54 ± 4.97 b	21.39 ± 4.54 b	80 ± 3.21 a	75 ± 12.29 a
P11	34.22	25.47	March 1–60	February 17–48
P12	46.23	39.4	March 3–62	February 3–34
Average G4	40.22 ± 16.2 a	32.43 ± 15.36 a	61 ± 1.41 bc	41 ± 9.9 b
Average	38.7	32.55	66	59

Values are mean ± SD of four independent determinations per palm. Means followed by same letter(s) in a column do not differ significantly at a 0.05 probability level.

Flowering in 2022 started slightly later than 2021, with the average number of days in the year for the harvest of the first inflorescence among the four groups being 66 and 59 days for 2021 and 2022, respectively. The pollen harvest in groups G1 and G4 were the earliest in 2021 and 2022 beginning on day 58 and day 41, respectively, being significantly earlier with respect to G2 and G3. The G3 trees were the ones that flowered the latest for the first time at 80 and 75 days, for 2021 and 2022, respectively, being significantly later with respect to G1 and G4. Finally, the earliest harvest dates were on 21 February 2021 (day 52) and 29 January 2022 (day 29) for G1, while the latest dates of the first harvest were 25 March 2021 and 2022 (both day 84) for G3.

No significant differences were detected in the amount of pollen or the date of collection among the inflorescences collected from the different cardinal points in each palm.

The pollen production of the final inflorescence collected from each palm is shown in Table 5. The average pollen production of the last inflorescences for 2021 was 10.7 g, while for 2022 it was 18.28 g. The greatest average pollen harvests of the last inflorescence were 13.49 and 24.77 g (both G2), but this was not statistically significant with respect to the rest of the groups. Likewise, the least were 7.12 (G3) and 12.36 g (G4) for 2021 and 2022, respectively, not being significant with respect to the rest of the groups. The greatest

individual pollen productions from the final inflorescence were 22.37 (P3) and 31.79 g (P5) for 2021 and 2022, respectively, while the least were 2.99 (P1) and 10.03 g (P11) for the same years, respectively.

Table 5. Pollen production of the last harvested inflorescence, in each of the twelve seedling date palm males, selected for pollen extraction.

Palm	Weight (g)		Harvest Date—Day Number	
	2021	2022	2021	2022
P1	2.99	20.6	April 26–116	March 25–84
P2	11.94	11.07	April 22–112	April 15–105
P3	22.37	31.27	April 22–112	April 13–103
P4	9.28	15.88	April 26–116	April 15–105
Average G1	11.65 ± 8.07 a	19.7 ± 8.64 a	114 ± 2.31 ab	99 ± 10.21 a
P5	11.36	31.79	April 23–113	April 15–105
P6	16.67	19.75	April 23–113	April 14–104
P7	12.45	22.79	April 22–112	April 18–108
Average G2	13.49 ± 2.80 a	24.77 ± 6.26 a	113 ± 0.58 bc	106 ± 2.08 a
P8	8.74	13.26	April 20–110	April 17–107
P9	7.26	11.42	April 22–112	April 15–105
P10	5.37	16.87	April 14–104	April 13–103
Average G3	7.12 ± 1.69 a	13.85 ± 2.77 a	109 ± 4.16 c	105 ± 2.08 a
P11	5.67	10.03	April 28–118	March 24–83
P12	14.3	14.69	April 28–118	April 8–98
Average G4	9.98 ± 6.1 a	12.36 ± 3.3 a	118 ± 4.16 a	90 ± 2 a
Average	10.7	18.28	113	100

Values are mean ± SD for each group. Means followed by same letter(s) in a column do not differ significantly at a 0.05 probability level.

The average days for the harvest of the last inflorescence among the four groups were day 113 and day 100 for 2021 and 2022, respectively. G4 had the latest final pollen harvest in 2021, beginning on day 118, while for 2022, G2 had the latest final harvest on day 106; however, they were not significantly later with respect to the rest of the groups. Surprisingly, G2's final pollen harvest was the earliest in 2021, beginning on day 113, while in 2022, G4's final pollen harvest began earliest on day 90, but they were not significantly earlier with respect to the rest of the groups.

The latest harvest dates for inflorescences were 28 April 2021 (day 52) and 18 April 2022 (day 29) for G4 and G2, respectively, while the earliest dates of the last flowerings were 14 April 2021 and 24 March 2022 (day 84) for G3 and G4, respectively. The last inflorescences harvested in 2021 were all cut in the month of April within a period of 14 days, while for 2022 the final cutting period was 25 days between the months of March and April. For 2022, we cut the final inflorescence off the palms in the second or third week of April. There was no association observed between the harvest date of the last inflorescence and its higher or lower pollen production.

Some studies have reported different results on pollen production from a male inflorescence. El-Amer et al. (1993) [24] reported a production of 0.26 to 42.95 g per florescence, while Dawoud (2001) [20] reported that the pollen produced by each inflorescence varied between 25.30 and 83.10 g depending on the characteristics of the plant. Shaheen (2004) found that depending on the age of the plant, an inflorescence can produce from 0.02 to 82.29 g [25]. In this research using 20-year-old palms, a minimum pollen production

weight per inflorescence of 2.99 g (Table 5) and a maximum of 71.64 g (P3 in Figure 4A) were identified.

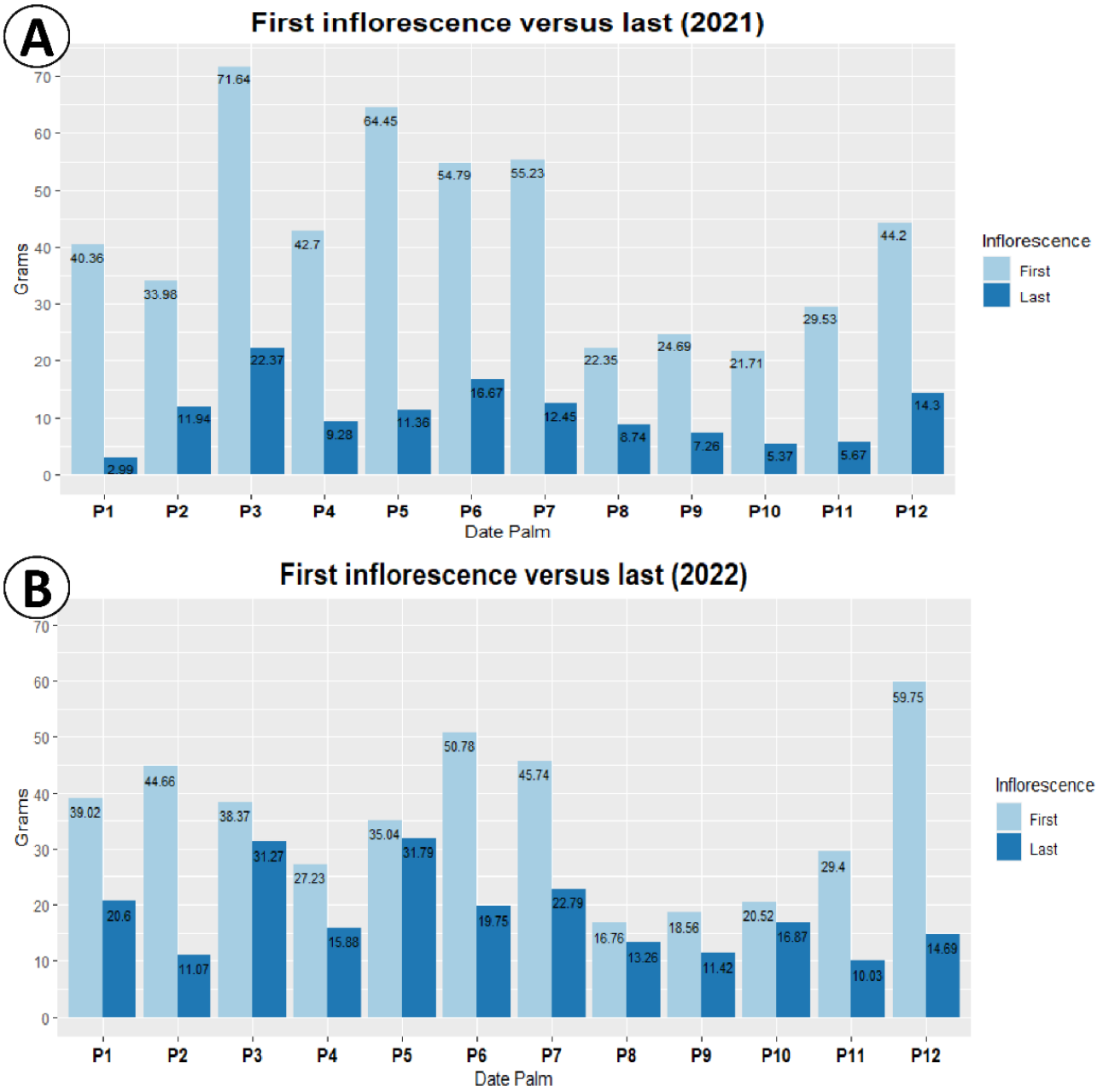

Figure 4. Pollen production of the first inflorescence in each palm, versus the pollen production of the last inflorescence in the same palm. (**A**) Comparison of pollen production of the first inflorescence versus the last one in the year 2021. (**B**) Comparison of pollen production of the first inflorescence versus the last one in the year 2022.

The pollen production of the first inflorescence, contrasted against the production of the last cut inflorescence, for the production years 2021 and 2022, respectively, is shown in Figure 4. In Figure 4A,B, it is observed that the pollen production of the last inflorescence was lower than the first one. In 2022, the pollen production of the last spathe was slightly higher than it was the previous year. This may be due to weather issues and better agricultural management, compared to the previous year.

It is notable that pollen quantity, as well as its production period, differ greatly from one area to another [26], and can also be associated with the origin of the seedling male

palm [27]. In our research with males from four groups, the group of palms with a phenotype similar to the Deglet Noor cultivar (G2) produced the greatest amount of pollen. These males had a short flowering period of 39 days on average during the two years observed, but they also began flowering later, starting on day 62.

The second group of palms that showed the next highest pollen production, were the male palms with a phenotype similar to the Medjool cultivar (G1). They had a long flowering period of 55 days on average, but had an early flowering start, beginning on day 29. These two groups of seedling male palms of local origin, having these valuable characteristics, should be considered for vegetative propagation in order to increase the number of good pollen sources available to the growers in the area. Seedling male palms from Khadrawy and Zahidi (G3 and G4) presented lower pollen production in relation to the first two groups, showing late and early flowering, with a short and long production period, respectively. They thus represent less desirable genotypes for further propagation.

Some parameters to consider for deciding on an appropriate selection of pollen-producing sources in male date palms are: the amount of pollen produced, its viability, number of spathes, number of flowers per strand, as well as time and period of flowering, among others [22,23]. In this study, some of these characteristics are present mainly in G1 and G2, which suggests that they could be considered as acceptable sources of pollen for the pollination of the Medjool cultivar in Mexico. Notably, tree P5 (similar to Deglet Noor cultivar) had high production of pollen (Table 3), which defines it as a superior palm that should be considered for clonal propagation.

Pollen viability can be evaluated through different methods. These can be direct methods (in vitro and in vivo) and indirect methods based on ecological parameters [28]. In this study, an in vivo viability test was carried out. The in vivo pollen viability for two seasons is presented in Table 6, as calculated from the fruit set percentage of 12 recipient Medjool female palms. G2 shows on average the greatest fruit set percentage (66.99 and 73.32%) for the years 2021 and 2022, respectively, being significantly greater with respect to G1 and G4. While the least fruit set was presented by G1 (52.04%) and G4 (63.48%) for the same years, respectively, with only G2 being significantly greater. The standard deviation of G3 shows a significant variation with respect to the rest of the groups. However, in general, very good viability of the four pollen sources is observed. The use of any of these four sources would be very viable.

Table 6. Evaluation of the in vivo viability of pollen from four different sources, expressed as a fruit set percentage.

Group	2021	2022
G1	52.04 ± 8.26 b	68.64 ± 9.7 b
G2	66.99 ± 7.72 a	73.32 ± 9.87 a
G3	54.24 ± 14.74 ab	67.39 ± 15.83 ab
G4	52.24 ± 8.15 b	63.48 ± 9.16 b

Values are mean ± SD of 36 bunches per group with 10 independent determinations per bunch. Means followed by same letter(s) in a column do not differ significantly at a 0.05 probability level.

4. Conclusions

The proper selection of good quality pollen-producing male date palms is of vital importance to farmers who decide to include male palms in their plantations. This selection may be through some traits related to its total production and early flowering. Likewise, the evaluation of the compatibility with the recipient females, through a pollen viability test, is extremely important.

This study evaluated the characteristics of pollen production, as well as its viability, in twelve seedling male date palms. The results suggest that small producers in the Valley of Mexicali, Mexico, could include in their plantations the necessary amount of seedling male palms, with the phenotype similar to Deglet Noor and Medjool cultivars,

due to their acceptable pollen production and compatibility with recipient females of the Medjool cultivar.

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