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Effects of Pollination Technique on Agronomic and Physicochemical Characteristics of Date Palm (*Phoenix dactylifera* L.) Fruits in the Sudan Savannah Region of Nigeria

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Abstract

Pollination is critical for producing many crops, and both insect- and wind-based pollination systems are increasingly disrupted by bloom asynchrony, weather events, and the high demand for available insect pollinators. Artificial pollination systems can provide yield security even in poor pollination scenarios and have attracted attention over the past decade. In Nigeria, date farmers still practice the oldest and most traditional technique of pollination, where male spikelets are manually inserted into the female inflorescence. This ancestral practice has many setbacks, which led to searching for other means for improving date yield. The present study aims to compare the agronomic and biochemical characteristics of the date 'Danshuwarin' cultivar under different pollination methods. Three methods were tested: traditional pollination, pollen dusting, and pollen suspension. The results obtained showed the dusting technique to be the most effective and efficient, followed by conventional methods. In contrast, pollen suspension has the highest number of fruit sets (80.79%) and retention rate (67.42%), while yield is 5.3% with the lowest parthenocarpic fruits of <2%. The results provide baseline information to uncover different pollination techniques on other Nigerian date palm varieties grown in diverse agroecological zones.

Keywords: date palm, *Phoenix dactylifera*, pollination, pollen grain, yield

Introduction

Date palm (*Phoenix dactylifera* L.) is a highly significant and ancient fruit-bearing tree, widely cultivated in arid and semi-arid regions of the world, particularly South Asia, the Middle East, North Africa, and West Africa, as well as Nigeria (Sunusi et al., 2024). Its sweetened, nutrient-dense fruits play a significant role in local farmers' savings, food, and cultural customs (Akhavan et al., 2021; Salomón-Torres et al., 2021). The origins of date palm farming date back over 5,000 years, probably to the areas neighboring the Persian Gulf and Mesopotamia, where it was first domesticated and integrated into cultivated crops (Food and Agriculture Organization of the United Nations, 2023; Wurz et al., 2021). Its monetary and cultural meaning stems from its long standing role in human diets and agricultural schemes (Kadri et al., 2022; Shahsavar & Shahhosseini, 2020). Current improvements have further highlighted its position in universal food security, motivated by high-value production and well-being associated with its antioxidant and fiber content (Bedjaoui & Benbouza, 2020; Kamara et al., 2021; Sunusi et al., 2024). Recent farming spans regions such as Nigeria, Egypt, Saudi Arabia, Iran, and Pakistan, with worldwide production above 9.45 million tonnes in 2020 (Food and Agriculture Organization of the United Nations, 2023).

Developments in production practices and also the introduction of effective pollination methods have meaningfully improved harvests and fruit quality, positioning date palms as vital in universal food security (Ahmad, 2023;

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Sunusi et al., 2024). Date palms are dioecious, requiring active pollination to guarantee fruit production. Old style approaches, such as the manual insertion of male spikelets into female inflorescences, continue to dominate in many date-growing counties. Nevertheless, these procedures are work-demanding and usually unproductive, resulting in inadequate fruit sets and high parthenocarpic rates (Akhavan et al., 2021; Jamro et al., 2020; Kadri et al., 2022; Munir, 2020). Comparatively, artificial pollination methods like pollen dusting and pollen suspension are gaining importance for their effectiveness and capability to advance fruit set rates, and retention, in addition to yield quality (Akhavan et al., 2021; Munir, 2020). Pollination productivity in date palms is predisposed by numerous factors, including pollen viability, timing, and environmental settings (Kadri et al., 2022). Recent studies propose artificial approaches, particularly liquid pollen suspension, outstrip natural pollination in both yield and fruit quality (Sunusi et al., 2024). This method not only improves yield but also aligns well with the prospects of mechanized farming, making it suitable for scaling up date palm production (El-Mardi et al., 2021; Kadri et al., 2022; Sunusi et al., 2024). However, we recognize that limited technical know-how among smallholder farmers in Nigeria may pose a barrier to widespread adoption. To facilitate large-scale implementation, capacity-building initiatives such as farmer field schools, extension agent demonstrations, and training workshops will be essential. Additionally, the pollen dusting and suspension methods are relatively low-cost and do not require highly specialized equipment, making them more accessible. Local fabrication of simple pollination tools (e.g., hand sprayers or dusting devices) can further support adoption.

Government and private-sector partnerships could also play a role in integrating these techniques into national date palm development programs, particularly in the northern regions where date palm cultivation is expanding. Moreover, cooperative farming systems and farmer groups can help share labor, knowledge, and resources to implement these methods more efficiently. (Kadri et al., 2022). The current study assesses the agronomic and physicochemical effects of three pollination practices-traditional, pollen dusting, and pollen suspension-on the ‘Danshuwarin’ date palm cultivar in the Sudan Savannah environment of Nigeria. This study evaluates the agronomic and physicochemical effects of three pollination methods traditional hand pollination, pollen dusting, and pollen suspension-on the ‘Danshuwarin’ date palm cultivar in the Sudan Savannah region of Nigeria. The goal is to identify the most effective pollination technique to help farmers enhance yield, improve fruit quality, and promote sustainable date palm cultivation in the country. This study aims to identify the most effective pollination method to help growers enhance yield, improve fruit quality, and promote sustainable date palm cultivation in Nigeria.

Materials and Methods

Plant Materials and Methodology

The study was carried out at the National Date Palm Research Institute Date palm substation Dutse and Federal University Dutse (Latitude 11° 69 N, Longitude 9° 34’ E, 446 m) above sea level. The climate of Dutse experiences extreme seasonal variation in monthly rainfall. The rainy period of the year lasts for 6.3 months, from April 12 to October 22, with a sliding 31-day rainfall of at least 0.5 inches. The month with the most rain in Dutse is August, with an average rainfall of 7.0 inches.

The male spathe samples were collected from one common pollinator, which was selected based on the following characteristics: (i) significant ability to produce inflorescences (more than 35 male spathe), (ii) Germination and pollen viability rate is higher than 85% and (iii) A high pollen yield. The female trees of the cultivar ‘Danshuwarin’ were 13 years old and received standard and uniform cultivation techniques (irrigation and fertilization). The fresh male inflorescences were collected from the male spathe and then cut into separate spikelets and dried at room temperature (22 – 25 °C) for 48

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hr in the shade. The spikelets were then shaken manually to obtain the pollen powder, which was collected in glass boxes and then stored at room temperature for imminent use. The two cultivars used (male and female) belong to the NIFOR sub-station.

Pollination

All pollen used in this study was collected from the same male date palm to maintain consistency and avoid any external influence on fruit development. Pollination was carried out in the first week of April 2021 under full sun and low wind conditions to ensure uniform environmental factors. One female date palm of the 'Danshuwarin' cultivar was selected, along with a 15-year-old male pollinator cultivated under similar management practices. Four female spathes were covered with paper bags to prevent cross contamination from external pollen sources. Three spathes were used to evaluate different pollination techniques; all applied to the same female palm to minimize variability due to plant physiology. The fourth spathe was left unpollinated and served as a control to confirm that fruit set was solely attributable to the applied treatments. The three pollination methods tested included the traditional method, which involved manually inserting five mature male spikelets, each containing approximately 5 mg of pollen per strand, in the opposite direction of the female spikelets. The second method, pollen dusting, involved applying a mixture of pollen and talcum powder in a 1 : 8 ratio onto the female spathe. One gram of pollen was measured and thoroughly mixed with seven equal portions of talcum to ensure even distribution. The third method, pollen suspension, involved mixing 1 gram of pollen in 10 ml of deionized water and spraying it uniformly over the female spathe using a handheld sprayer.

Measured Parameters

To evaluate fruit set and retention, five spikelets were randomly tagged for each treatment and replicated to obtain a total of 15 spikelets per bunch per pollination technique. The number of attached and fallen fruits was counted, and the fruit set ratio was calculated using the method described by El-Salhy et al. (2010). Fruit set was assessed two months after pollination, following the procedure of Hussain et al. (2020). Fruit retention rate was determined at the middle of the seed developmental stage using the formula:

$$\text{Fruit retention rate (\%)} = \frac{\text{Number of retained fruits}}{\text{Total number of fruit set}} \text{ x } 100$$

To assess yield, the fruits from each pollinated bunch were harvested and weighed at the final stage of fruit development, known as the Tamar stage, when the fruits are fully ripe, dry, and have reached their maximum size and weight.

The quality of date palm fruit was evaluated using 15 randomly selected fruits from each pollinated bunch. These fruits were analyzed for weight, thickness, seed weight, length, width, diameter, and volume. Moisture content was determined by calculating the difference between the fresh matter (FM) and the dry matter (DM) until a constant dry weight was achieved. The moisture percentage was calculated using the formula:

$$\text{Moisture content (\%)} = \frac{\text{FM} - \text{DM}}{\text{FM}} \text{ x } 100$$

The pH of the fruit was measured by heating a mixture of 10 g of date fruit and 30 ml of distilled water at 100 °C for 30 min. The mixture was then crushed, filtered, and the pH of the filtrate was measured using a pH meter. Total soluble solids (TSS) were determined using filtered juice obtained after dilution, with readings taken using a refractometer. Titratable acidity was measured following the standard procedure outlined by George (2016). Water activity was assessed at 25 °C using a water activity meter.

Statistical Analysis

The experiment was laid out in a completely randomized design with five replications per treatment. All the data collected were subjected to analysis of variance (ANOVA). Least significant

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differences (LSD) at α = 5% level of significance were used to compare the means of treatments. The statistical analyses of agronomic traits were performed using SAS.

Results and Discussion

Effect of Different Pollination Methods on Fruit Set and Retention Rate

The effect of pollination techniques on the date palm fruit set is shown in Table 1. The different pollination methods had a significant impact on fruit set percentage. The highest fruit set of 81.45% was recorded from the dusting method, while the lowest (39.56%) was observed in the pollen suspension method. Fruit retention was also significantly affected, with the traditional method recording the highest retention rate of 67.24%, and pollen suspension showing the lowest at 14.56%. Bunch weight was likewise significantly influenced by the pollination method. The effect of pollination techniques on the date palm fruit set is shown in Table 1. The different pollination methods had a significant impact on fruit set percentage. The highest fruit set of 81.45% was recorded from the dusting method, while the lowest (39.56%) was observed in the pollen suspension method. Fruit retention was also significantly affected, with the traditional method recording the highest retention rate of 67.24%, and pollen suspension showing the lowest at 14.56%. Bunch weight was likewise significantly influenced by the pollination method. For the bunch weight at the final fruit stage, the traditional pollination method yielded the highest yield (5.47 kg per bunch), a direct consequence of high fruit set and retention rates (Table 1). The pollen dusting method yields an average of 4 kg per bunch, while the pollen suspension method records the lowest yield of 2.72 kg per bunch, primarily due to the high parthenocarpic fruit rate.

Effect of Pollination Methods on Physicochemical Characteristics of 'Danshuwarin' Dates

The results show that pollination methods have a significant influence on the weight of date palm fruits. The highest fruit weight (13.41 g) was recorded at the middle stage using the pollen suspension method, followed by dusting (11.18 g) and traditional pollination (10.6 g). Similarly, fruit length, width, and diameter were affected by pollination techniques at various growth stages, as presented in Table 2. While fruit length showed no significant differences across all stages, fruit width was significantly influenced by the dusting method at the final stage of development. The results show that pollination methods have a significant influence on the weight of date palm fruits. The highest fruit weight (13.41 g) was recorded at the middle stage using the pollen suspension method, followed by dusting (11.18 g) and traditional pollination (10.6 g). Similarly, fruit length, width, and diameter were affected by

Table 1

Influence of Various Pollination Techniques on Fruit Set, Fruit Retention, and Yield of Date Palm 'Danshuwarin'

Pollination method	Fruit set (%)	Fruit retention (%)	Bunch weight (kg)
Traditional pollination	81.45[a]	67.24[a]	5.47[a]
Pollen dusting	72.21[b]	57.98[b]	4.00[b]
Pollen suspension	39.56[c]	14.56[c]	2.72[c]
Significance	***	***	***

Note. Means within each column with the same letters are not significantly different at $p < 0.05$. *P* level of significance *** significant at $p < 0.001$.

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pollination techniques at various growth stages, as presented in Table 2. While fruit length showed no significant differences across all stages, fruit width was significantly influenced by the dusting method at the final stage of development.

Effect of Pollination Techniques on Date Fruits' Chemical Characteristics

The total soluble solids (TSS) indicate the carbohydrate richness of the dates. Based on our findings, no significant effect was observed, as seen in Table 3. However, a significant effect was observed on acidity at the final fruit maturation stage, with the highest acidity obtained by suspension methods (0.20%), followed consecutively by the traditional method (0.18%) and pollen dusting pollination methods (0.17%, Table 3).

The date's moisture was affected significantly ($p < 0.05$) by the pollination technique only at the middle fruit ripening stage (Table 3). Moreover, the highest moisture content (62.35%) was obtained under the pollination method, followed by dusting (61.34%) and the traditional technique (60.22%) (Table 3). The influence of different pollination techniques on the water activity was significant ($p < 0.05$) only for the middle fruit ripening stage, with a maximum under both pollen suspension and traditional pollination techniques (0.93) (Table 3). The obtained results showed that fruit pH underwent significant effects ($p < 0.001$) according to pollination techniques during all three stages of fruit growth. The present study aims to unveil the effect of different pollination methods on the 'Danshuwarin' dates. The results obtained indicate that pollination methods have a significant effect on fruit set, fruit retention, and, lastly, yield. Pollen dusting proved to have a good result compared with the pollen suspension and traditional methods, which could be ascribed to the non-homogenized mix of the water /pollen as reported by Al-Najm et

Table 2

Effects of Different Pollination Methods on Physical Fruit Characteristics of 'Danshuwarin' at Various Developmental Stages

Techniques	Weight (g)	Length (mm)	Width (mm)	Diameter (mm)	Volume (ml)	Thickness (mm)
			5 weeks			
Traditional pollination	8.76 b	39.37 a	18.21 a	32.10 a	24.31 ab	5.00 b
Pollen dusting	8.82 b	39.35 a	19.75 a	34.10 a	20.99 b	5.85 a
Pollen suspension	11.23 a	39.42 a	18.75 a	29.86 b	26.24 a	6.00 a
			19 weeks			
Traditional pollination	10.61 b	36.72 b	17.45 c	30.10 c	21.23 c	5.34 b
Pollen dusting	11.18 b	40.78 ab	20.30 b	33.10 b	33.57 a	6.25 a
Pollen suspension	13.41 a	44.67 a	21.40 a	35.30 a	27.45 b	5.30 b
			29 weeks			
Traditional pollination	8.43 b	37.20 a	14.90 a	3.69 a	17.00 a	4.11 a
Pollen dusting	7.89 b	37.60 a	15.19 a	2.80 b	14.00 b	3.59 b
Pollen suspension	10.88 a	35.67 a	15.27 a	2.70 b	15.00 b	4.20 a
Fruit growth stages	***	ns	***	*	***	***
Techniques	**	ns	ns	*	***	ns
Fruit growth stage x Techniques	**	ns	**	*	***	ns

Note. Means within each column followed by the same letter are not significantly different at the level $p < 0.05$. ns: not significant, *Significant at $p < 0.05$, **Significant at $p < 0.01$, ***Significant at $p < 0.001$.

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al. (2021). Although there is clear evidence that traditional pollination methods have been reported to make a heterogeneous distribution of pollen grains to the female flowers (Al-Najm et al., 2021). Whereas the pollen dusting method seldom makes a homogeneous distribution of pollen grain and creates direct contact between the pollen and the flower, as reported by (Kadri et al., 2019). Our findings corroborate those of other researchers like Bedjaoui and Benbouza (2020) who work with 'Barhee', 'Hillawi', and 'Deglet Nour' varieties (Alyafei et al., 2022; Kadri et al., 2019; Ullah et al., 2018). Contrary to our findings, the highest fruit set percentage was observed in a cultivar 'Saidy' in traditional pollination at 86.3% followed by pollen dusting at 72.11%, and the least was pollen suspension at 62.76%. However, in another study with the cultivar 'Khalas' pollen suspension methods ranked first with 85.7% followed by the pollen dusting methods with 82.07% (Munir et al., 2020).

It is noteworthy that the retention rate is also considered a yield indicator (Herrera, 2020). According to El-Mardi et al. (2002), while in traditional pollination, fruit retention was reduced by 21% at the last fruit maturation time, dusting pollination has been reported to make a 2% increase in fruit setting (Al-Najm et al., 2021). Contrary to our results traditional pollination has also been reported to increase the fruit retention rate in 'Medjol' cultivar with 885 fruit per bunch (Taleb & Mohamed, 2019) Furthermore, similar results were recorded in 'Khalas' with maximum retension rate under suspension pollination to have high retention rate by 85% followed by dusting pollination 83% (Munir et al., 2020). Additionally, our findings align with those of Munir et al. (2020), who reported that the dusting pollination method yielded the maximum (6.14 kg per bunch), followed by the suspension pollination method (6.14 kg per bunch), and finally, the traditional pollination method (4 kg per bunch). The same results were obtained for the cultivar 'Hillawi' as reported by (Ullah et al., 2018). The results of the harvested dates at the end of the fruit maturation stage specified the highest yield for the dusting pollination method (5.5 kg per bunch) as a direct value of high fruit set and retention rates. The same results were observed for the bunch weight in the 'Medjol' and 'Barhee' varieties, and the values were 22.3 kg and 48.1 kg, respectively, obtained after the traditional pollination method (Taleb & Mohamed, 2019). Similar to our results, those of Awad (2011) are also consistent with the fact

Table 3

Effects of Different Pollination Methods on the Physical Characteristics of 'Danshuwarin' Seeds

Techniques	TSS (°Brix %)	Acidity (%)	Moisture (%)	Water activity	pH
	Fruit maturation stage				
Traditional pollination	17.80 c	0.10 a	60.22	0.91 a	5.60 a
Pollen dusting	20.82 b	0.11 a	61.34	0.92 a	5.58 ab
Pollen suspension	26.85 a	0.11 a	62.35	0.92 a	5.49 b
	Middle fruit ripening stage				
Traditional pollination	18.93 a	0.17 b	20.90 a	0.62 b	5.63 a
Pollen dusting	19.89 a	0.18 b	21.33 a	0.70 a	5.65 a
Pollen suspension	20.52 a	0.20 a	21.66 a	0.64 ab	5.66 a
Fruit growth stages	***	***	***	***	***
Techniques	ns	ns	ns	**	***
Fruit growth stage x techniques	ns	**	ns	ns	***

Note. Means within each column followed by the same letter are not significantly different at the level $p < 0.05$. ns: not significant, *Significant at $p < 0.05$, **Significant at $p < 0.01$, ***Significant at $p < 0.001$.

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that the traditional pollination method led to 8.54 kg of dates per bunch. In contrast, the traditional pollination method also obtained for 'Lulu' date palm cultivar, where the traditional pollination technique led to 8.54 kg dates per branch, while the suspension method with the doses of 0.5, 1, and 1.5 g/L induced respective yields of 5.52, 6.21 and 7.19 kg dates per branch (Awad, 2011). The pragmatic variability of yield across pollination techniques underscores the importance of varietal components on date palm yield, regardless of the applied pollination technique. While our study focused on pollination methods, it is important to acknowledge that this variability could also be influenced by other factors such as genetic differences among cultivars and prevailing environmental conditions during flowering and fruit development. Our study confirmed that the rate of parthenocarpic fruits depended on pollination technique. The presence of parthenocarpic fruits is a significant threat to the yield and market value of date palm fruits, as they often result in malformed or underdeveloped fruits that are unfit for sale. In this study, parthenocarpic fruit formation was observed at a measurable rate, particularly in the traditional and pollen dusting methods. At the same time, the suspension technique resulted in the lowest incidence, making it economically favorable for farmers, as also reported by Kadri et al. (2019).

The rate of parthenocarpy observed in our study aligns with findings from other regions. For example, Awad (2011) reported parthenocarpic rates ranging between 5% and 15% depending on pollination efficiency and environmental factors. Similarly, Kadri et al. (2019) observed that poorly timed or incomplete pollination can lead to higher parthenocarpic fruit formation, especially in varieties such as 'Deglet Nour.' In our case, the 'Danshuwarin' cultivar showed relatively lower parthenocarpic rates under suspension pollination, suggesting that this method enhances fertilization success and reduces economic losses. These differences highlight the importance of selecting suitable pollination techniques not just for fruit set but also to minimize parthenocarpic formation, which can vary by cultivar, environment, and management practices. Further comparative studies across agroecological zones would be useful to generalize these findings. These results differ from those of Munir et al. (2020), who reported that the lowest level of parthenocarpic fruits was obtained with the suspension pollination technique, followed by the dusting pollination and traditional pollination techniques, respectively. The presence of parthenocarpic fruits is a real threat affecting the yield and market value of date palm fruits. Thus, the suspension pollination technique is economically the best pollination for farmers (Kadri et al., 2019). These results are closely related to the fruit set rate. A negative correlation exists between the fruit set rate and the fruit weight.

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Our study showed no significant variation in the weight, length, and width of the seeds between the different pollination techniques throughout the stages of fruit ripening. These results are consistent with those of Awad (2011) and Al-Qurashi (2011). However, other studies have shown contrasting results. Ullah et al. (2018) reported that the suspension pollination technique led to a higher seed weight (1.67

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g) compared to the traditional pollination (1.3 g). Similarly, Munir et al. (2020) found that the traditional method showed an increase in seed weight (1.15 cm) and seed length (20.4 mm), followed by the suspension and dusting methods, respectively.

These differences may be attributed to several factors, including genetic variation between the date palm varieties used, differences in environmental and climatic conditions (e.g., temperature, humidity, and soil type), and variations in experimental protocols such as the number of pollen grains applied, the timing of pollination, and the physiological status of the female palms. For instance, Munir et al. (2020) and Ullah et al. (2018) used different cultivars ('Hillawi' and 'Khalas'), which may inherently respond differently to pollination methods than the varieties used in our study. Moreover, seasonal and regional differences could influence nutrient accumulation, seed development, and hormonal responses, thus leading to contrasting outcomes.

Furthermore, no significant effect was observed on TSS, acidity, and fruit humidity across the different pollination methods. These findings are in agreement with Awad and Al-Qurashi (2012) for the 'Sabbaka' and 'Nabut Ali' varieties. However, other studies have shown that pollination techniques influence TSS. For example, Ullah et al. (2018) found that the highest TSS was obtained with the sprinkle pollination method (38.43%) on the 'Hillawi' cultivar, while Munir et al. (2020) reported the highest TSS (71.62%) in 'Khalas' using the sprinkle technique. Again, such discrepancies could stem from varietal responses to pollen source and technique, environmental variation, or differences in ripening stages at harvest. Some cultivars may exhibit stronger sink strength or sugar accumulation in response to specific pollination stimuli. In terms of acidity, our results align with earlier findings by Awad and Al-Qurashi (2012), suggesting that in certain varieties, pollination method does not significantly affect acidity levels. Our study showed no significant variation in the weight, length, and width of the seeds between the different pollination techniques throughout the stages of fruit ripening. These differences may be attributed to several factors, including genetic variation between the date palm varieties used, differences in environmental and climatic conditions (e.g., temperature, humidity, and soil type), and variations in experimental protocols such as the number of pollen grains applied, the timing of pollination, and the physiological status of the female palms. Ullah et al. (2018) showed that the suspension pollination technique led to a higher seed weight (1.67 g) compared to the traditional pollination (1.3 g). Munir et al. (2020) found that the traditional method resulted in an increase in seed weight (1.15 cm) and seed length (20.4 mm), followed by the suspension and dusting methods, respectively. Furthermore, no significant effect related to TSS, acidity, and fruit humidity. These results agree, which is consistent with the findings of Awad and Al-Qurashi (2012) on the varieties 'Nabut Ali' and 'Sabbaka.' Still, in our study, no significant effect of the different pollination methods was recorded on TSS, acidity, and fruit humidity.

The lack of significant effects on TSS and acidity in our study could be due to the intrinsic physiological and genetic control of these traits, which tend to be less influenced by external factors like pollination methods compared to characteristics such as fruit weight or moisture content (Awad & Al-Qurashi, 2012). Fruit weight and moisture are more directly affected by the efficiency of fertilization and subsequent resource allocation during fruit development, which can vary with pollination success. In contrast, TSS and acidity are influenced by internal metabolic processes and may exhibit greater stability across pollination methods, especially under uniform environmental and cultivation conditions (Awad & Al-Qurashi, 2012). These findings suggest that while pollination technique can influence some aspects of fruit development, its impact on certain biochemical parameters may be limited or cultivar-dependent. Further studies under varying environmental and genetic conditions could help clarify these relationships. These results agree with those of Awad and Al-Qurashi (2012) on the varieties 'Sabbaka' and 'Nabut Ali.' However, other studies have shown that pollination techniques influence TSS, like

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Ullah et al. (2018), who investigated the 'Hillawi' cultivar and found that the highest rate of TSS was obtained by the sprinkle pollination method (38.43%) compared to the traditional technique (35.77%). Likewise, Munir et al. (2020) reported that the highest TSS was recorded for the 'Khalas' cultivar using the sprinkle technique (71.62%), followed by the suspension method (69.60%) and the traditional pollination method (67.51%). Regarding fruit acidity, previous studies, such as Awad (2011) related to the 'Kenazy' cultivar and Awad and Al-Qurashi (2012) regarding the 'Nabut Ali' and 'Sabbaka' varieties, have shown that pollination techniques do not involved in fruit acidity.

Conclusions

Enhancing pollination methods is imperative for improving the production and quality of date palm fruits. The results of this study revealed that the pollen dusting method is the most efficient among all the methods tested for the dates 'Danshuwarin' cultivar, outperforming both the traditional and suspension pollination techniques. The effectiveness of the pollen dusting method is particularly promising, given its low cost and minimal technical expertise requirements. However, while this study focused on short-term outcomes such as fruit set and initial yield, it did not assess long-term effects on tree health, fruit quality over multiple seasons, or yield consistency. Therefore, further research is recommended to evaluate the sustainability of these techniques, including their potential impact on other date palm varieties across diverse agroecological zones in Nigeria.

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