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Phenotypic diversity of date palm male clones (*Phoenix dactylifera* L.) in morocco: a selection study

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Abstract

The selection of date palm interesting cultivars has focused over years on female trees, overlooking the importance of male trees despite their critical role in influencing date quality and yield. This study evaluated 20 male genotypes from southeast Morocco based on spathe morphology, strand traits, and pollen characteristics, revealing substantial phenotypic variability. Pearson's correlation revealed complex relationships among morphological traits analyses and dendrogram analysis grouped the genotypes into four clusters, highlighting the phenotypic diversity and informing targeted breeding and pollinator selection. Four genotypes INRA-DK17, INRA-DK16, INRA-DK5, and especially INRA-DK4, exhibited strong pollination potential, making them promising candidates for future breeding programs aimed at improving date production. Overall, this study sheds light on date palm male phenotypic diversity and emphasize the importance of investigating this diversity to orient male selection programs in Morocco.

Keywords Date palm male, *In vitro* germination, Phenotypic diversity, Pollen viability, Selection

1 Introduction

Date palm (*Phoenix dactylifera* L.), belongs to the family of *Arecaceae* and is one of the oldest fruit crops grown in the North African and middle eastern semi-arid and arid regions. It is a cornerstone of oasis agriculture, supporting food security, economic development, and environmental stabilization. World date production has increased at steady rate over the last three decades reaching 9.7 million tons in 2023, which is twice as much the production recorded in 1994 (4.6 million tons) [1]. This increase reflects growing international demand and the expansion of date palm cultivation in both traditional and new agricultural zones.

In Morocco, date palm is an essential element of the oasis ecosystem in the Saharan and pre-Saharan areas. Due to its economic importance and its ecological adaptation, it offers shade that protects the underlying crops against hot and dry winds and contributes to desertification mitigation. National efforts to boost the sector - through the



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Green Morocco Plan 2010–2020 and the Generation Green 2020–2030 strategy - have resulted in an expansion of cultivated area from 39,000 ha in 2009 to over 67,000 ha in 2023, raising national production to approximately 107,000 tons in 2023 [1].

Date palm is a dioecious species, meaning that male (staminate) and female (pistillate) flowers are borne on separate individuals. Artificial pollination, which involves manually transferring pollen from male to female inflorescences, is essential to achieve optimal fruit set [2]. A vigorous male palm can produce enough pollen to pollinate between 100 and 120 female trees [3]. However, one of the challenges facing date palm cultivation today is the limited availability of male plants, due to the widespread establishment of modern news plantations that have not maintained an appropriate male-to-female ratio [4]. This scarcity of pollen sources has made the selection and large-scale propagation of elite male genotypes a pressing priority for sustaining and enhancing date production.

In most date palm growing countries, including Morocco, growers commonly use pollen from seed-derived male plants to pollinate female palms without considering genetic quality. As a result, male populations are highly heterogeneous in terms of flowering time, pollen viability, spathe morphology, and overall pollination efficiency [5–11]. This variability has a significant effect on fruit yield and quality, influenced notably by metaxenia effects and pollen compatibility [12]. indicated that male and female individuals of the same or close date palm cultivars produce dates with higher quality compared with genetically separated ones. Several studies have demonstrated that pollen characteristics, including viability and compatibility, can significantly impact date set, quality and ripening time in several palm cultivars [13–16]. Consequently, selecting and characterizing superior male genotypes is crucial for optimizing productivity and improving fruit quality.

Although considerable efforts have been made to characterise female date palm cultivars using morphological and molecular markers [17–25], the selection and description of male palms remains relatively neglected [4, 26–28]. In Morocco in particular, information on the morphological and genetic variability of male palms is scarce, despite some recent progress [27]. In addition, innovative approaches such as artificial neural networks and predictive modelling are now being developed to assess pollen viability and predict pollination performance more efficiently [29]. Given the increasing reliance on artificial pollination, the identification and selection of elite male genotypes has become a critical priority, as the choice of pollen source significantly affects fruit set, quality and commercial value [28].

Despite the recognised importance of the pollen source for fruit set and quality, few studies have systematically explored the phenotypic diversity of male date palms, particularly in Morocco. Most existing reports are fragmentary and limited in scope, resulting in an inability to identify superior pollinators adapted to modern orchard conditions. Closing this knowledge gap is crucial for ensuring reliable pollination, enhancing productivity and supporting the long-term sustainability of the phoeniculture sector.

The purpose of this study was to investigate the diversity and performance of male date palms in Morocco. The study aimed to evaluate the variability in morphological traits and pollinating capacity of selected male date palms from southeastern Morocco compared to established reference genotypes. Additionally, the study sought to identify and select elite male genotypes with desirable characteristics for use in artificial pollination programs on a larger scale in the future.

2 Materials and methods

2.1 Plant material

The plant material used in this study consisted of 20 date palm (*Phoenix dactylifera* L.) male genotypes (Fig. 1). Seventeen palm males were selected from different geographical locations in southeastern Morocco during the season of 2023 in addition to three palm males (INRA-GS, INRA-NP3 and INRA-NP4) from a collection established at the experimental station of the National Institute for Agricultural Research, INRA-Morocco [3] (Table 1). These reference males were originally selected by INRA-Morocco primarily for their tolerance to Bayoud disease, and have since been widely used in breeding and pollination programmes, particularly within the framework of the state subsidy scheme under the ‘Plan Maroc Vert’ for oasis rehabilitation [30]. Although published data on their agronomic performance is scarce, a previous report confirmed their high pollen quality [31]. This study provides the first detailed phenotypic characterisation of these reference clones, highlighting the novelty and importance of this research. All plant material was collected with permission from the National Institute for Agricultural Research, INRA - Morocco and in accordance with national regulations for the conservation and use of plant genetic resources. For each male palm, three fully mature spathe at the stage of complete emergence were randomly sampled for all laboratory observations and measurements.

2.2 Spathe morphological characteristics

For each male, mean spathe length (MSL), width (MSWi), and weight (MSWe), were measured. In addition, the average number of strands per spathe (NSS), the total strand weight (TSW), the mean strand length (MSTL), as well as the average number of flowers per strand (NFS) were recorded based on measurements made on twenty randomly

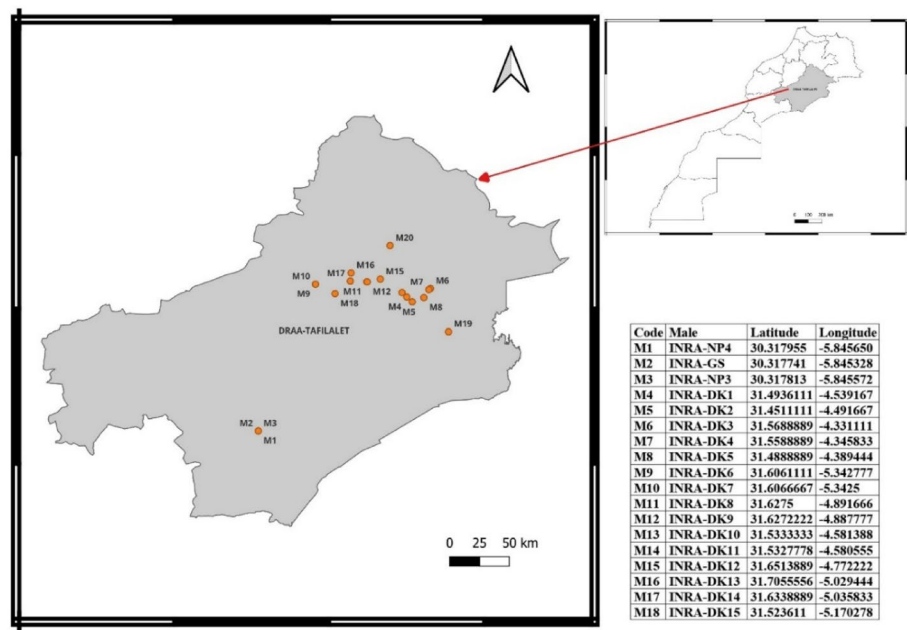


Fig. 1 Geographic distribution and identification codes of selected male date palm (*Phoenix dactylifera* L.) genotypes from the Draa-Tafilalet region, Southeastern Morocco

Table 1 Codes and geographic origins of male date palm genotypes selected from different geographical origins in south-eastern Morocco

Male	Origin	Latitude	Longitude
INRA-NP4	INRA Experimental Station of Zagora	30.317955	− 5.845650
INRA-GS		30.317741	− 5.845328
INRA-NP3		30.317813	− 5.845572
INRA-DK1	Fezna, Arfoud	31.4936111	− 4.539167
INRA-DK2		31.4511111	− 4.491667
INRA-DK3		31.5688889	− 4.331111
INRA-DK4		31.5588889	− 4.345833
INRA-DK5	Aarab Sebbah Gheris, Arfoud	31.4888889	− 4.389444
INRA-DK6	Aghbalou N'Kerdous, Goulmima	31.6061111	− 5.342777
INRA-DK7		31.6066667	− 5.3425
INRA-DK8	Melaab, Goulmima	31.6275	− 4.891666
INRA-DK9		31.6272222	− 4.887777
INRA-DK10		31.5333333	− 4.581388
INRA-DK11		31.5327778	− 4.580555
INRA-DK12	Gheris Es-Soufli, Goulmima	31.6513889	− 4.772222
INRA-DK13	Gheris El Ouloui, Goulmima	31.7055556	− 5.029444
INRA-DK14	Ferkla Es-Soufla, Goulmima	31.6338889	− 5.035833
INRA-DK15	Ferkla el oulia, Goulmima	31.523611	− 5.170278
INRA-DK16	Ksar Jir, Rissani	31.18932	− 4.17225
INRA-DK17	Tadighoust, Goulmima	31.9466667	− 4.686944

selected strands per spathe. Moreover, floral linear density (FLD) of each genotype was determined according to the equation: $FLD = NFS / MSTL$.

2.3 Pollen grains characteristics

For each genotype, pollen was collected by shaking the spathes, sifted, and allowed to dry for three days in a clean chamber before determining its weight. As soon as the pollen grains were collected, their viability was tested using an acetocarmine staining technique. Briefly, pollen was mounted between a slide and a coverslip in a drop of 45% acetocarmine. After a latency time of 5 min, the observation was made under light microscope. The estimation of the percentage of viability consisted of counting the proportion of viable to total pollen (stained). The percentage of viability was estimated on 300 pollen grains by observing 03 microscopic fields containing 100 pollen grains each.

In vitro germination test was carried out under aseptic conditions by plating an aliquot of 30 μ l of a pollen grain suspension having a concentration of 5000 grain/ml on standard media consisting of 100 ml of distilled water, 15 g of sucrose; 0.05 g of H_3BO_3 ; 0.03 g of $Ca(NO_3)_2 \cdot 4H_2O$; 0.02 g of $Mg SO_4 \cdot 7H_2O$; 0.01 g of KNO_3 and 1 g of agar [32]. Plates were incubated for one day under 27 °C. Subsequently, the percentage of germinating grains was estimated by observing 03 microscopic fields as described above. For each genotype, pollen germination percentage was defined as the ratio of the number of germinated grains to the total number of plated grains.

2.4 Pollinating potential

The pollinating potential (PP) of each genotype was determined according to the following equation:

$$PP_i = PGW * (PGR/100).$$

where P_{Pi}, P_{GW}, and P_{GR} representing respectively pollinating potential of genotype *i*, mean pollen grain weight per spathe (g), and mean pollen germination rate (%).

Genetic gain/loss in PP of different male palm genotypes compared to reference genotypes (INRA-GS, INRA-NP3 and INRA-NP4) was computed as the ratio of P_{Pi} (of male genotype) to P_{Pr} (of the reference genotypes).

2.5 Statistical analysis

All analyses were conducted on three spathe samples per date palm male using the SPSS software for Windows (Version 22). One-way ANOVA, followed by Duncan's new multiple range test (DMRT) was performed to determine differences among the studied date palm males at the significance level of $p < 0.05$. Additionally, Pearson's test was used to correlate the investigated parameters. Finally, cluster analysis of male palms was performed using squared Euclidean distance and Ward's method.

3 Results

3.1 Spathe morphological characteristics

There was a significant variability ($P < 0.001$) in spathe morphological traits among male palms (Fig. 2). The mean spathe length (MSL) ranged between 59.67 cm and 91.67 cm, found respectively on INRA-DK4 and INRA-DK9 for an average MSL of 81.2 cm (Fig. 2a). Similarly, the amplitude of variation in the mean spathe width (MSWi) was 10.67 cm (INRA-NP4) to 21.03 cm (INRA-DK13), with an average MSWi of 16.2 cm (Fig. 2b). This resulted in significant differences in male mean spathe weight (MSWe) among genotypes, though these dissimilarities were not tightly associated with MSL and MSWi as males with extreme MSWe, INRA-DK2 (3 kg) and INRA-NP4 (0.74 kg) (Fig. 2c), did not have the greatest or the smallest values of MSL or MSWi.

3.2 Strand characteristics

Significant variability ($P < 0.001$) was observed in the morphological strand characteristics of male palms, as shown in Fig. 3. The number of strands per spathe (NSS) ranged from 520.33 to 161 strands/spathe, with INRA-DK15 and INRA-DK12 exhibiting respectively the highest and lowest values, resulting in an average NSS of 279 strands/spathe (Fig. 3a). Similarly, the mean strand length (MSTL) showed considerable amplitude of variation from 23.5 cm for INRA-DK4 to 10.73 and INRA-DK7, and an average MSWi of 15.5 cm (Fig. 3b). These variations resulted in significant differences in male number of flowers per strand (NFS) among genotypes. However, it is noteworthy that differences in NSS were not closely related to variations in NFS or MSTL. For example, INRA-DK14 and INRA-GS having respectively the greatest (80.3 flowers/strand) and smallest (25 flowers/strand) NFS (Fig. 3c) did not have the highest or lowest values of NFS or MSTL. In terms of floral linear density (FLD), clear differences were observed among males, with the highest average FLD recorded for the INRA-DK8 male (4.5) and the lowest for the INRA-GS male (2.01), with an average NSS of 3.1 (Fig. 3d).

3.3 Pollen grains characteristics

Significant variability ($P < 0.001$) was observed in pollen grain characteristics of the male palm genotypes, as illustrated in Fig. 4. The mean pollen grain weight per spathe (MPWS) varied widely from 17.3 (INRA-DK15) to 75 (INRA-DK4) with an average NSS

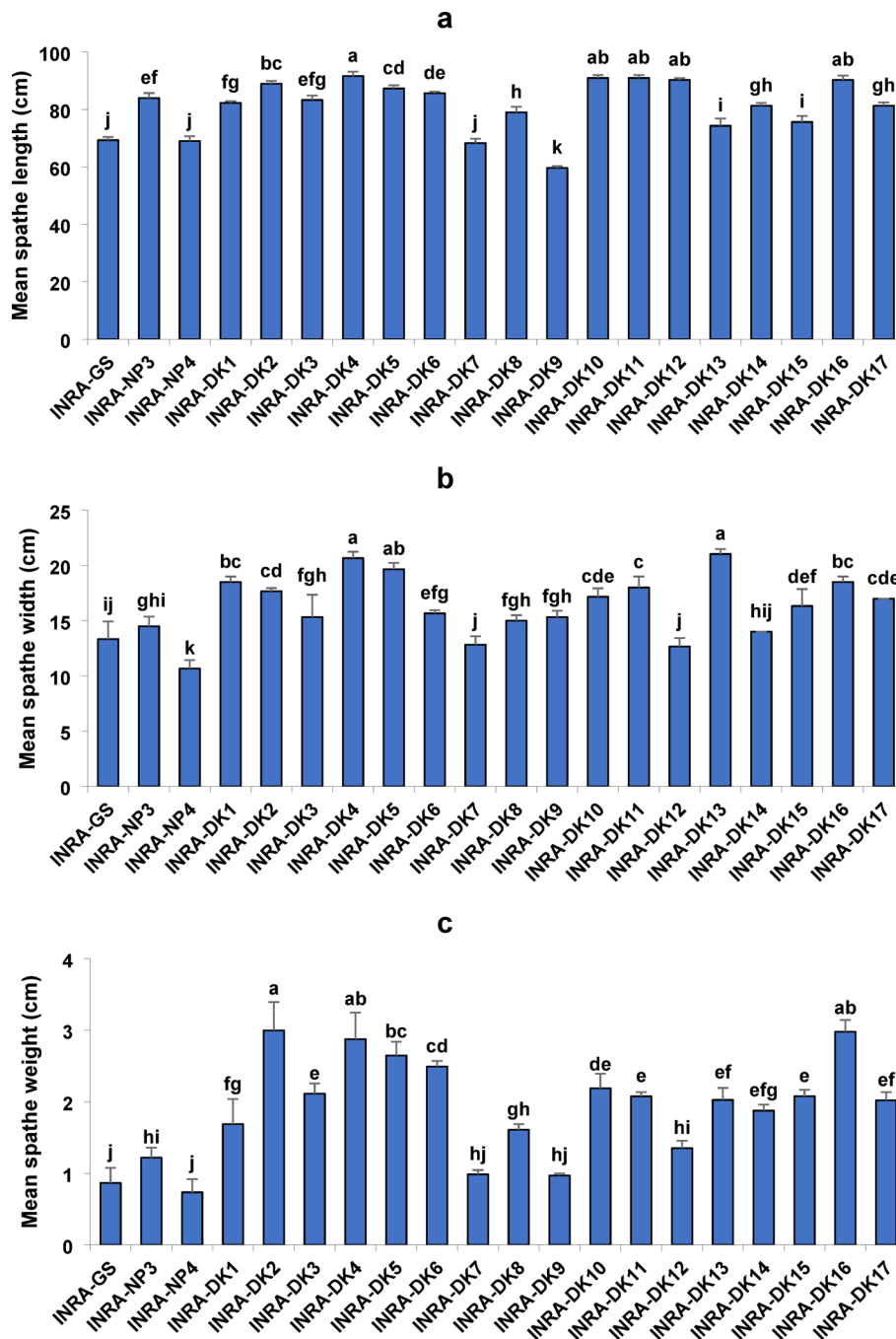


Fig. 2 Morphological spathe characteristics of the evaluated 20 male palm trees. **a** Mean spathe length (cm) **b** Mean spathe width (cm) **c** Mean spathe weight (Kg). Values with different alphabetical superscripts are significantly different ($p \leq 0.05$) according to DMRT

of 33.6 g (Fig. 4a). Similarly, pollen grain viability (PGV) fluctuated between 88.8% for INRA-DK1 and 98.7% for INRA-DK14 and averaged at 96.4% (Fig. 4b). Likewise, pollen grain germination rate (PGR) differed among selected males. The greatest PGR were recorded on INRA-DK5 (94.2%) and INRA-DK16 (93.7%), while the lowest was observed for INRA-DK1 (74.1%), resulting in an average PGR of 86.74% (Fig. 4c).

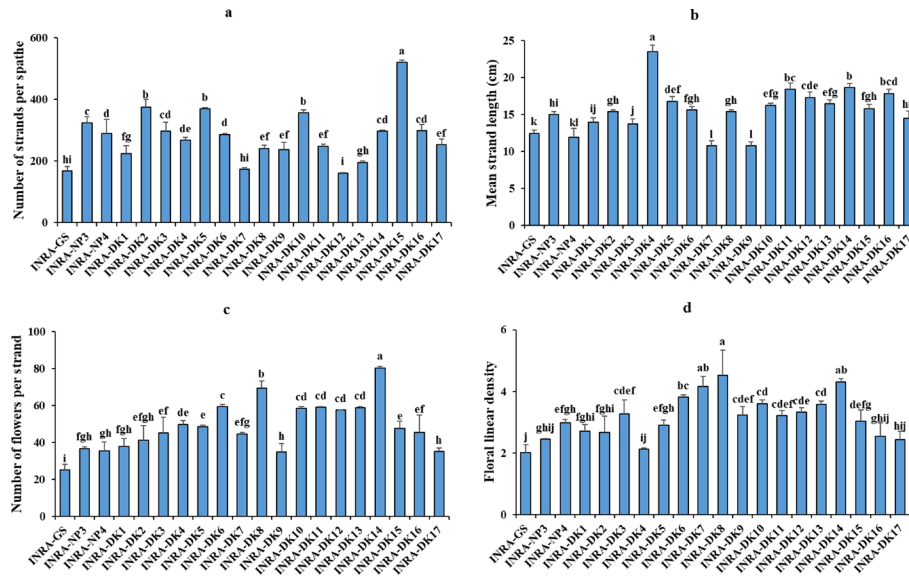


Fig. 3 Strand characteristics of the evaluated 20 male palm trees. **a** Number of strands per spathe **b** Mean strand length (cm) **c** Number of flowers per strand **d** Floral linear density. Values with different alphabetical superscripts are significantly different ($p \leq 0.05$) according to DMRT

3.4 Pollinating potential

This study revealed significant variation in pollinating potential (PP) among all the palm males under investigation (Fig. 5). Better pollinating traits in the genotypes INRA-DK1, INRA-DK2, INRA-DK3, INRA-DK4, INRA-DK5, INRA-DK10 INRA-DK16 and INRA-DK17 resulted in higher PP compared to two control genotypes, INRA-GS and INRA-NP4. More importantly, the PP of INRA-DK4 exceeded also that of the third control male, INRA-NP3. In fact, this genotype had a PP that is twice as high as that of INRA-GS and INRA-NP4 and three times greater than INRA-NP3.

3.5 Correlation among morphological spathe, strand, and pollen grains attributes

Pearson's correlation coefficients among the morphological spathe, strand and pollen grains traits evaluated in this study are shown in Table 2. A positive and highly significant association was observed between MSWe and MSWi ($r=0.756$, $P<0.01$), MSL ($r=0.737$, $P<0.01$) and MSTL ($r=0.686$, $P<0.01$). In addition, FLD exhibits a highly significant positive correlation with NFS ($r=0.752$, $P<0.01$) while demonstrating a significantly negative correlation with MPWS ($r = -0.64$, $P<0.01$). Additionally, MSTL was a significant positive correlate of MSL (0.759 , $P<0.01$), MSWi ($r=0.570$, $P<0.01$), NFS ($r=0.64$, $P<0.05$), PGR ($r=0.525$, $P<0.05$) and MPWS ($r=0.511$, $P<0.05$). Furthermore, a positive and highly significant association was observed between PGV and PGR ($r=0.783$, $P<0.01$), suggesting that a great PGV obtained by a rapid test of viability can be used as a caveat for assessing PGR before use at field scale.

3.6 Morphological classification of date palm pollinators

A dendrogram was constructed to assess the phenotypic relationships among 20 male date palm genotypes collected from southeast Morocco based on their morphological traits (Fig. 6). Using Ward's method, the pollinators were classified into four main groups, which showed significant differences in their morphological characteristics.

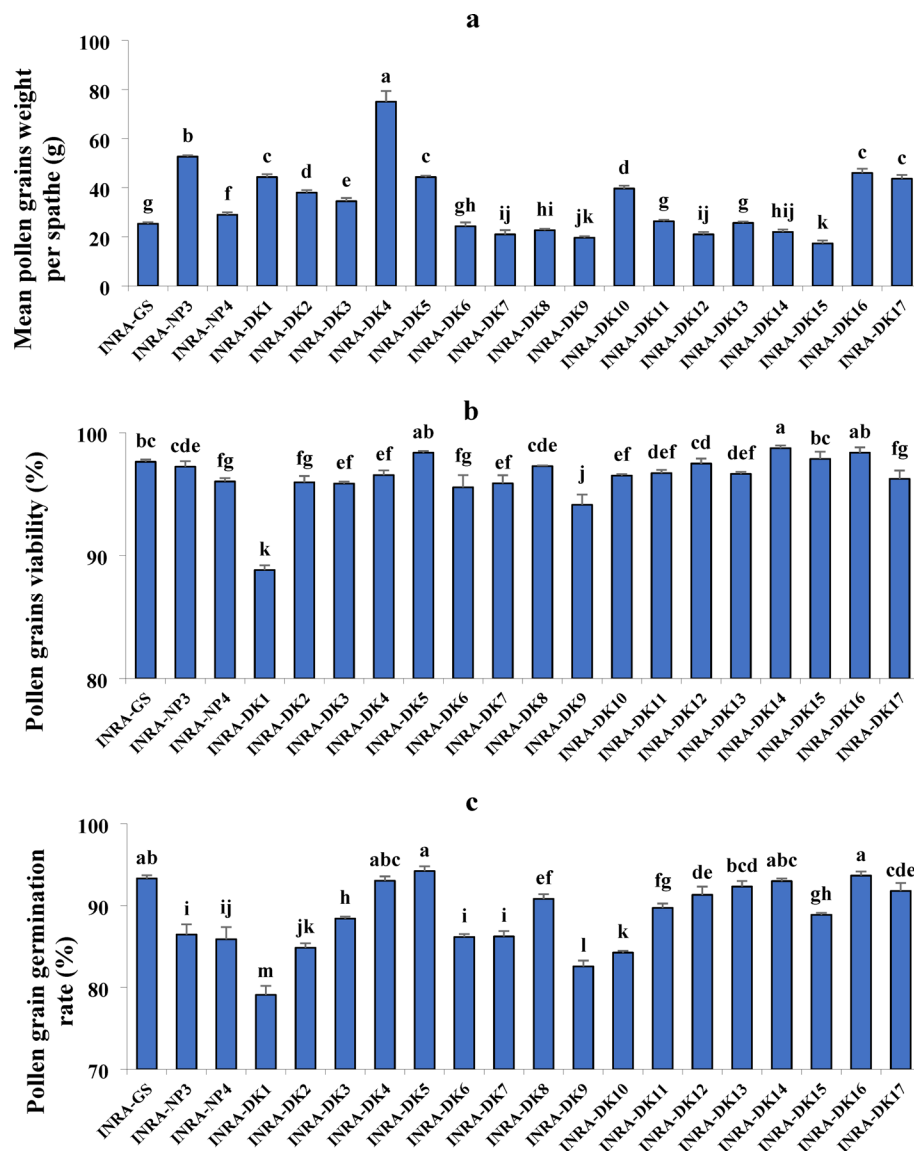


Fig. 4 Pollen grains characteristics of the evaluated 20 male palm trees. **a** Mean pollen grains weight per spathe (g) **b** Pollen grains viability (%) **c** Pollen grain germination rate (%). Values with different alphabetical superscripts are significantly different ($p \leq 0.05$) according to DMRT

Cluster 1 contains three genotypes (INRA-DK2, INRA-DK5 and INRA-DK10), which are phenotypically similar, as indicated by the short branch lengths. These genotypes share common morphological characteristics such as NSS, MSTL, and NFS. This close grouping suggests that these pollinators are well adapted to similar environmental conditions and could potentially have comparable reproductive performance, making them ideal candidates for breeding programs targeting uniformity in flowering time and pollen quality.

Cluster 2, the largest group, comprises the genotypes INRA-DK8, INRA-DK11, INRA-DK1, INRA-DK17, INRA-DK9, INRA-DK6, INRA-DK14, INRA-DK3, INRA-DK16, INRA-NP4, INRA-NP3, and INRA-DK4. The moderate branch lengths within this cluster indicate that although the genotypes are phenotypically related, there is still a considerable degree of variability in traits such as spathe size, pollen viability, and pollen

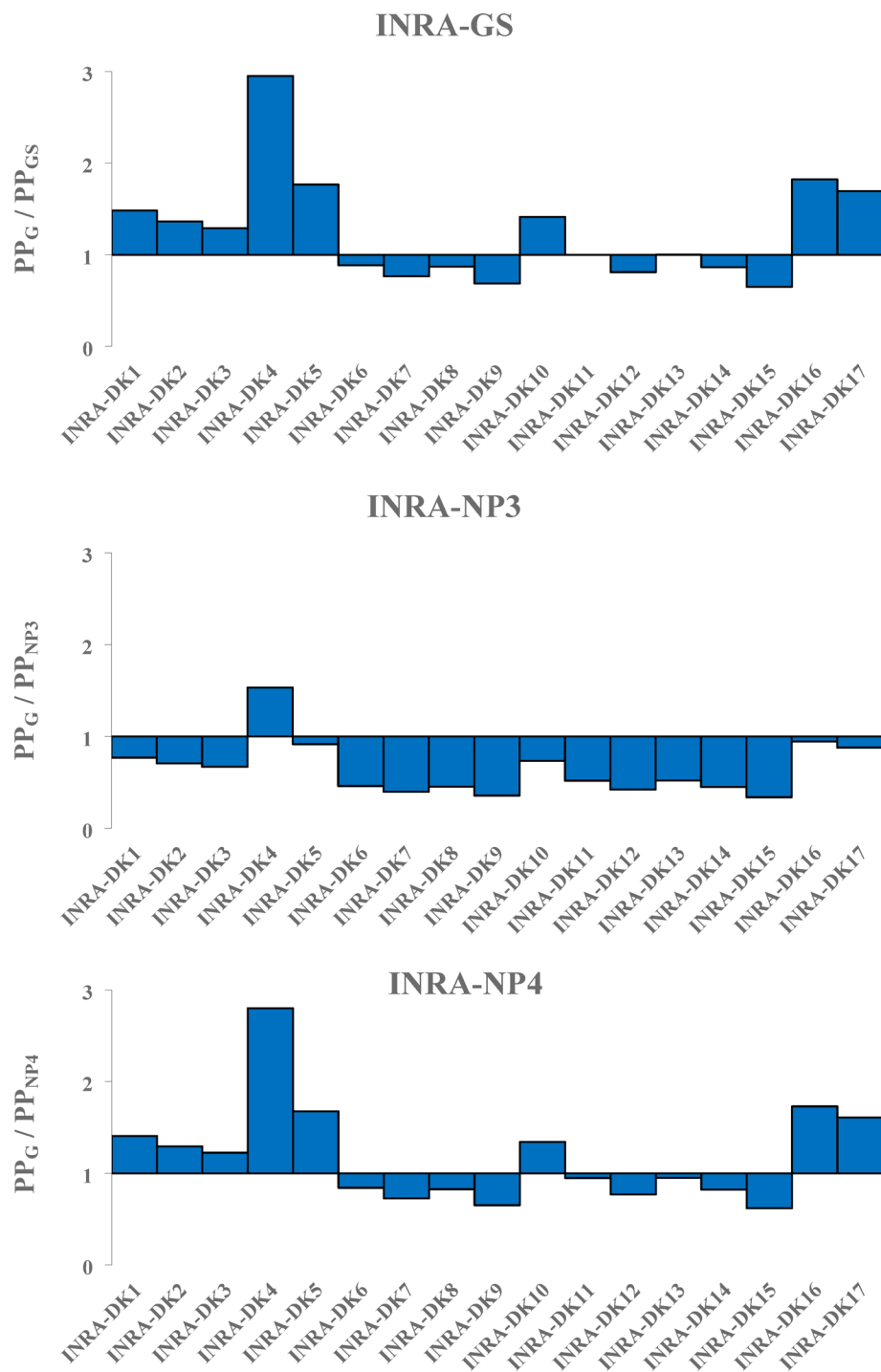


Fig. 5 Genetic gain in Pollinating Potential (PP) of different male palm genotypes compared to the check genotypes INRA-GS, INRA-NP3 and INRA-NP4. PP_G / PP_{GS} : Ratio of Pollinating Potential of male genotypes to Pollinating Potential of the check INRA-GS; PP_G / PP_{NP3} : Ratio of Pollinating Potential of male genotypes to Pollinating Potential of the check INRA-NP3; PP_G / PP_{NP4} : Ratio o Pollinating Potential of males genotypes to Pollinating Potential of the check INRA-NP4

Table 2 Matrix of correlation coefficients among characters of spathe morphology, strand and pollen grains of 20 male palm genotypes

	MSL (cm)	MSWi (cm)	MSWe (Kg)	NSS	MSTL (cm)	NFS	FLD	MPWS (g)	PGV (%)	PGR (%)
MSL (cm)		0.456*	0.737**	0.248	0.759**	0.377	-0.159	0.530*	0.168	0.230
MSWi (cm)			0.756**	0.209	0.570**	0.121	-0.267	0.527*	-0.126	0.179
MSWe (Kg)				0.468*	0.686**	0.301	-0.149	0.479*	0.162	0.275
NSS					0.191	0.055	-0.058	0.131	0.248	-0.069
MSTL (cm)						0.542*	-0.115	0.511*	0.335	0.525*
NFS							0.752**	-0.245	0.337	0.289
FLD								-0.640**	0.114	-0.091
MPWS (g)									-0.125	0.096
PGV (%)										0.783**
PGR (%)										

*, **Significant at the 0.05 and 0.01 level, respectively.

MSL, Mean spathe length (cm); MSWi, Mean spathe width (cm); MSWe, Mean spathe weight (kg); NSS, Number of strands per spathe; MSTL, Mean strand length (cm); NFS, Number of flowers per strand; FLD, Floral linear density; MPWS, Mean pollen grains weight per spathe (g); PGV, Pollen grains viability (%); PGR, Pollen grains germination rate (%).

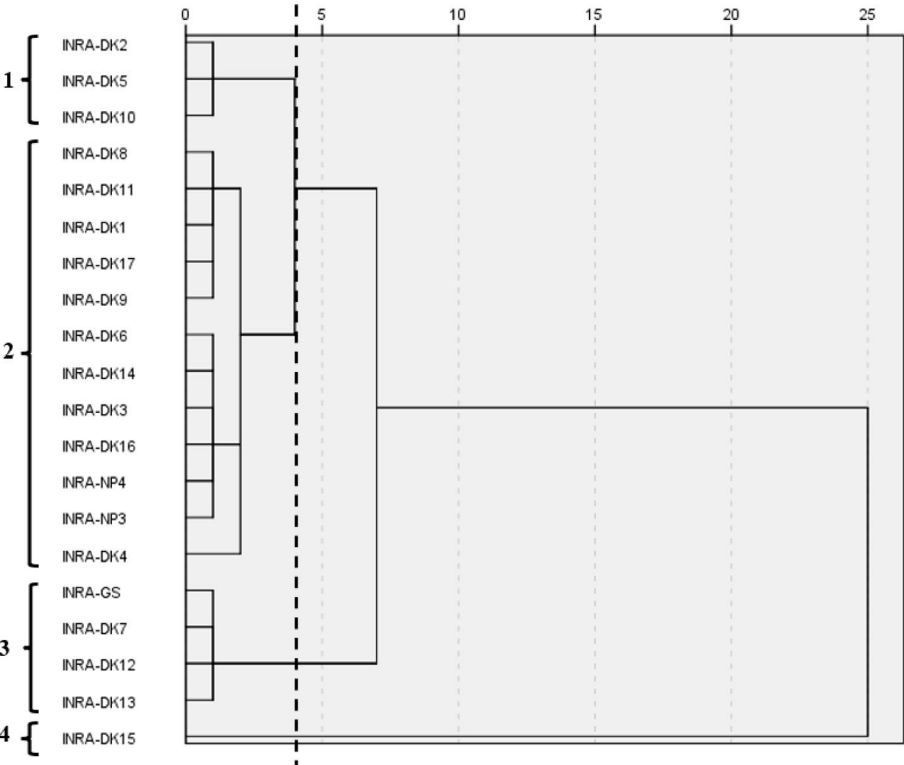


Fig. 6 Cluster of 20 male date palm genotypes collected from south-eastern Morocco genotypes based on morphological data using the Ward's method. The 20 pollinizers were classified into 4 main phenotypically related groups

germination rate. Cluster 3 (INRA-GS, INRA-DK7, INRA-DK12, and INRA-DK13) forms a distinct group, with genotypes showing significant differences from most of the population. The longer branch lengths separating these pollinators from other clusters suggest that they may exhibit unique morphological traits, such as a reduced spathe shape, along with lower quantities of pollen, as well as reduced pollen viability and germination rates.

Cluster 4, which includes INRA-DK15, stands out as the most distinct genotype. The large distance separating these genotypes from others suggests significant phenotypic divergence, possibly driven by adaptations to specific environmental stresses or unique genetic backgrounds. These genotypes may have traits that are rare in the wider population, such as reduced spathe shape and lower pollen production.

4 Discussion

This study revealed significant variation in spathe, strand and pollen grain traits, as well as pollinating potential among Moroccan male date palms. This variability reflects the wide genetic diversity found in local populations and highlighting their importance as a source for breeding and improvement programs. The observed differences are consistent with earlier reports on male palm populations in Egypt, Saudi Arabia, and Tunisia [14, 33, 34], confirming that reproductive morphology in date palms is highly influenced by both genotype and environmental factors.

Spathe size and weight were found to be key determinants of reproductive potential. Males with larger, heavier spathes are expected to produce greater pollen yields, enhancing their value as reliable pollinators. The identification of Moroccan genotypes surpassing reference males in spathe dimensions underscores their potential role to improve pollination efficiency in commercial plantations. Similarly, strand traits displayed wide variation, with some genotypes combining higher numbers of strands, longer strand length, and increased flower production. These attributes collectively contribute to a stronger reproductive capacity, confirming the value of strand architecture as a selection criterion for efficient pollinators.

Pollen grain characteristics further emphasized the presence of superior genotypes. High pollen viability and germination rates observed in several males indicate strong fertilization efficiency, in line with findings from [35, 36]. Such genotypes represent an untapped resource for improving fruit set and yield, especially in regions where traditional pollinators show reduced efficiency. The consistently strong correlation between viability and germination suggests that simple viability assays could serve as reliable predictors of pollen performance, facilitating rapid selection of superior pollinators for field use.

The observed variation in pollinating potential (PP) highlights the importance of considering both morphological and reproductive traits when selecting male genotypes for breeding and propagation. Genotypes such as INRA-DK4, which combine favourable spathe morphology with high pollen viability and superior PP, demonstrate how certain males can outperform traditional pollinators. These findings suggest an opportunity to enhance pollination efficiency in commercial orchards by prioritising genotypes that maximise both pollen output and fertilisation capacity. Furthermore, identifying such superior males provides a valuable resource for enhancing not only Moroccan date production, but also pollination systems in other date-growing regions worldwide.

The correlation analysis further clarified the relationships among spathe, strand, and pollen grain traits. Strong positive associations between spathe size, width, and strand length suggest coordinated morphological development, supporting earlier findings on integrated regulation of male reproductive traits [28]. Conversely, the negative relationship between floral density and pollen output reflects a trade-off between investment in flower number versus pollen quality, a pattern consistent with other reproductive

systems [37]. These correlations reveal a complex web of interdependencies among different morphological traits and shed light on the intricate dynamics governing male development and reproduction. In particular, the coherent relationship between larger spathe size and its concomitant wider and longer dimensions suggests a coordinated morphological evolution, pointing to underlying regulatory mechanisms at play. In addition, increased floral linear density, corresponding to an increased number of flowers per strand, is accompanied by a decreased mean pollen grain weight per spathe. This negative correlation underscores a nuanced equilibrium in floral development, accentuating the multifaceted intricacies within floral architecture. Such observations emphasize the necessity for a comprehensive understanding of reproductive processes underlying the interconnectedness of morphological traits and their collective impact on plant reproduction [28, 37]. Moreover, the integration of morphological traits influencing strand formation, as evidenced by the associations with strand length, spathe dimensions, and pollen grain characteristics, highlights the intricate coordination in shaping reproductive structures. The consistently strong correlation between pollen grain viability and germination rate further reveals a fundamental link between viability and functional efficiency, underlining the central role of reproductive success in plant fitness. Overall, these findings highlight the complex network of relationships between morphological traits in male palms and provide valuable insights into the underlying mechanisms governing male palm development and reproduction.

Cluster analysis revealed four groups of male palms, showing both phenotypic similarities and differences within the population. Genotypes in clusters 1 and 2 exhibited favourable reproductive traits, making them ideal candidates for breeding programmes aimed at improving pollen quality and synchronising flowering with female varieties. In contrast, the distinct genotypes in clusters 3 and 4, while less productive, may harbour unique adaptations to marginal environments, such as stress tolerance. Including them in breeding programmes would help to conserve genetic diversity and introduce traits that improve resilience and adaptability. This is consistent with findings from Tunisian and Saudi male populations [29, 37].

Overall, the variability documented in this study highlights the biological and agronomic importance of Moroccan male date palms. Identifying males with superior spathe morphology, high pollen viability and strong pollinating potential, particularly INRA-DK4, provides valuable opportunities to improve orchard productivity and stabilise fruit set. At the same time, the presence of divergent genotypes ensures a genetic buffer against environmental stress, supporting the long-term sustainability of date palm cultivation in arid regions.

These findings provide a basic framework for the systematic selection and propagation of elite male date palm genotypes to improve pollination efficiency and contribute to the sustainability of date production systems in Morocco. However, further studies are needed to validate the pollination efficiency of the identified genotypes under controlled hybridisation conditions with elite female cultivars (Boufeggous, Mejhoul). This will be essential to quantify their effects on fruit yield and quality through metaxenia and compatibility interactions. Although such validation was beyond the scope of this study, it remains an important avenue for future research.

To enhance the understanding of the observed traits, it is highly recommended to use molecular tools to uncover the genetic underpinnings. This integration will not only

support morphological evaluations but also aid in marker-assisted selection, leading to the faster development and adoption of high-quality male clones in date palm farming. The identification of superior male genotypes like INRA-DK4, INRA-DK5, INRA-DK16, and INRA-DK17 is a significant advancement in optimizing date palm cultivation in Morocco and enhancing the industry's sustainability.

5 Conclusion

This study assesses 20 male date palm genotypes in southeastern Morocco, highlighting variations in spathe morphology, strand features, and pollen traits. Among the genotypes, INRA-DK4, INRA-DK5, INRA-DK16, and INRA-DK17 exhibited superior pollen production, viability, and germination rates. INRA-DK4, in particular, shows promise for breeding and artificial pollination initiatives to improve fruit yield and quality due to its exceptional pollination potential. The correlations observed among morphological and reproductive traits provide valuable criteria for selecting high-performing pollinators, and cluster analysis confirms the genetic resources available for breeding and conservation. These findings establish a framework for the systematic selection and propagation of elite males to enhance pollination efficiency and orchard productivity.

Author contributions

Souhail CHANNAOUI, Reda Meziani, and Adil Essarioui contributed to the conception and design of the study. Material preparation, data collection, and analysis were conducted by Souhail CHANNAOUI, Safae AQIL, and Achraf HDOUDOUCH. The first draft of the manuscript was written by Souhail CHANNAOUI, while Reda Meziani and Adil Essarioui provided comments on previous versions. All authors reviewed and approved the final manuscript.

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Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval and consent to participate

Collection and handling of date palm plant material complied with Moroccan national guidelines on plant genetic resource conservation. All plant material was sourced from cultivated palms, and no endangered or protected species were involved. This study was conducted in accordance with Moroccan national guidelines on the collection and use of plant genetic resources. Appropriate institutional permissions for plant material collection were obtained from the National Institute for Agricultural Research, INRA-Morocco.

Clinical Trial Registration

Not applicable.

Consent to publish

Not applicable.

Consent to participate

Not applicable.

Competing interests

The authors declare no competing interests.

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