Selection of elite male date palm (*Phoenix dactylifera* L.) genotypes based on floral phenology, stability and pollen production potential at Kachchh, India

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Receipt: 27.04.2025 Revised: 28.08.2025 Acceptance: 30.08.2025
DOI: https://doi.org/10.53552/ijmfmap.11.2.2025.46-55

ABSTRACT

Date palm (Phoenix dactylifera L.) is a vital crop in arid and semi-arid regions, where genetic diversity of the females is majorly studied for its commercial point of view. While, worldwide there are a few selected male varieties, overall, their presence is limited compared to females. In dates males are equally important as they contribute to the fruit yield and quality. Thus, a study has been conducted at Date Palm Research Station, Mundra for nine male date palm genotypes for the reproductive traits during 2020 to 2023. The data were analyzed using principal component analysis and hierarchical cluster analysis. The results revealed that MDP-M1, MDP-M3 and MDP-M5 are early flowering genotypes with stable flowering period, while MDP-M3 and MDP-13 are superior in pollen production. Male dates showed diversity in spathe opening time ranged for 45 days (27 January to 12 March). The flowering duration for each genotype was 23.25 to 30.50 days with a narrow range of duration. The genotypes showed early, medium and late flowering period. PCA with first three principal components with eigen value greater than unity explained 87.6 % of total variance majorly based on pollen yield and spathe traits. The genotypes, MDP-M3 and MDP-M13 depicted association with pollen production quantity per spathe and per palm making them efficient pollinizers and HCA further clustered these genotypes into same cluster. This study helps to accumulate the data for high pollen yielding ability and early flowering genotypes for identification of superior male as pollinizers.

Keywords: Date palm, hierarchical clustering, male genotypes, PCA, variability

INTRODUCTION

Date palm (*Phoenix dactylifera* L.) is a dioecious perennial fruit crop of importance in the arid and semi-arid regions of the world. Around the world there are more than 5000 varieties have been identified, among them, few are of prime importance around the world (Jaradat and Zaid, 2004). Most identified female genotypes had significant variation, however, variability among the male is also play a crucial role in artificial pollination, which is essential for optimizing fruit yield and quality (Jaradat and Zaid, 2004). The flowering period and fruiting has genotypic specificity and it also depends on geographic location and environmental conditions of the area (Sharma *et al.*, 2025).

Farmers often use stored pollen grains from the known male for pollination, however in some cases inability of the stored pollens led farmers to use pollens grains from unknown male which might cause reduced fruit set and/or may produce negative metaxenic effects on fruit yield and quality (Kadri *et al*., 2019, Sharma *et al*., 2023). In such cases, there is need to study pollinisers to be used for pollinating the female dates (Abdel-Sattar *et al.*, 2024). The selection of good quality male pollinisers for flowering duration, spathe related traits and pollen production help us to identify the desirable male dates for further use. In this regards, Sharma *et al*. (2023) reported important traits to identify the superior male genotypes as a pollinator such as pollen production, pollen viability, spathe size and related characters. Despite their importance, male date palm genotypes remain relatively unexplored compared to female genotypes or cultivars, leading to a lack of systematic characterization and conservation efforts. Kadri *et al.* (2022) reported pollens collected from spathes developed at the middle of flowering stage depicted high viability up to 90% with germinability of 85%.

In India, particularly in the Kachchh region of Gujarat, date palm cultivation is present for 450 years, however, a major exploration and expansion has taken place in the last two decades (Baidiyavadra *et al*., 2019; Sharma *et al*., 2019). However, the information on the diversity and characteristics of locally available male genotypes is limited. Previously, in few of the date palm growing region, the male genotypes are characterized for their variability and the identification of their distinctness which can contribute to improve fruit production (El-Kadri *et al*., 2019; Raza *et al*., 2020). Such assessment helps in the identification of genetically distinct and superior male palms. The comprehensive study of the available genetic resource of the location help us to generate data which contribute to preserve the diversity of the region also support the development of conservational aspects of agricultural practices in the country (Musayev and Bayramov, 2025). This study aims to evaluate the morphological diversity among the male date palm genotypes in Kachchh, India using standard descriptors and identify the relationship between the characters and genotypes using principal component analysis and hierarchal study.

MATERIALS AND METHODS

The experiment was conducted at Date Palm Research Station, Sardarkrushinagar Dantiwada Agricultural University, Mundra-Kachchh, Gujarat, India (22°49’19.7”N,69°43’16.7”E) during 2020-2023. The nine male genotypes under study (MDP-M1, MDP-M2, MDP-M3, MDP-M4, MDP-M5, MDP-M6, MDP-M13, MDP-M19 and MDP-M29) are the selection from the in-situ germplasm at Date Palm Research Station, Mundra which were primarily evaluated for further screening. The plants selected for the study were uniform with age of 15 years old. The soil conditions of the research station were sandy soil with pH of 8.22, EC of 0.170 dSm^{-1}. The selected palms for the present study were maintained under uniform agronomic practices including pollination, pruning, dethorning, etc. Irrigation was provided through drip with an average of 200 liters of water per palm per day. The water quality for irrigation during the experimental period was pH of 7.57, EC of 7.5 dSm^{-1}, Sodium Adsorption Ratio (SAR) of 25.40, Residual Sodium Carbonate (RSC) of 3.30 meq/lit. The climatic condition of the regions was semi-arid with an annual temperature ranges from 6°C to 42 °C and average of annual rainfall 472 mm (average of 30 years), falling under Gujarat North Agro-Climatic Zone -V.

Key phenological, reproductive, and morphological parameters were recorded to assess variability among male date palm genotypes, i.e., phenological traits like the day of first spathe opening, day of last spathe opening, number of spathes per plant, and flowering duration (measured as the number of days between the first and last spathe opening); reproductive characters like the

average amount of pollen per spathe (g) and estimating the approximate total pollen production per palm (g) based on the number of spathes; and morphological characters of spathe like its length (cm), width (cm), average number of strands per spathe, and average number of florets per strand. The characters and flowering duration were recorded for four years for each plant.

Statistical analyses were analyzed using R programming to examine the variability in recorded traits. Descriptive statistics, including mean, standard deviation were computed to quantify the extent of variation among the genotypes. Each genotype was having single plant which were analyzed for four years treated as local replications for analysis. Principal component analysis, biplot analysis and hierarchical cluster analysis were generated using R programming (R Core Team, 2024) using FactoMineR and ggplot2 packages.

RESULTS AND DISCUSSION

Morphological characterization

The flowering period with first and last date of spathe opening for different date palm genotypes over four years are presented in the Table 1. In all the four years, genotypes like MDP-M1, MDP-M2, and MDP-M3 shows consistent early flowering, while MDP-M6 and MDP-M29 tended to flower late. Early flowering is desirable as it facilitates synchronisation of pollination for early maturing females. The last spathe opening also followed a pattern of stability, with MDP-M1, MDP-M3, and MDP-M5 completing flowering by end of February or in March first week in most years proposing predictable timing for pollination making it more economical trait, whereas MDP-M6 and MDP-M29 often ends flowering in mid or late of March. This makes the genotype MDP-M1, MDP-M3, and MDP-M5 advantageous for predictable pollination timing. In contrast, MDP-M6 and MDP-M29 exhibited the most variation, extending flowering periods in certain years, which might require additional pollen availability for effective pollination. There is around 45 days of span for male spathe openings in all genotypes. Some late flowering genotypes could be used for female flowered lately in the field. This staggered flowering among the genotypes facilitates pollen availability over a time. For efficient pollination, early maturing male genotypes are preferred as fresh pollen is available for current season pollination (Sharma *et al*., 2023).

The phenotypic traits of male date palm genotypes are presented in the Table 2. The analysis of phenotypic traits across nine date palm genotypes reveals significant variation in reproductive characteristics, pollen production, and spathe morphology. The number of spathes per plant ranged from 15.25 in MDP-M4 to 31.25 in MDP-M3, with an average of 21.00 and a standard deviation of 5.86, indicating moderate variability among genotypes. The flowering duration varied from 23.25 days (MDP-M3) to 30.50 days (MDP-M2), with a mean of 26.08 days, suggesting a relatively narrow range of flowering time among the genotypes. Pollen yield among the various genotype showed that MDP-M3 produced the highest average pollen per spathe (21.20 g) followed by MDP-M13 (20.60 g) and the total pollen per palm (662.18 g and 418.19 g, respectively), while MDP-M4 produced lower amount of pollen (11.07 g per spathe and 168.44 g per palm). This shows that MDP-M3 and MDP-M13 are important genotype for selection for pollen production. Since manual pollination is practiced, male dates with high pollen yield could be advantageous for large scale dates cultivation. Maturation of early flowering allows availability of pollen for pollinating female plants. It has been observed that pollen receptivity of plants varies from one day to one week based on the genotype but after that period, the pistillate fails to receive the pollen and may cause parthenocarpic fruits which are of inferior quality and does not possess any market value (Sharma *et al*., 2023; Muralidharan *et al*., 2020). Moreover, higher pollen production may allow pollinating a greater number of spathes or

plants (Sharma *et al*., 2021). Additionally, pollen has commercial value and are sold at premium prices during peak flowering season. Hence, late availability of pollen may be useful for late flowering females.

The length of the spathe ranged from 50.82 cm in MDP-M5 to 83.57 cm in MDP-M1, with an average of 60.61 cm, while spathe width varies from 9.16 cm in MDP-M6 to 18.87 cm in MDP-M3. The average number of strands per spathe was highest in MDP-M2 (203.01) followed by MDP-M13 (195.25) and lowest number of strands were observed in MDP-M5 (127.83), while, the average number of florets per strand varied between 38.79 (MDP-M29) and 71.30 (MDP-M4), with a mean of 57.31. Earlier, El-Kadri *et al.* (2019) reported the presence of largest spathe with 40.00 cm long, 10.00 cm wide and 413.33 average number of spikelets, suggesting the potential of the number of strands in males. The spathe weight ranges from 0.87 kg (MDP-M5) to 1.84 kg (MDP-M1), and spathe weight without cover followed a similar trend, varying from 0.33 kg in MDP-M5 to 0.81 kg in MDP-M1 and MDP-M13. It can be noted that MDP-M1 have largest spathes, both in length (83.57 cm) and weight (1.84 kg), however, the overall pollen production is low, while MDP-M5 and MDP-M4 exhibited smaller spathes and lower pollen production suggesting making them unfit for commercial usage. For prioritizing high pollen yielding genotypes MDP-M3 and MDP-M13 are better, while selecting genotypes with early flowering and moderate spathe structures MDP-M13 and MDP-M2 may be beneficial. Other traits of MDP-M3 and MDP-M 13 showed being moderate in length, number of strands per spathe, florets per strand and spathe weight its pollen load was superior making them better pollinizers with medium flowral structure. Early flowering of male allows higher success of pollination thus allows better revenue, while higher pollen production enhances commercial value. Also, medium length of the spathe might be efficient pollen producers and dispersal, while larger spathe could be less manageable.

Principal Component Analysis

The variance and eigen value of the principal component analysis are presented in Table 3. The first two principal components (PCs) accounts for high variability with 49.6% and 24.3 %, respectively, representing cumulative variability of 73.9 % explaining major variability of the data set. The eigen value of first two PCs were 5.578 and 2.739, respectively. PC3 and PC4 explains 13.7 % and 6.7% and from PC5 to PC9 combined explains 5.6% of the variance. This indicates that the first two or three components are sufficient for visualizing genotype differences and reducing dimensionality while, retaining most of the data's information. The high variance explained by PC1 and PC2 suggests strong correlations among the original traits, making them useful for genotype differentiation and classification in breeding programs.

The PC scores for are presented in Table 4 and the character loading is presented in Table 5, which provides insight of how different date palm genotypes are distributed across the first three principal components (PCs). The genotype, MDP-M1 (3.12) and MDP-M3 (2.83) have high positive values for PC1, which indicates that they exhibit strong characteristics related to the spathe characters like spathe weight (with or without cover), spathe width, number of strands, and number of spathes per plant. These characters can be considered as key characters to differentiate among the genotypes. On the other hand, MDP-M6 (-2.97) and MDP-M5 (-2.85) have low PC1 values, suggesting they show opposite trends in these traits. In PC2, high scores were observed in MDP-M3 (2.92) and MDP-M5 (1.58) which shows strongly association of traits like amount of pollen per spathe, pollen per palm and negatively linked with flowering duration, and number of florets per strand. This also indicates that MDP-M3 and MDP-M5 are important genotypes for pollen

production but have shorter flowering period and lower number of florets. In PC3, MDP-M4 (2.44) stands out with the highest value, suggesting it has distinct features with negatively linked traits like flowering duration, length of spathe, and number of spathes per plant (-0.387), whereas MDP-M29 (-1.27) and MDP-M6 (-0.99) have negative values, indicating their negative relationship.

The principal component analysis biplot is presented in Figure 1. The collective presentation of PC1 and PC2 explains 73.9 % of the total variation, where, MDP-M3 and MDP-M13 are positioned in the upper right quadrant, showing a strong association with amount of pollen per spathe pollen per palm, suggesting these genotypes are superior in pollen production. While, genotypes MDP-M1 and MDP-M2 are located towards the right which are strongly influenced by characters like number of spathes per plant and weight of spathe without cover, indicating their relationship with spathe characters. In contrast, MDP-M19 and MDP-M4 are positioned on the negative PC1 axis, meaning they exhibit opposing traits compared to those in the right quadrant. The direction and length of the arrow for the trait represents the contribution of the trait towards variation and its correlation with other trait. The traits such as average amount of pollen per spathe, approximate pollen per palm, number of spathes per plant and width of the spathe are grouped together and pointing upper right quadrant suggesting these traits are positively associated. The weight and length of the spathe could be indicator of overall male flower quality and pollen production ability of the male dates.

Hierarchical Cluster Analysis

The hierarchical cluster analysis (HCA) dendrogram is presented in the Figure 2 providing a structured representation of the genetic relationships among different genotypes using Ward's method. The different genotypes are presented in x-axis while the dissimilarity (distance) among the genotypes is presented in y-axis, with larger values indicating greater differences and they are grouped based on their similarity. The analysis reveals three distinct clusters, each highlighted in different colors, *i.e.*, pink, red and orange. The first cluster (pink) is the largest, comprising MDP-M19, MDP-M4, MDP-M1, and MDP-M2, implying that these genotypes have closely related characteristics like high number of florets. The second cluster (red) consists of MDP-M13 and MDP-M3, suggesting moderate similarity between them but distinct differences from the first group. These two genotypes are high pollen producing genotypes. The third cluster (orange) includes MDP-M5, MDP-M29, and MDP-M6, and as per PCA they are distinct group with limited similarity.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1: Flowering period of different date palm male genotypes

Genotype	2020		2021		2022		2023	
	Day of First spathe opening	Day of Last spathe opening	Day of First spathe opening	Day of Last spathe opening	Day of First spathe opening	Day of Last spathe opening	Day of First spathe opening	Day of Last spathe opening
MDP-M1	27-Jan	01-Mar	30-Jan	28-Feb	28-Jan	25-Feb	10-Feb	28-Feb
MDP-M2	30-Jan	06-Mar	02-Feb	08-Mar	01-Feb	02-Mar	05-Feb	27-Feb
MDP-M3	02-Feb	28-Feb	05-Feb	25-Feb	10-Feb	10-Mar	08-Feb	02-Mar
MDP-M4	10-Feb	01-Mar	05-Feb	03-Mar	09-Feb	03-Mar	03-Feb	28-Feb
MDP-M5	01-Feb	28-Feb	06-Feb	03-Mar	05-Feb	03-Mar	10-Feb	26-Feb
MDP-M6	15-Feb	20-Mar	08-Feb	10-Mar	09-Feb	01-Mar	05-Feb	05-Mar
MDP-M13	11-Feb	03-Mar	05-Feb	01-Mar	04-Feb	05-Mar	10-Feb	01-Mar
MDP-M19	11-Feb	01-Mar	03-Feb	06-Mar	01-Feb	10-Mar	12-Feb	02-Mar
MDP-M29	06-Feb	05-Mar	10-Feb	03-Mar	05-Feb	11-Mar	10-Feb	12-Mar

Table 2: Phenotypic variation in different male date palm genotypes (averaged for the year 2020-2023)

Genotype	Number of spathes per plant	Flowering Duration (days)	Avg. Amount of pollen per spathe (g)	Approx. pollen per palm (g)	Length of spathe (cm)	Width of spathe (cm)	Avg. No. of strands per spathe	Avg. No. of Florets per strand	Weight of spathe (kg)	Weight of spathe without cover (kg)
MDP-M1	26.25	26.75	13.72	360.70	83.57	14.32	187.95	70.68	1.84	0.81
MDP-M2	27.50	30.50	11.19	309.21	60.94	14.58	203.01	63.08	1.53	0.52
MDP-M3	31.25	23.25	21.20	662.18	61.77	18.87	177.63	49.92	1.46	0.73
MDP-M4	15.25	23.50	11.07	168.44	52.07	16.00	188.60	71.30	1.32	0.55
MDP-M5	16.00	23.50	17.93	285.83	50.82	11.74	127.83	45.51	0.87	0.33
MDP-M6	15.75	28.00	16.93	266.30	56.11	9.16	129.67	46.47	0.99	0.35
MDP-M13	20.25	23.75	20.60	418.19	65.22	15.71	195.25	60.49	1.26	0.81
MDP-M19	18.00	27.25	11.54	208.89	55.89	15.36	153.96	69.54	1.31	0.58
MDP-M29	18.75	28.25	12.22	229.96	59.11	10.55	141.58	38.79	0.91	0.51
Mean	21.00	26.08	15.15	323.30	60.61	14.03	167.27	57.31	1.28	0.58
S.D.	5.86	2.66	4.08	148.27	9.77	3.03	29.28	12.36	0.32	0.18
Max.	31.25	30.50	21.20	662.18	83.57	18.87	203.01	71.30	1.84	0.81
Min.	15.25	23.25	11.07	168.44	50.82	9.16	127.83	38.79	0.87	0.33

Table 3: Eigen value and variance of principal component for variables

Principal Component	Eigen value	Variance Explained	Per cent cumulative variation
PC1	5.578	0.496	49.6
PC2	2.739	0.243	73.9
PC3	1.539	0.137	87.6
PC4	0.759	0.067	94.4
PC5	0.269	0.024	96.7
PC6	0.216	0.019	98.7
PC7	0.140	0.012	99.9
PC8	0.010	0.001	100.0
PC9	0.000	0.000	100.0

Table 4: PC scores for different genotypes across PCs

Genotype	PC1	PC2	PC3
MDP-M1	3.12	-1.32	-1.04
MDP-M2	1.09	-1.88	-1.05
MDP-M3	2.83	2.92	-0.22
MDP-M4	-0.13	-1.31	2.44
MDP-M5	-2.85	1.58	0.54
MDP-M6	-2.97	0.35	-0.99
MDP-M13	1.69	1.30	0.73
MDP-M19	-0.39	-1.44	0.85
MDP-M29	-2.40	-0.20	-1.27

Table 5: Character loading of different principal components for various traits

Principal Components	Number of spathes per plant	Flowering Duration	Avg. Amount of pollen per spathe (g)	Approx. pollen per palm (g)	Length of spathe (cm)	Width of spathe (cm)	Avg. No. of strands per spathe	Avg. No. of Florets per strand	Weight of spathe (kg)	Weight of spathe without cover (kg)
PC1	0.358	-0.078	0.078	0.286	0.318	0.366	0.380	0.262	0.405	0.407
PC2	0.103	-0.412	0.596	0.456	-0.100	0.093	-0.176	-0.394	-0.227	0.034
PC3	-0.387	-0.576	-0.026	-0.203	-0.396	0.375	0.142	0.392	-0.065	0.031
PC4	0.416	0.270	-0.207	0.187	-0.609	0.377	0.183	-0.126	-0.021	-0.337
PC5	-0.182	0.202	0.106	-0.115	-0.087	-0.105	0.705	-0.276	-0.423	0.361
PC6	0.095	-0.168	-0.573	-0.073	0.068	0.295	-0.325	-0.395	-0.202	0.485
PC7	-0.196	0.557	0.291	0.095	-0.202	0.255	-0.396	0.331	-0.158	0.400
PC8	0.501	-0.047	0.193	-0.442	0.292	0.200	-0.038	0.249	-0.546	-0.165
PC9	0.359	-0.190	-0.187	0.240	-0.319	-0.597	-0.038	0.392	-0.211	0.293

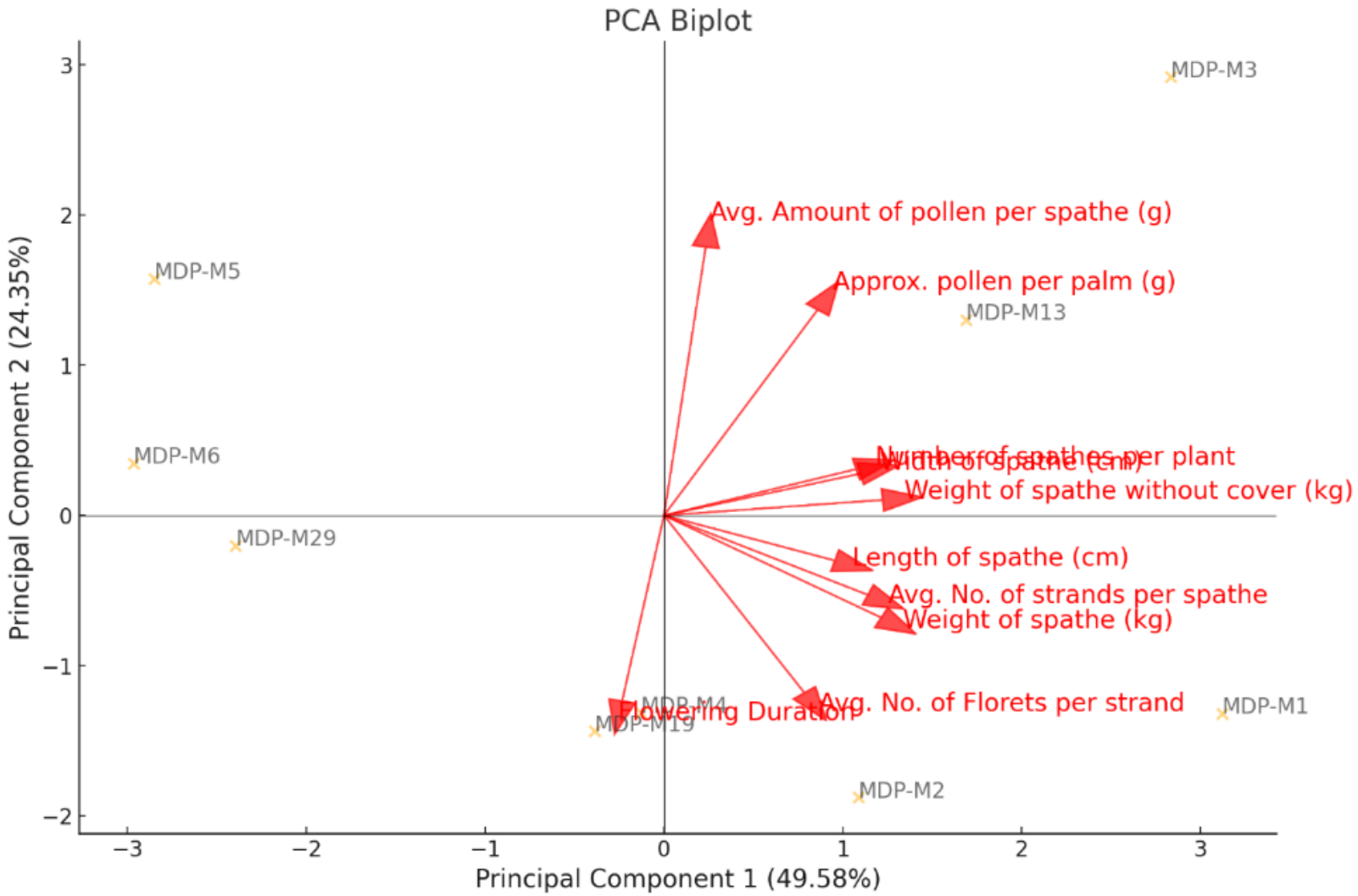

Figure 1: PCA Biplot of male date palm genotype for different genotypes and traits

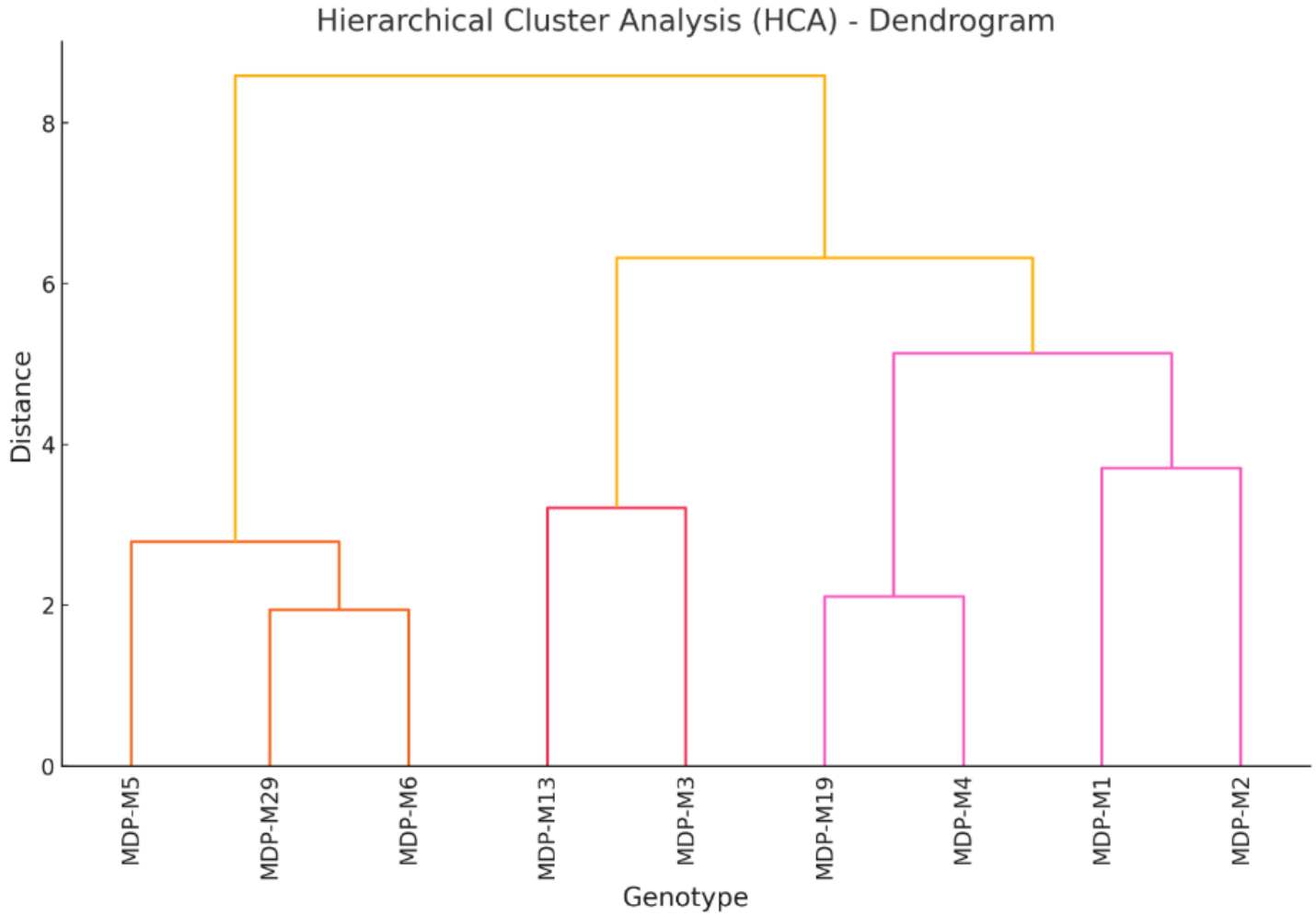

Figure 2: Hierarchical cluster analysis for different male date palm genotypes