Received: 11 Nov 2025 | Revised: 29 Dec 2025 | Accepted: 30 Dec 2025

Electronic Journal of Plant Breeding

Research Article

Morpho-phenological diversity and performance of Palmyrah (*Borassus flabellifer* L.) accessions

J. Phani Kumar[1]*, P.C. Vengaiah[1], K. Rajendra Prasad[2], G. Narasimha Murthy[3], B. Augustine Jerard[4] and S. Sumitha[5]

[1]Dr. YSRHU–Horticultural Research Station, Pandirimamidi–533288, Andhra Pradesh, India.
[2]KVK, Pandirimamidi -533288.
[3]College of Horticulture, Parvathipuram- 535502
[4]AICRP on plantation crops, ICAR-CPCRI, Kasargod, Kerala-671124
[5]ICAR-CPCRI, Kasargod, Kerala- 671124
***E-Mail**: phani515202@gmail.com

Abstract
A comprehensive morpho-phenological evaluation was conducted on thirteen Palmyrah (*Borassus flabellifer* L.) accessions planted in 2003 at the Horticultural Research Station (HRS), Pandirimamidi, Andhra Pradesh, India, to assess phenotypic diversity and identify superior genotypes for improvement and conservation. Significant variability was observed across vegetative and reproductive traits, indicating substantial heterogeneity within the germplasm. Correlation analysis revealed strong positive associations among palm height, total leaves, and total leaf length, while fruit weight showed positive relationships with fruit circumference, reflecting coordinated growth and yield attributes. Principal Component Analysis (PCA) extracted four principal components explaining 82.41% of the total variation. The first principal component (PC1) accounted for 27.61% of the variation and was predominantly influenced by fruit and reproductive traits, whereas the second component (PC2), explaining 16.82%, was mainly associated with vegetative growth parameters. Cluster analysis grouped the accessions into four distinct clusters, reflecting divergence driven by both vegetative and fruit traits. Path coefficient analysis indicated that fruit circumference exerted a strong direct positive effect on fruit weight, underscoring its importance in yield improvement. Accessions IC 0630888 (ACC-2), IC 0630892 (ACC-6), and IC 0630895 (ACC-9) were identified as superior for fruit yield and quality, while IC 0630890 (ACC-4) and IC 0630894 (ACC-8) exhibited robust vegetative vigor. The observed diversity is likely influenced by the dioecious nature of Palmyrah, local adaptation, and cumulative selection pressure. These findings highlight the importance of systematic germplasm evaluation for effective conservation and targeted improvement of Palmyrah under changing climatic conditions.

Keywords: Palmyrah palm, morphological diversity, PCA, cluster analysis, phenotypic variability

INTRODUCTION

The Palmyrah palm (*Borassus flabellifer* L.) stands as a remarkable tropical species of the family Arecaceae, revered as the 'tree of life' due to its immense ecological and economic value. It provides diverse products such as sap, jaggery, fiber, fruit, and timber, serving as a cornerstone for rural livelihoods in South and Southeast Asia (Davis and Johnson, 1987; Morton, 1988). Its tolerance to drought and salinity, derived from a deep root system, allows it to thrive in marginal and degraded soils (Veilmuthu, 2014). Despite its importance, Palmyrah improvement programs have remained limited, primarily due to dioecy, long gestation, and inadequate genetic characterization (George and Karun, 2011). Comprehensive morphological and phenological characterization of conserved germplasm provides a basis for identifying elite lines and enhancing the efficiency of breeding programs (Arulraj and Augustine, 2008; Behera *et al.*, 2021). The present study was designed to assess the morpho-phenological diversity among thirteen 2003-planted Palmyrah accessions maintained at HRS, Pandirimamidi, employing descriptive statistics and multivariate analyses to elucidate the structure of genetic variability and identify superior genotypes for further evaluation.

MATERIALS AND METHODS

The study was conducted at the Horticultural Research Station (HRS), Pandirimamidi (17°27′ N, 81°45′ E; 27 m MSL) in Alluri Sitaramaraju district, Andhra Pradesh. The site experiences a humid tropical climate with an annual rainfall of approximately 1200 mm and mean maximum and minimum temperatures of 34°C and 22°C, respectively. Thirteen Palmyrah (*Borassus flabellifer* L.) accessions (IC 0630887 to IC 0630899) were collected during September 2003 from various locations of the Nidadavolu region of Andhra Pradesh and established at a spacing of 4 × 4 m, with twelve palms per accession. Passport information of each accession is presented in **Table 1**. All accessions were planted simultaneously and maintained on the same land under uniform rainfed conditions to minimize environmental heterogeneity. Routine intercultural practices, including ploughing, weeding, leaf pruning, and fruit harvesting, were carried out uniformly across all accessions as and when required. Morphological and fruiting traits were recorded during 2025, with four independent observations per accession for each trait, and for the assessment of fruit-related traits, observations were recorded from fruits harvested at the edible (endosperm) stage. From each selected fruit bunch, five representative fruits were randomly sampled for data collection. Measurements included fruit circumference (horizontal and vertical), fruit colour, and number of endosperms per fruit, following standard observational procedures and mean values were used for statistical analyses. The data were subjected to descriptive statistics (mean, range, CD, CV, SEM), correlation analysis, Principal Component Analysis (PCA), cluster analysis, and path coefficient analysis using R software packages *FactoMineR* and *factoextra* (Johnson *et al.,* 1955).

RESULTS AND DISCUSSION

Descriptive statistical analysis revealed wide phenotypic variability among the thirteen Palmyrah accessions for vegetative and reproductive traits (**Table 2**). Considerable differences were observed in plant stature and canopy architecture, as reflected by palm height (3.69–8.67 m), total leaves (21.75–38.00), total leaf length from 1.9 to 3.5 m, petiole length (0.88–1.36 m), lamina length (0.82–1.84 m), and number of leaflets (71.50–82.75). Inflorescence and flowering traits also exhibited substantial variation, with

Table 1. Passport information of 2003 planted Palmyrah accessions

S. No	Accession (IC Number)	Village	Mandal	Soil Type	Fruit Color / Shape	Category
1.	IC 0630887 (ACC-1)	Chagallu	Chagallu	Black	Black / Round	Dwarf and Nungu
2.	IC 0630888 (ACC-2)	Chagallu	Chagallu	Red	Black-orange bottom / Round	Dwarf and heavy fruiter
3.	IC 0630889 (ACC-3)	Kalavapalli	Chagallu	Red	Orange-yellow / Round	Dwarf and small fruited
4.	IC 0630890 (ACC-4)	Nidadavolu	Nidadavolu	Alluvial black	Black / Round	Heavy fruiter, two flushes
5.	IC 0630891 (ACC-5)	Undeswrapuram	Sitanagaram	Light black	Black / Round	Monoecious
6.	IC 0630892 (ACC-6)	Kakoteswaram	Nidadavolu	Black	Yellow-black patches / Round-oval	Dwarf, good fruit size
7.	IC 0630893 (ACC-7)	Kakoteswaram	Nidadavolu	Black alluvial	Yellow-black patches / Round-oval	Heavy fruiter
8.	IC 0630894 (ACC-8)	Kurukuru	Devarapalli	Red	Yellow / Round-oval	Heavy fruiter
9.	IC 0630895 (ACC-9)	Gopalapuram	Gopalapuram	Red	Black-orange tinge / Round	Dwarf, high leaf yielder
10.	IC 0630896 (ACC-10)	Byyanagudem	Koyalagudem	Red sandy	Black-yellow back / Round	Good for foliage
11.	IC 0630897 (ACC-11)	Jagarampalli	Rampachodavaram	Red	Yellowish-black tinge / Round	Dwarf, yellow fruited
12.	IC 0630898 (ACC-12)	Jagarampalli	Rampachodavaram	Red	Shining yellow / Round	Yellow fruited
13.	IC 0630899 (ACC-13)	Jagarampalli	Rampachodavaram	Red	Turmeric yellow / Round	Heavy fruiter, high leaf yield

Note: Accessions were collected from various locations of Andhra Pradesh in September 2003 and established at HRS, Pandirimamidi. Each accession was represented by 12 palms planted at 4 × 4 m spacing.

Table 2. Performance of Palmyrah accessions for morphological parameters

S. No	Parameter	Mean	Minimum	Maximum	CD (±)	SEM	CV (%)
1.	Palm height (m)	7.27	3.69	8.67	0.65	0.33	16.51
2.	Stem girth at 0.5 m height (m)	1.73	1.1	2.02	0.14	0.07	14.55
3.	Stem girth at 1 m height (m)	1.61	0.93	1.97	0.11	0.06	13.31
4.	Stem girth at 1.5 m height (m)	1.25	0.84	1.41	0.08	0.04	12.42
5.	Number of leaf scar up to 50 cm	11.11	10.43	12.0	0.28	0.14	4.64
6.	Number of leaf scar 50 to 100 cm	11.39	10.25	12.0	0.27	0.14	4.44
7.	Number of leaf scar 100 to 150 cm	11.52	10.25	12.71	0.39	0.2	6.17
8.	Length of 10 leaf scars at 50 cm height (cm)	45.88	43.56	48.71	0.75	0.38	3.00
9.	Length of 10 leaf scars at 100 cm height (cm)	45.14	42.5	47.2	0.71	0.36	2.90
10.	Annual leaf production	11.99	11.75	12.27	0.08	0.04	1.20
11.	Total leaves	28.52	21.75	38.0	2.13	1.08	13.71
12.	Petiole length (m)	1.25	0.88	1.36	0.07	0.03	9.72
13.	Total leaf length (m)	2.28	1.66	2.51	0.11	0.06	9.00
14.	Petiole girth at lamina (cm)	15.43	12.0	17.0	0.85	0.43	10.15
15.	Petiole girth at middle portion of the leaf (cm)	18.00	14.00	20.00	0.01	0.00	9.06
16.	Lamina length (m)	1.09	0.82	1.84	2.62	1.34	26.18
17.	Lamina breadth (m)	1.48	1.23	1.64	0.06	0.03	7.05
18.	Number of leaflets	77.1	71.5	82.75	1.76	0.9	4.21
19.	Number of flowering bunches per plant	7.57	5.25	9.0	0.55	0.28	13.42
20.	Number of flowers per bunch	14.08	8.00	18.17	1.84	0.94	24.06
21.	Inflorescence length (m)	0.7	0.48	1.14	0.15	0.07	32.36
22.	Inflorescence stalk length (m)	0.39	0.2	0.71	0.12	0.05	46.42
23.	Length of flowered portion of inflorescence (m)	0.32	0.25	0.43	0.04	0.02	18.95
24.	Number of female spikelets per inflorescence	1.82	1.00	4.00	0.66	0.30	53.99
25.	Number of inflorescences per palm	8.09	6.00	11.00	0.87	0.39	16.07
26.	Number of fruits per inflorescence	15.36	8.00	28.00	4.65	2.09	45.03
27.	Fruit circumference (horizontal) (m)	0.32	0.23	0.38	0.03	0.01	14.71
28.	Fruit circumference (vertical) (m)	0.39	0.34	0.46	0.03	0.01	11.18
29.	Fruit weight at immature (endosperm) stage (g)	799.64	490	1225	163.97	73.59	30.52
30.	Bunch weight with fruits (kg)	9.34	5.250	13.22	21.55	9.67	30.34
31.	Endosperm weight (g)	141.09	40.00	255.0	46.23	20.75	48.77
32.	Number of endosperms per fruit	3.00	3.00	3.00	0.00	0.00	0.00

inflorescence length ranging from 0.48 to 1.14 m, number of inflorescences from 6.00 to 11.00, female flowers per inflorescence from 1.00 to 4.00, and number of fruits per inflorescence from 8.00 to 28.00, indicating differences in reproductive potential among accessions. Fruit-related traits showed marked differences, particularly for fruit weight at immature (endosperm) stage (177.75–1277 g), bunch weight with fruits (5.2–13.7 kg), and endosperm weight (40–255 g), while fruit circumference (horizontal and vertical) exhibited relatively narrower ranges. Such patterns are consistent with the polygenic inheritance observed in other perennial palms (Rahman *et al.*, 2019; Thangavelu *et al.*, 2020). The observed trait ranges and dispersion values collectively indicate substantial phenotypic diversity within the germplasm, providing a strong basis for subsequent multivariate analyses to identify divergent and promising Palmyrah accessions.

Principal Component Analysis (PCA) extracted four principal components with eigenvalues greater than unity, cumulatively explaining 82.41% of the total variance among Palmyrah accessions (**Table 3**). The first principal component (PC1) accounted for 27.61% of the total variation and was predominantly influenced by reproductive and fruit-related traits such as fruit weight at immature stage, inflorescence weight with matured fruits, endosperm weight, and fruit circumference. The second principal component (PC2) explained 16.82% of the variation and was mainly associated with vegetative growth traits including palm height, stem girth at different heights, total leaves, petiole length, and lamina dimensions. The third (PC3) and fourth (PC4) components contributed 15.26% and 13.95% of the variation, respectively, reflecting combined effects of inflorescence and vegetative attributes (**Fig. 1**). Together, the first two

https://doi.org/10.37992/2025.1604.060

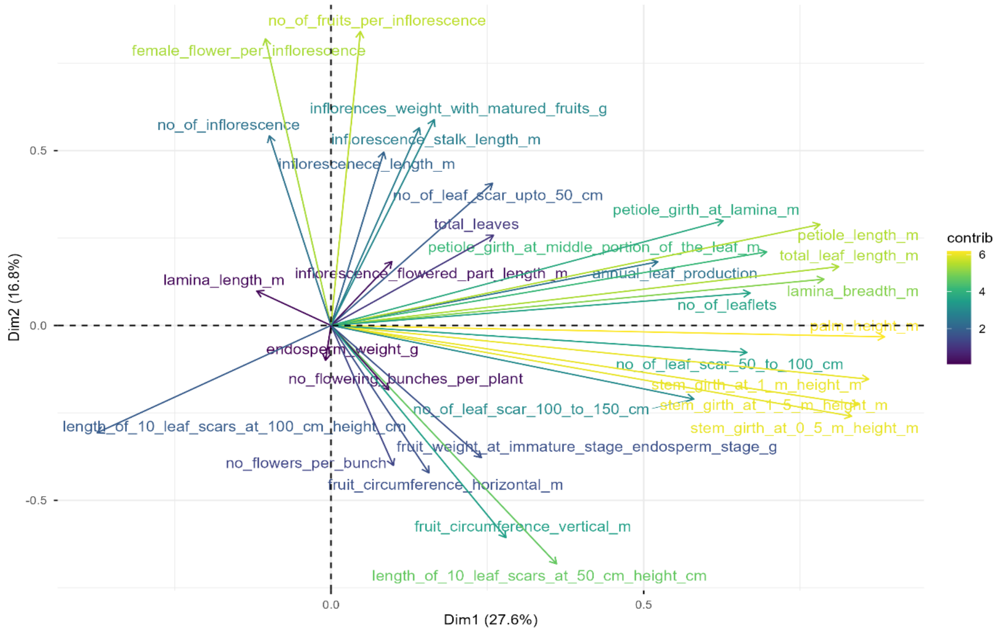

Fig.1. PCA Biplot showing trait contribution and accession grouping

Table 3. PCA eigenvalues and variance explained for morpho-phenological traits in Palmyrah accessions

PC	Eigenvalues	Variance (%)	Cumulative (%)
PC1	7.325	27.61	27.61
PC2	5.483	16.82	44.43
PC3	5.042	15.26	56.58
PC4	4.326	13.95	71.53
PC5	2.659	8.58	82.41

components represented the major axes of diversity within the germplasm, indicating that both vegetative and reproductive traits jointly governed phenotypic divergence among Palmyrah accessions.

Correlation analysis revealed strong positive associations among palm height, number of leaves, and total leaf length, implying that taller palms exhibit larger canopies and potentially higher photosynthetic capacity (**Table 4**). Fruit weight showed positive correlations with fruit length and diameter, emphasizing their joint contribution to yield enhancement (**Fig. 2**). The hierarchical cluster analysis grouped the thirteen Palmyrah accessions into four distinct clusters, revealing substantial phenotypic divergence within the germplasm (**Fig. 3**). Cluster I, represented solely by IC 0630891 (ACC-5), showed maximum dissimilarity from all other accessions, indicating its unique morpho-phenological and reproductive profile. Cluster II, comprising IC 0630897 (ACC-11) and IC 0630898 (ACC-12), formed a closely allied group, suggesting similarity in growth and inflorescence-related traits. Cluster III, the largest and most heterogeneous cluster, included IC 0630888 (ACC-2), IC 0630890 (ACC-4), IC 0630892 (ACC-6), IC 0630893 (ACC-7), IC 0630896 (ACC-10), IC 0630887 (ACC-1), and IC 0630894 (ACC-8), reflecting moderate variability across vegetative architecture, leaf traits, and fruit dimensions. Cluster IV, consisting of IC 0630899 (ACC-13), IC 0630889 (ACC-3), and IC 0630895 (ACC-9), was characterized by closer similarity among accessions with superior fruit and yield-associated attributes. The clear separation of clusters suggests that both vegetative vigour and reproductive performance collectively contributed to the observed diversity, providing a valuable basis for selection of parental lines in Palmyrah improvement and conservation programs. The clustering pattern was consistent with PCA results, confirming that both vegetative growth and fruit-related traits contributed significantly to genetic divergence among Palmyrah accessions.

Path coefficient analysis revealed that lamina length exerted a strong, positive, and significant direct effect on the dependent trait, indicating that it is the most influential character contributing to the observed variation (**Table 5**). Stem girth at 1.5 m height and number of flowers per bunch also exhibited positive and significant direct effects, although their contributions were comparatively lower than that of lamina length (**Fig. 4**). The observed variability among Palmyrah accessions can be partly attributed to the dioecious reproductive system of the species, which enforces obligate outcrossing and thereby maintains high levels of phenotypic heterogeneity. Such reproductive biology is known to enhance trait dispersion, particularly for reproductive and fruit-related characters (**Fig. 5**). These findings corroborate those of

Table 4. **Genotypic correlation coefficients among vegetative and reproductive traits in Palmyrah**

Trait	Palm height	Stem girth at 0.5 m height	Stem girth at 1.0 m height	Stem girth at 1.5 m height	Number of flowers per bunch	Number of female spikelets per inflorescence	Number of flowering bunches per plant	Number of fruits per inflorescence
Palm height	1.00	0.805***	0.833***	0.849***	-0.012	-0.144	-0.068	0.139
Stem girth at 0.5 m height		1.00	0.969***	0.978***	-0.105	-0.364	-0.266	0.283
Stem girth at 1.0 m height			1.00	0.978***	-0.044	-0.280	-0.179	0.228
Stem girth at 1.5 m height				1.00	-0.140	-0.357	-0.238	0.209
Number of flowers per bunch					1.00	-0.123	0.668*	0.846***
Number of female spikelets per inflorescence						1.00	0.924***	0.919***
Number of flowering bunches per plant							1.00	0.874***
Number of fruits per inflorescence								1.00

*, ** and *** indicate significance at P ≤ 0.05, P ≤ 0.01 and P ≤ 0.001, respectively.

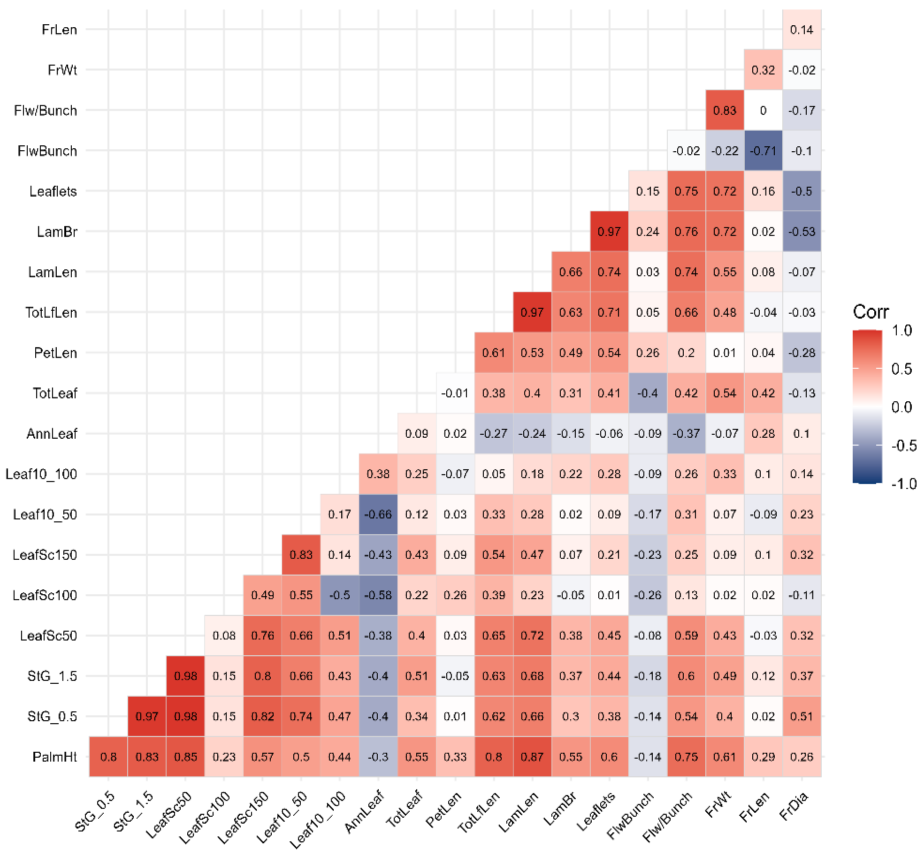

Fig. 2. Correlation Heatmap illustrating inter-trait relationships among the traits

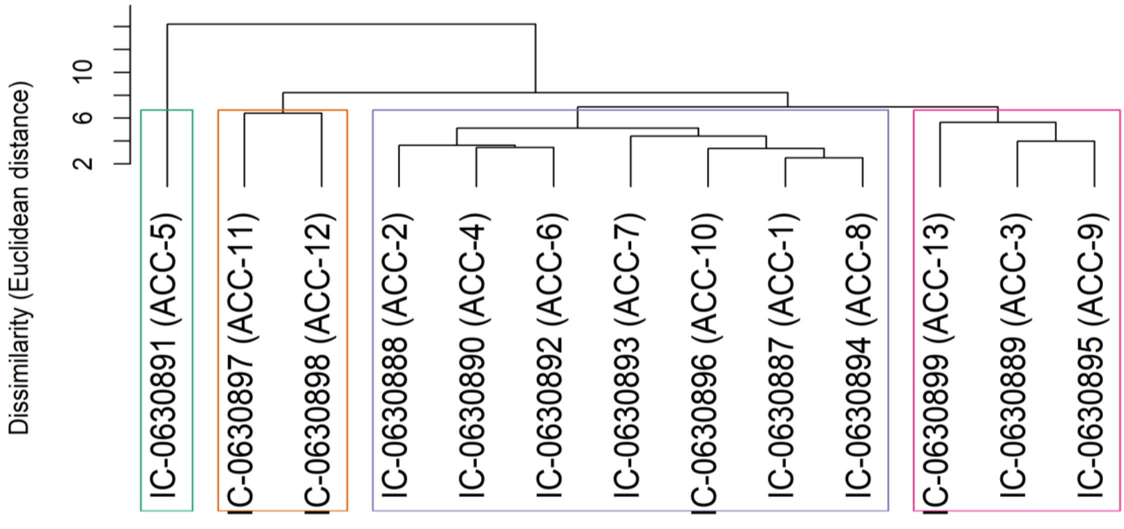

Fig.3. Hierarchical cluster dendrogram of 13 Palmyrah accessions

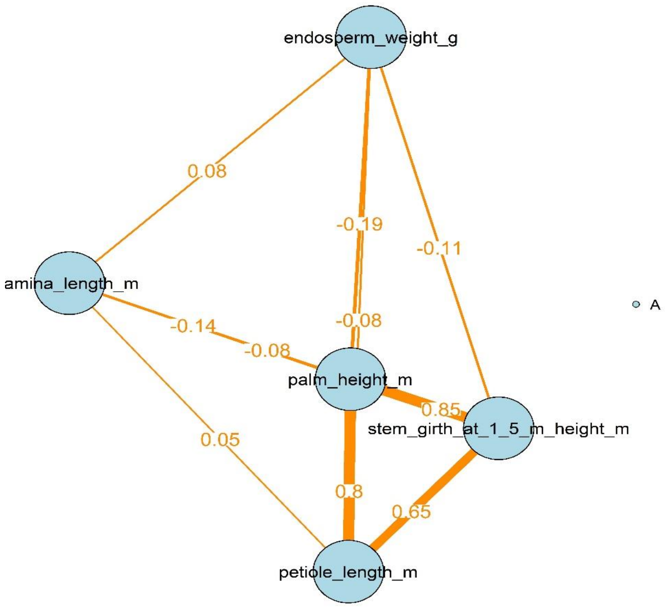

Fig.4. Path coefficient diagram showing direct effects of selected vegetative and reproductive traits on number of fruits per inflorescence in Palmyrah

Table 5. Direct effects of selected traits on number of fruits per inflorescence in Palmyrah

Character	Direct effect (standardized)
Palm height	−0.122
Stem girth at 0.5 m height	−0.344
Stem girth at 1.0 m height	−0.220
Stem girth at 1.5 m height	0.782*
Number of flowers per bunch	0.813*
Lamina length	0.988*
Inflorescence length	−0.056

* indicate significance at P ≤ 0.05. Dependent variable: Number of fruits per inflorescence.

Fig.5. Morphological variations among Palmyrah germplasm

Johnson *et al.* (1955) in soybean and Siju and Sabu (2020) in palmyrah, highlighting that selection based on fruit size traits would be most effective for yield improvement. In addition, the long-term establishment of these accessions under diverse source environments prior to collection may have promoted local adaptation, contributing to differential expression of vegetative growth and reproductive traits even under uniform field conditions.

The present investigation demonstrated substantial morpho-phenological diversity among thirteen Palmyrah accessions established in 2003 and collected from the Nidadavolu region. Fruit-related traits emerged as the principal contributors to overall phenotypic variation, whereas vegetative traits primarily influenced plant architecture and growth behaviour. The observed diversity is likely shaped by the dioecious nature of Palmyrah, long-term local adaptation, and cumulative selection pressure acting on reproductive performance. Accessions IC 0630888 (ACC-2), IC 0630892 (ACC-6), and IC 0630895 (ACC-9) were identified as superior for fruit yield and quality attributes, while IC 0630890 (ACC-4) and IC 0630894 (ACC-8) exhibited vigorous growth, making them suitable candidates for resilience-oriented breeding. The distinct clustering of accessions highlights the need for systematic germplasm conservation to preserve genetic breadth. Future studies integrating molecular characterization with phenotypic evaluation will be essential to validate genetic relationships and strengthen Palmyrah improvement programs under changing climatic conditions.

REFERENCES

Arulraj, P. and Augustine, A. 2008. Palmyrah: A multipurpose tree for the 21st century. ICAR–CPCRI, Madurai.

Behera, P. C., Pradhan, S. and Mishra, D. 2021. Morphological and economic diversity of Palmyrah in coastal India. *J. Appl. Nat. Sci.*, **13**(2): 324–332.

Davis, T. A. and Johnson, D. V. 1987. Current utilization and further development of Palmyrah. *Econ. Bot.*, **41**(2): 247–266. [Cross Ref]

George, J. and Karun, A. 2011. Advances in Palmyrah palm research. *J. Plant. Crops*, **39**(2): 95–102.

Johnson, H. W., Robinson, H. F. and Comstock, R. E. 1955. Estimates of genetic and environmental variability in soybeans. *Agron. J.*, **47**(7): 314–318. [Cross Ref]

Morton, J. 1988. Palmyrah palm. In: *Fruits of Warm Climates*. Julia F. Morton, Miami, Florida, pp. 11–18.

Rahman, M. S., Alam, M. Z. and Islam, M. R. 2019. Multivariate analysis of morphological diversity in coconut accessions. *Plant Genet. Resour.*, **17**(1): 12–20.

Siju, T. and Sabu, M. 2020. Genetic diversity assessment of Palmyrah palm using morphological traits. *Genet. Resour. Crop Evol.*, **67**(6): 1351–1361.

Thangavelu, C., Karthikeyan, A. and Jeyakumar, P. 2020. Morphological diversity and trait correlation in date palm germplasm. *Sci. Hortic.*, **265**: 109248.

Veilmuthu, G. 2014. Soil and climatic adaptability of Palmyrah palm. *J. Appl. Hortic.*, **16**(1): 76–82.