Range Management and Agroforestry 46 (2) : 267-273, 2025
ISSN 0971-2070 (Print); 2249-5231 (Online)
https://doi.org/10.59515/rma.2025.v46.i2.12

Research article

Unveiling the superior provenances of khejri (*Prosopis cineraria* (L.) Druce) trees in arid lands of western Rajasthan

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Received: 04th September, 2024 Accepted: 21st November, 2025

Abstract

The study aimed to assess and identify the superior khejri (*Prosopis cineraria*) provenance in the western arid drylands through habitat site characterization using GIS mapping, *in-situ* variability studies, germination and progeny-cum-provenance trial. Eight provenances among the nine identified were selected for *in-situ* study based on their distinct growth characteristics. The analysis of various morphometric traits revealed significant differences among provenances, emphasizing their genetic variability. Correlation analysis demonstrated a strong positive relationship between plant height and both stem girth (r = 0.70*) and crown diameter (r = 0.93**), indicating the importance of considering tree height as a reliable indicator of early growth assessment during provenance selection. Germination (ranging from 75% in Karola (Jalore) to 82% in Lamba (Jodhpur) also indicated the variable germination potential of these provenances. Subsequently, in progeny-cum-provenance trial, at 5 months after transplanting (MAT), no significant differences in plant height were observed among the provenances. However, at 15 MAT, significant variations in plant height emerged, with Absar (Churu) exhibiting a height of 87.22 cm. By 25 MAT, all provenances displayed further increases in plant height, with Bhadriya (Jaisalmer) attaining the greatest height of 181.11 cm. Based on the ranking of growth across the three-time intervals, the study concluded that Absar consistently demonstrated superior growth performance. Thus, Absar can be identified as the most favourable provenance considered for khejri cultivation in the western drylands.

Keywords: Drylands, Germination, GIS-mapping, Progeny trial, Prosopis, Provenance

Introduction

Prosopis cineraria (L.) Druce), commonly referred to as Khejri, stands out as a tree species renowned for its remarkable adaptability to arid and semi-arid environments. Within desert ecosystems, it plays a crucial role in supporting ecological stability and sustaining farming communities. (Jatasra and Paroda, 1981; Shankarnarayan *et al.*,1987). The tree is known by various local names such as Jandi or Khejri in India, Jand in Pakistan, and Ghaf in Arabic regions. Taxonomically, it belongs to the family Leguminosae and subfamily Mimosoideae. Geographically, it is primarily distributed in dry regions of Southwest Asia and Africa (Khatri *et al.*, 2010). This magnificent tree, deeply rooted in arid landscapes, stands as a testament to its resilience and ability to flourish in the face of adversity. It plays a crucial role in sustaining local ecosystems and supporting the livelihoods of communities in arid regions.

To understand and harness its potential, a provenance trial has been initiated to evaluate the growth and performance of different populations of *Prosopis cineraria* in a new location. This trial holds great significance for the conservation and management of the species as well as to identify the most suitable populations of *Prosopis cineraria* for restoration and conservation programs. Factors such as habitat and rainfall patterns at the provenance sites provide valuable insights into the adaptive traits of different populations. This information helps determine their tolerance to drought, soil types, and other environmental factors, offering valuable insights into the species' adaptation and potential for use in restoration and reforestation efforts.

Materials and Methods

Study site and design: Habitat site characterization was carried out using GIS-based mapping/ assessment for the selection of tree provenances for the present study. After site selection, a field survey was carried out to study the *in-situ* variation in tree growth and collection of fresh seed material of diverse khejri (*Prosopis cineraria*) provenances (native populations) occurring in arid western Rajasthan. To select the provenance sites, three field surveys were conducted during the summer of 2019. During these surveys, one Khejri provenance was identified from each of the following districts: Jaisalmer, Jalore, Barmer, Jodhpur, Nagaur, Churu, Jhunjhunu, and Sikar. Morphometric data on four tree growth parameters *viz*., tree height (TH), stem girth (SG), branch number (BN) and crown diameter (CD) was recorded on six random trees of each provenance and dry mature pods were also collected from the sample trees. Further, the pods or seeds were randomly sampled and data on pod length (PL), pod width (PW), seeds per pod (SPP) and 100-seed weight (100-SW) were recorded.

Observations and data analyses: Forty eight entries out of 8 provenances (six trees per provenance) were grown in a nursery with four replications in RBD. Observations on germination were made 12 days after sowing (DAS). After proper survival, five-month-old *P. cineraria* seedlings were transplanted into the field in an RBD design with three replications in December 2020 at ICAR-CAZRI, Jodhpur experimental field. Observations were recorded for plant height (PH) at regular intervals after 5 months after transplanting (5MAT) in 2021, fifteen months (15MAT) in 2022 and twenty-five months (25MAT) in 2023. The recorded data were subjected to statistically analyses.

Results and Discussion

Selection of provenance sites: Based on GIS mapping and habitat site characterization, normal monsoon rainfall, habitat or landform pattern, eight provenances of Khejri were identified in Rajasthan (Table 1) which includes Bhadariya (PS-I), Karola (PS-II), Kundal (PS-III), Lamba (PS-IV), Nimbri Kalan (PS-V), Abasar (PS-VI), Baragaon (PS-VII) and Thikariya (PS-VIII). These provenances varied in rainfall pattern and soil forms (Fig 1).

PS-VIII had the highest rainfall followed by PS-VII, while PS-I had the lowest average rainfall. Additionally, they also differed in landform types ranging from sandy undulating plains to older alluvial plains. This diversity highlights the complexity of ecological and agricultural conditions in the western drylands.

In-situ variability among provenances for growth characteristics: The average growth characteristics across various provenances showed wide variability among them (Table 2). Analysis by statistical parameters revealed a high degree of variation among the sampled trees, as evidenced by coefficient of variation (CV) values ranging from 27 to 34 per cent.

TH ranged from 6.0 m to 18.0 m, SG 63 cm to 260 cm, BN 2 to 11 per tree and CD 5.45 m to 23.2 m. The pod and seed characters showed less variation with 13 to 26 per cent CV. The range of values recorded for the reproductive

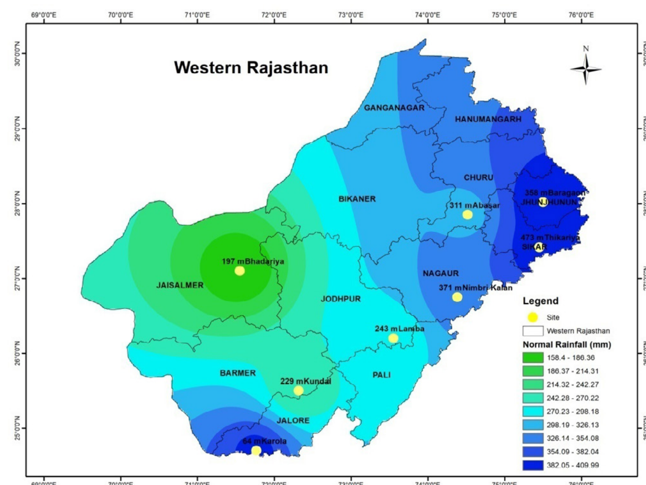

Fig 1. Provenances of *Prosopis cineraria* in western Rajasthan with site details

Table 1. Selected provenance sites of *Prosopis cineraria* in arid western Rajasthan

Provenance	Name of provenance site	District	Habitat/ land form	Normal monsoon rainfall (mm)*
PS-I	Bhadriya	Jaisalmer	Cropland / sandy undulating plains	158.4
PS-II	Karola	Jalore	Cropland / older alluvial plain	394.2
PS-III	Kundal	Barmer	Cropland / hill valley slope	243.4
PS-IV	Lamba	Jodhpur	Cropland / alluvial flood plain of Luni River	274.5
PS-V	Nimbri kalan	Nagaur	Cropland / alluvial plain	348.5
PS-VI	Absar	Churu	Cropland / sandy plain	313.7
PS-VII	Baragaon	Jhunjhunu	Cropland / sandy plain	410.0
PS-VIII	Thikariya	Sikar	Cropland / flat alluvial plain	402.5

*Source: Monsoon Report 2017, Water Resources Department, Government of Rajasthan. 2018. pp. 86

Table 2. Variation in growth characters of *Prosopis cineraria* trees

Character	Range	Mean	CV (%)
Tree height (m)	6.0-18.0	10.05 ± 0.40	27.8
Stem girth (cm)	63-260	148.6 ± 7.42	34.6
Branch nos./tree	2-11	5.42 ± 0.27	34.2
Crown diameter (m)	5.45-23.2	11.24 ± 0.55	34.0
Pod length (cm)	11.0-33.5	17.55 ± 0.60	23.6
Pod width (mm)	4.8-8.6	6.50 ± 0.13	13.4
Seeds per pod	7.6 -26.7	16.96 ± 0.66	26.9
100-Seed weight (g)	3.61-6.31	4.71 ± 0.09	13.9

growth traits was 11.0 cm to 33.5 cm for PL, 4.8 mm to 8.6 mm for PW, 7.6 to 26.7 for SPP and 3.6 g to 6.3 g for 100-SW (Table 2).

Analysis of variance revealed that differences between the provenances were significant (P<0.05) for all of these growth parameters (Table 3). Between-provenance variation is larger than within-provenance variation for all traits, indicating that differences between sites have a greater impact on growth characteristics than variation within a site.

Comparative provenance analysis revealed that PS-VIII (11.23m) and PS-III (12.77m) had the tallest trees, while PS-I (8.42m) had the shortest trees. Similarly, PS-II (158.2 cm) and PS-III (200.7 cm) had the thickest stem girths, while PS-VI (105.2 cm) had the thinnest stem girth. Moreover, some provenances produced more branches per tree and had larger crown diameters than others, which indicates better branching habits and greater canopy cover. PS-III (6.33) and PS-II (7.17) had the highest number of branches per tree, while PS-IV (3.0) had the smallest number of branches per tree. Similarly, PS-II (14.15m) had the largest crown diameter, while PS-I (9.12 m) had the smallest crown diameter.

A fundamental understanding of seed variation about seed parameters is crucial for ensuring the production of high-quality seedlings (Singh *et al.*, 2010). Notably, significant variation was observed among provenances in terms of pod and seed characteristics. PS-III exhibited the longest pods (15.90 cm), contrasting with PS-I, which had the shortest pods (9.12 cm). Additionally, PS-VII (Jhunjhunu) featured the widest pods (14.22 mm), while PS-IV had the narrowest pods (5.40 mm). Seed parameters such as SPP ranged from 13.08 (PS-VI) to 22.80 (PS-II), and the 100-SW varied from 4.19 g (PS-IV) to 5.32 g (PS-VI) (Table 4).

Correlation coefficients (Fig 2) among growth parameters in *Prosopis cineraria* revealed the correlation matrix, which offers insights into their interrelationships across various locations. Notably, TH demonstrates a strong positive correlation with CD (0.926**), suggesting that taller trees tend to have wider crowns. SG also shows a significant positive correlation with CD (0.787**), emphasizing the coherence between these two structural traits. Additionally, SPP exhibits a significant positive correlation with PL (0.933**), indicating that longer pods tend to contain more seeds. Interestingly, 100-SW does not show significant correlations with other traits, suggesting that factors other than tree structure might influence seed weight.

Evaluation based on germination traits: The germination percentage, representing the survival rates of all provenances, was meticulously documented in 20 plants per entry across 48 entries (six trees per provenance), employing a Random Block Design with four replications. The observed germination percentages ranged from 75% in PS-II to 82% in PS-IV (Fig 3).

Progeny cum provenance trial: By 5MAT, uniform plant heights ranging from 26.8 cm to 39.3 cm were observed across all provenances. However, notable disparities in plant heights emerged at 15 MAT, with PS-VI exhibiting the tallest plants at 87.22 cm, while PS-V had the shortest at 62.56 cm. Subsequently at 25 MAT, all provenances displayed a further increase in plant height. PS-I recorded the highest plant height at 181.11 cm, while PS-V exhibited the lowest at 136.67 cm.

Based on the linear mixed model, an interaction plot (Fig 4) based on estimated marginal means of plant height, calculated using a posthoc test (Bates *et al.*, 2015), shown by different provenances over time was derived using R software. Where, X-axis represents the different time points (5MAT, 15MAT, 25MAT), Y-axis shows the estimated marginal means of plant height, each

Table 3. Analysis of variance for different growth characters in *Prosopis cineraria*

Source of variation	df	Mean squares							
		Tree height	Stem girth	Branch nos./tree	Crown diameter	Pod length	Pod width	Seeds per pod	100-seed weight
Between provenances (sites)	7	22.74*	7236.2*	9.476*	51.34**	49.07*	2.255*	70.03*	1.188*
Within provenances (sites)	40	5.18	1838.6	2.383	8.20	11.50	0.494	12.19	0.291

*(P<0.05); **(P<0.01)

Table 4. Mean performance of *Prosopis cineraria* provenances for different growth characters

Provenance sites (PS)	TH (m)	SG (cm)	BN	CD (m)	PL (cm)	PW (mm)	SPP	100-SW (g)
PS-I	8.42 ± 0.46	105.8 ± 8.6	5.00 ± 0.26	9.12 ± 0.81	19.75± 1.10	6.23 ± 0.20	19.57 ± 1.79	4.68 ± 0.18
PS-II	12.90 ± 1.25	158.2± 19.7	7.17 ± 0.98	14.15± 1.32	21.22 ± 1.02	6.63± 0.15	22.80 ± 1.03	4.20 ± 0.18
PS-III	12.77 ± 0.59	200.7 ± 12.0	6.33 ± 0.42	15.90 ± 0.61	21.08 ± 2.51	6.77± 0.34	18.82 ± 1.56	4.43 ± 0.17
PS-IV	8.48 ± 0.78	158.2 ± 17.8	3.00 ± 0.37	9.40 ± 1.27	13.85 ± 0.92	5.40 ± 0.24	13.30± 0.88	4.19 ± 0.20
PS-V	8.40 ± 0.39	120.0 ± 14.9	4.67 ± 0.38	10.20 ± 0.63	16.30± 1.90	6.13 ± 0.19	16.77± 2.02	4.60 ± 0.20
PS-VI	9.03 ± 0.70	105.2 ± 1.9	5.50 ± 0.50	7.84 ± 0.45	15.77± 0.69	6.73 ± 0.44	14.00 ± 1.30	5.28 ± 0.19
PS-VII	9.18 ± 0.95	165.7 ± 29.9	5.50 ± 0.50	9.55 ± 1.20	14.72 ± 0.48	7.53± 0.39	13.08± 0.59	5.32 ± 0.27
PS-VIII	11.23 ± 1.62	175.5 ± 20.0	6.17 ± 1.11	13.76 ± 2.13	17.72± 1.27	6.57 ± 0.21	17.33 ± 1.63	4.96 ± 0.33

TH: Tree height; SG: Stem girth; BN: Branch number; CD: Crown diameter; PL: Pod length; PW: Pod width; SPP: Seeds per pod; 100-SW: 100-seed weight

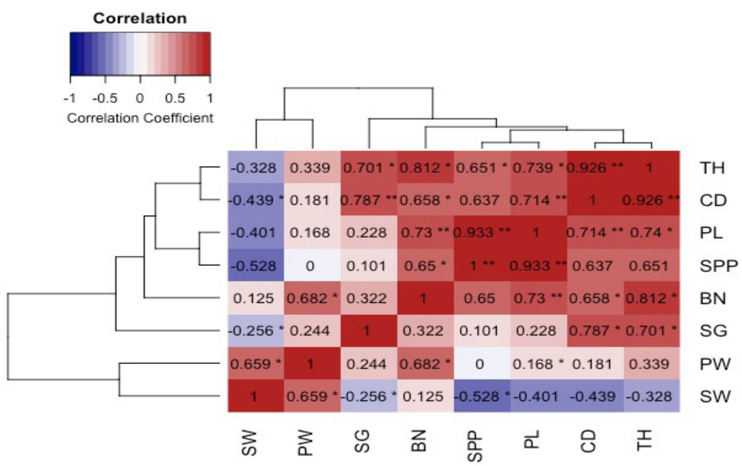

Fig 2. Correlation among different traits in provenances [*(P<0.05); **(P<0.01)]

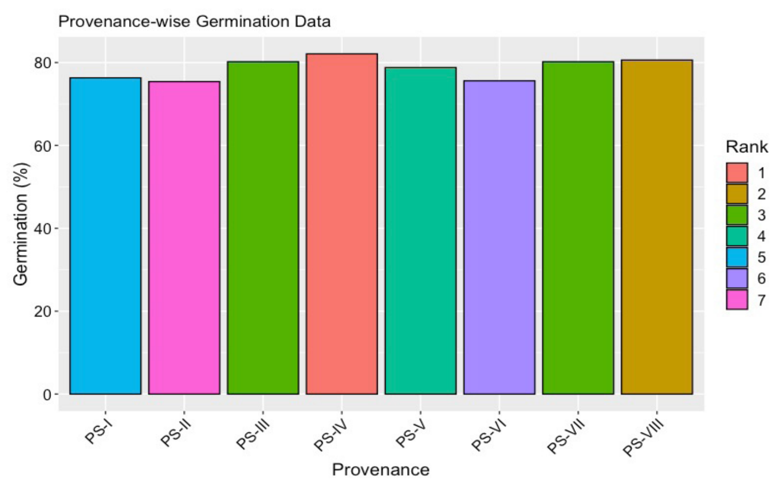

Fig 3. Provenance wise germination data of *P. cineraria*

line represents a different provenance and the colour distinguishes between them. The lines connect the mean values for each time point within each provenance. The slope and pattern of the lines indicate the interaction effect between time and plant height, varying by provenance. A simplified Linear Mixed Model (LMM), to reduce complexity for ease of interpretation, was fitted (Table 5) using R software to examine the impact of time on plant

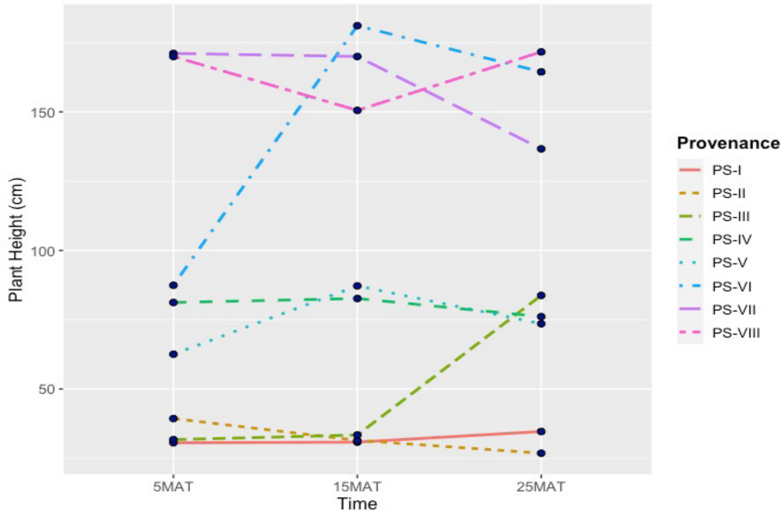

Fig 4. Interaction plot of estimated marginal means over time by provenances

Table 5. Results of simplified linear mixed model for fixed and random effects

Fixed effect	Estimate	SE	df	T value	P value
5MAT (Intercept)	84.25	20.09	7	4.192	0.0034**
15MAT	11.656	6.48	62	1.799	0.076
25MAT	11.715	6.48	62	1.808	0.075
Random effect	Variance	Std. Deviation			
Provenance	3063.3	55.35			
Residual	503.7	22.44			

height, focusing on random intercepts for provenance. The model was successfully fitted without encountering singularity issues. In fixed effects, the estimated intercept at 5MAT is 84.25cm and was found statistically significant (P = 0.00349), indicating a significant baseline plant height. While, at 15MAT (11.65) and 25MAT, it was marginally significant (P = 0.076 and P = 0.075, respectively), indicating a potential increase in plant height, but with some uncertainty. Moreover, in random effects (provenances) estimated variance (3063.3) depicted the corresponding standard deviation of 55.35, reflecting the substantial variability in plant height between different provenances, emphasizing the importance of considering the differences between provenances when assessing plant height. Additionally, the correlation matrix shows that there is no significant correlation between the intercept and 15MAT (-0.161) or 25MAT (0.500) variables. Notably, PS-IV demonstrates the highest mean tree height, while both PS-VI and PS-III exhibit relatively consistent growth at various stages post-transplanting.

The ranking of different provenances based on their growth during various time intervals (MAT) allows us to compare the performance of the provenances and identify the best one based on overall growth. During growth from 5 MAT to 15 MAT, PS-VI ranks first, indicating the highest growth during the initial period after transplantation. The provenance PS-VIII ranks second, showing significant growth during this interval. During growth from 15 MAT to 25 MAT, the provenance PS-I ranks first, exhibiting the highest growth during the later stage after transplantation and PS-IV ranks second, indicating notable improvement in growth during this interval. In overall growth from 5 MAT to 25 MAT, the provenance PS-VI ranks first, displaying the highest overall growth from the initial to the later stages after transplantation and PS-I and PS-VIII rank second and third, respectively, showcasing consistent growth throughout the entire period. Based on the rankings, it can be concluded that the provenance PS-VI ("Absar (Churu)") identified as the best provenance, performed exceptionally well in terms of growth, showing consistently high rankings across all three intervals.

Comprehending the diversity within provenances and progenies holds paramount importance in tree improvement initiatives (Weber *et al.*, 2008). The elevated CV observed for numerous traits across diverse provenances suggests a substantial potential for provenance selection at the seedling stage. This trend aligns with findings in several other tree species, as reported in studies by Xu *et al.* (2023), Dong *et al.*

(2020), Li *et al.* (2020), Su *et al.* (2020) and Yuan *et al.* (2020). Additionally, the significant difference identified in length, width and seed weight among provenances confirms that provenances are important genetic entities within a species (Weber *et al.* 2008; Hathurusingha *et al*., 2010; Singh and Thapliyal, 2012; Shu *et al.,* 2012). The differentiation of provenances could be due to genetic factors shaped by evolutionary forces (Wright, 1931; Finkeldey and Hattemer, 2007) and environmental variability including geographic location, altitude, climate and soils in their growing regions (Moleele *et al*., 2005; Singh *et al*., 2010; Shu *et al*., 2012; Ginwal *et al*., 2005; Loha *et al*., 2008; Hathurusingha *et al*., 2010).

Regarding the correlation observed among different traits in the present study, it has provided valuable insights into the relationships among key tree-related traits, offering guidance for managing and optimizing tree growth in diverse agricultural contexts.

In nursery studies, the outcome underscores the intricate nature of germination as a physiological response. The variability in germination rates may stem from a multitude of factors, including seed source, parental nutrition, seed maturity, tree age, as well as environmental conditions during both seed development and germination as also stated by Chaisurisri *et al*., (1992). It is important to note that, even under identical growth conditions and cultivation procedures, genetic variances among seedlings may contribute to differences in their ability to adapt to the external environment.

In the progeny cum provenance trial, the observed disparities in plant height among distinct provenances can be attributed to variations in genetic composition, as well as differences in the soil and climatic conditions under which they were cultivated. These findings indicate that various provenances exhibit diverse growth rates, implying potential differences in their adaptability to distinct agro-climatic regions. Consequently, the selection of suitable provenances for afforestation programs should be informed by their performance under specific agro-climatic conditions. This emphasizes the importance of considering the unique characteristics of each provenance to enhance the success and effectiveness of afforestation initiatives in different regions.

Nevertheless, the identification of superior provenances necessitates a comprehensive evaluation, taking into account factors such as growth rate, biomass accumulation, drought tolerance, and resistance to pests and diseases, for that, local environmental conditions and the specific requirements of the planting site should be carefully considered. While acknowledging the need for a more thorough assessment, preliminary conclusions can be tentatively drawn based on the limited plant height data available. These particular provenances may merit further evaluation as potential candidates. It is important to emphasize that numerous prior studies have explored the genetic diversity and growth characteristics of *Prosopis cineraria* in various regions of India, providing valuable insights for future assessments.

Conclusion

Significant genetic variation for growth characteristics exists in *Prosopis cineraria* trees in western drylands. Further studies are needed to identify the most promising provenances for specific planting sites and to evaluate the potential of *P. cineraria* for ecological restoration and other applications.

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