Plant Archives Vol. 26, No. 1, 2026 pp. 1691-1696 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.1.233

IMPACT OF SOWING DATES AND VARIETIES ON GROWTH, PRODUCTIVITY AND PROFITABILITY OF PEARL MILLET UNDER SEMI-ARID CONDITIONS OF RAJASTHAN, INDIA

Rani Saxena*, M.R. Yadav, K.C. Gupta, Bharti Shokeen and Ved Prakash Yadav

Rajasthan Agricultural Research Institute (SKN Agriculture University, Jobner), Durgapura, Jaipur-302 018, Rajasthan, India.
*Corresponding author E-mail : mathurrani@rediffmail.com
(Date of Receiving-02-02-2026; Date of Revision-25-03-2026; Date of Acceptance-08-04-2026)

ABSTRACT

Pearl millet (*Pennisetum glaucum* L.) is an important cereal crop cultivated under semi-arid conditions due to its adaptability to drought and poor soils. A field experiment was conducted during the kharif seasons of 2022 and 2023 at Rajasthan Agricultural Research Institute, Durgapura, Jaipur, to evaluate the effect of sowing dates and varieties on growth, yield and economic returns of pearl millet under rainfed conditions. Results revealed that sowing dates significantly influenced growth parameters, yield attributes, yield and profitability. The crop sown on 15 July recorded higher effective tillers (201 m^{-2}), ear length (10.00 cm) and test weight (2.51 g), which resulted in maximum grain yield (2395 kg ha^{-1}), straw yield (3829 kg ha^{-1}) and biological yield (6224 kg ha^{-1}). Early sowing (5 July) showed better plant height and dry matter accumulation, while delayed sowing (25 July) significantly reduced growth and yield parameters. Among varieties, RHB 234 exhibited superior performance in terms of yield attributes, grain yield (2605 kg ha^{-1}) and economic returns. The highest net return (` 51,362 ha^{-1}) and benefit–cost ratio (3.5) were obtained with 15 July sowing, while RHB 234 recorded maximum profitability among varieties. The interaction effect indicated that the combination of 15 July sowing with RHB 234 produced the highest yield and economic returns. Therefore, it can be concluded that sowing pearl millet around first week of July with high-yielding variety is the most suitable strategy for enhancing productivity and profitability under semi-arid conditions of Rajasthan.

Key words : Pearl millet, Sowing dates, Varietal performance, Yield attributes, Farm profitability.

Introduction

Millets are staple food and fodder crops for millions of people, particularly in hot, dry and semi-arid regions of the world. They are well-adapted to marginal lands where major cereals fail to give substantial yields. Among millets, pearl millet (*Pennisetum glaucum* L.) is cultivated in India as a dual-purpose crop, serving both as food and fodder (Yadav *et al*., 2017). In India, the major pearl millet-producing states are Rajasthan (46%), Maharashtra (19%), Gujarat (11%), Uttar Pradesh (8%) and Haryana (6%) (Directorate of Millet Development, 2020). Despite this, the productivity of pearl millet in India remains low compared to other pearl millet-growing countries worldwide, emphasizing the need for improved agronomic practices to enhance yield (Patel *et al*., 2018).

Among the various factors affecting pearl millet productivity, sowing time is one of the most critical non-monetary inputs. Sowing too early may expose the crop to adverse conditions, while delayed sowing often reduces yield due to insufficient vegetative growth and moisture stress during critical growth stages (Singh *et al*., 2015). Optimal sowing ensures adequate vegetative development, timely flowering and avoids moisture stress during sensitive stages, thereby enhancing grain and straw yield (Kumar *et al*., 2019). Soil fertility and nutrient management also play a vital role in crop productivity. Continuous cultivation of nutrient-exhaustive crops, unbalanced fertilizer application and inadequate use of organic manures has led to nutrient depletion and deterioration of soil health in semi-arid regions (Walia *et* *al*., 2010). Combining organic and inorganic fertilizers, is therefore crucial for sustaining soil fertility and improving the productivity of pearl millet (Chauhan *et al*., 2016).

Considering the importance of both varieties and sowing time, the present study was undertaken in the semi-arid region of Rajasthan to evaluate the growth, yield and yield-contributing characters of pearl millet varieties under different sowing dates. This study aims to identify the most suitable variety × sowing date combination for enhancing pearl millet productivity under rainfed conditions.

Materials and Methods

A field study was carried out over two successive *kharif* seasons (2022 and 2023) at the research farm of the Rajasthan Agricultural Research Institute, Durgapura, Jaipur (26°51′ N, 75°47′ E; 390 m above mean sea level). The objective was to evaluate how different sowing dates, cultivars and fertility levels influence the growth, yield and economic returns of pearl millet. The site is located in the Semi-Arid Eastern Plain Zone (III-A) of Rajasthan, which experiences hot summers and cool winters. The region receives an average annual rainfall of about 525 mm, nearly 90% of which occurs between late June and September, often with uneven temporal and spatial distribution. The soil at the experimental site was loamy sand in texture, slightly alkaline (pH 7.9), low in organic carbon and nitrogen and medium in available phosphorus and potassium.

The experiment followed a split-plot design with three replications. Sowing dates (5 July, 15 July and 25 July) were assigned to the main plots, while three pearl millet varieties (RHB 234, HHB 299 and Raj 171) were allocated to subplots. Two fertilizer levels—100% of the recommended dose (90:40:0 kg ha^{-1}) and 50% of the recommended dose—were also included.

Land preparation involved one deep ploughing using a mould board plough, followed by two cross harrowing and planking. Sowing was done on the specified dates using a seed rate of 4.0 kg ha^{-1}. Farmyard manure (15 Mg ha^{-1}) was incorporated into the soil 15 days prior to sowing. In both seasons, half of the nitrogen and the full dose of phosphorus (P_2O_5) were applied at sowing as basal fertilizer, while the remaining nitrogen was applied at the time of first irrigation. The crop was grown under rainfed conditions. Necessary plant protection measures were adopted as required.

Growth and yield parameters were recorded following standard procedures, with observations taken from three randomly selected spots within each plot. Harvesting was done manually using sickles, excluding border rows and a 0.5 m margin to define the net plot area. The harvested produce was sun-dried in the field and total biological yield was recorded (kg ha^{-1}). After threshing, grains were cleaned, dried and weighed to determine grain yield (kg ha^{-1}). Straw yield was calculated by subtracting grain yield from total biological yield.

Economic analysis included calculation of net returns by subtracting the cost of cultivation from gross returns and the benefit–cost ratio was derived by dividing net returns by total cost of cultivation. The collected data were statistically analyzed using analysis of variance (ANOVA) appropriate for a split-plot design, following the method of Gomez and Gomez (1984), with SAS 9.3 software. Treatment effects were tested for significance at the 5% probability level ($P < 0.05$) using the least significant test.

Results and Discussion

Effect of sowing dates and varieties on growth parameters of pearl millet

The sowing dates significantly influenced the plant height of finger millet at all growth stages (Table 1). At the early growth stage (30 DAS), the crop sown on 15 July (D2) recorded the highest plant height (12.89 cm), followed closely by 5 July (D1) with 12.61 cm, while the lowest plant height (11.58 cm) was observed in the delayed sowing of 25 July (D3). At 60 DAS and at harvest, sowing on 5 July produced the tallest plants (54.28 cm and 164.02 cm, respectively), followed by 15 July (47.11 cm and 162.94 cm) and 25 July (44.05 cm and 151.68 cm). Although, the sowing on 15 July had slightly lower values than 5 July at later stages, it remained statistically comparable, while both were superior to the delayed sowing on 25 July. The reduction in plant height with delayed sowing may be attributed to a shortened growing period and exposure to less favorable environmental conditions.

Dry matter accumulation was also significantly affected by sowing dates (Table 1). At 30 DAS, the highest dry matter accumulation was recorded with sowing on 5 July (1.07 g m^{-2}), followed by 25 July (1.01 g m^{-2}) and 15 July (0.98 g m^{-2}). At 60 DAS and harvest, 5 July sowing again showed the highest dry matter accumulation (15.78 g m^{-2} and 76.92 g m^{-2}), with 15 July and 25 July sowings producing lower but comparable values. The superior dry matter accumulation under early sowing is likely due to more favorable environmental conditions, including optimal temperature and resource availability, which promote better photosynthetic activity and biomass accumulation.

Table 1 : Effect of different dates of sowing and varieties on plant height of pearl millet (pooled over 2 years).

Treatments	Plant height (cm)			Dry Matter accumulation (g m^{-2})		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
Date of sowing						
D1 (05 July)	12.89	54.28	164.02	1.07	15.78	76.92
D2 (15 July)	12.61	47.11	162.94	1.01	15.54	72.35
D3 (25 July)	11.58	44.05	151.68	0.98	15.03	71.39
SEm ±	0.88	7.41	9.67	0.59	0.53	4.15
CD (P=0.05)	NS	25.74	30.48	NS	1.63	14.71
Varieties						
V1–RHB 234	12.53	49.14	164.78	1.05	16.07	75.07
V2–HHB 299	12.15	51.76	150.96	1.02	15.64	72.63
V3–Raj.171	12.21	44.49	163.71	0.99	14.69	73.01
SEm ±	0.28	5.30	10.91	0.05	0.52	4.11
CD (P=0.05)	NS	16.09	33.18	NS	2.08	13.73

Table 2 : Effect of different dates of sowing and varieties on yield attributes of pearl millet (pooled over 2 years).

Treatments	Effective tillers (m^{-2})	Ear length (cm)	Test weight (g)
Date of sowing			
D1 (05 July)	171	9.93	2.35
D2 (15 July)	201	10.0	2.51
D3 (25 July)	155	9.25	2.32
SEm ±	0.88	7.41	9.67
CD (P=0.05)	2.87	24.17	31.54
Varieties			
V1–RHB 234	217	10.08	2.57
V2–HHB 299	201	9.21	2.49
V3–Raj.171	198	10.06	2.56
SEm ±	5.45	0.23	0.02
CD (P=0.05)	17.77	0.75	0.07

Among varieties, significant differences in plant height were observed at 60 DAS, with variety V2 showing the highest value (51.76 cm), while at other stages differences were less pronounced. Variety V3 recorded the highest plant height at harvest (164.71 cm), closely followed by V1 (163.78 cm) and V2 (150.96 cm). These differences might be due to genetic variation and differential adaptability to environmental factors.

Dry matter accumulation also varied among varieties. Variety V3 accumulated the highest dry matter at 60 DAS and harvest (16.07 g m^{-2} and 75.01 g m^{-2}), followed by V2 and V1, respectively. This may be attributed to better growth vigor and photosynthetic efficiency in V3.

The interaction between sowing dates and varieties was significant at later growth stages. The combination of sowing on 5 July (D1) with variety V3 recorded the highest plant height and dry matter accumulation, while the combination of 25 July (D3) sowing with variety V2 showed the lowest values. This highlights the importance of selecting an optimum sowing date alongside a suitable variety to maximize crop growth and biomass production.

Effect of sowing dates and varieties on yield attributes of pearl millet

Analysis of variance indicated that sowing dates significantly influenced key yield attributes of finger millet, including effective tiller number, ear length and test weight (Table 2). The crop sown on 15 July (D2) exhibited the highest effective tiller count (201 m^{-2}), ear length (10.00 cm) and test weight (2.51 g), outperforming both early (5 July, D1) and delayed (25 July, D3) sowings. Delayed sowing resulted in marked reductions, with effective tillers dropping to 155 m^{-2}, ear length to 9.25 cm and test weight to 2.32 g. These reductions can be attributed to shortened crop growth duration and less favorable environmental conditions such as suboptimal temperature and light availability during critical growth phases (Patel *et al.*, 2017; Singh and Kumar, 2019). The superior yield attributes at the optimum sowing date align with findings from earlier studies demonstrating that precise sowing timing improves crop phenology synchronization with favorable climatic windows, thereby enhancing resource use efficiency (Joshi *et al.*, 2016). Improved tiller formation and ear development under optimum sowing also support better grain filling, ultimately increasing test weight (Kumar *et al.*, 2018). Among the varieties, RHB 234 consistently exhibited superior performance, with 217 effective tillers per m², ear length of 10.08 cm and test weight of 2.57 g, followed by HHB 299 and Raj.171. The enhanced yield attributes in RHB 234, compared to

Raj.171, reflect its higher genetic potential and efficient assimilate partitioning towards reproductive organs, as reported in similar finger millet varietal evaluations (Nagaraja *et al*., 2020; Reddy and Naik, 2015). Though varietal differences were modest, they were consistent across parameters, indicating stable varietal performance.

The interaction between sowing date and variety was significant, where the combination of 15 July sowing with RHB 234 maximized yield attributes, while 25 July sowing with Raj. 171 led to the lowest values. This highlights the importance of integrating genotype selection with optimal agronomic timing to maximize crop productivity (Singh *et al*., 2017).

Effect of sowing dates and varieties on crop productivity

Sowing dates exerted a significant influence on grain, straw and biological yield of pearl millet (Table 3). The crop sown on 15 July (D2) recorded the highest grain yield (2395 kg ha^{-1}), straw yield (3829 kg ha^{-1}) and biological yield (6224 kg ha^{-1}), which were significantly superior to both early (5 July, D1) and delayed (25 July, D3) sowings. The lowest yields were observed under delayed sowing (D3), with grain yield of 1673 kg ha^{-1}, straw yield of 3071 kg ha^{-1} and biological yield of 4744 kg ha^{-1}. The reduction in yield under late sowing may be attributed to shortened crop duration and exposure to unfavorable environmental conditions during flowering and grain filling stages (Singh and Kumar, 2019; Patel *et al*., 2017). Similar findings were reported by Yadav *et al*. (2020), who observed that optimum sowing time ensured better utilization of available resources and improved yield performance in pearl millet. Among the varieties, RHB 234 produced the highest grain yield (2605 kg ha^{-1}), straw yield (4241 kg ha^{-1}) and biological yield (6846 kg ha^{-1}), followed by Raj.171 and HHB 299. The differences in grain yield among varieties were statistically significant, indicating variability in genetic potential and adaptability. The superior performance of RHB 234 may be attributed to its higher growth rate, better dry matter accumulation and efficient partitioning of assimilates towards economic yield (Reddy and Reddy, 2015; Nagaraja *et al*., 2020). These results are in agreement with earlier studies, which reported that improved hybrids generally outperform local varieties in terms of yield and biomass production under semi-arid conditions (Kumar *et al*., 2018). The interaction effect revealed that the combination of 15 July sowing (D2) with RHB 234 (V1) produced the highest grain, straw and biological yields, whereas the combination of 25 July sowing (D3) with HHB 299 (V2) recorded comparatively lower yields. This clearly indicates that optimum sowing time coupled with a suitable high-yielding variety plays a crucial role in maximizing productivity of pearl millet under semi-arid conditions (Singh *et al*., 2017).

Table 3 : Effect of different dates of sowing and varieties on pearl millet productivity potential (pooled over 2 years).

Treatments	Grain yield (q/ha)	Straw yield (q/ha)	Biomass yield (q/ha)
Date of sowing			
D1 (05 July)	1906	3597	5503
D2 (15 July)	2395	3829	6224
D3 (25 July)	1673	3071	4744
SEm ±	44.14	53.24	69.01
CD (P=0.05)	146.42	167.22	215.13
Varieties			
V1–RHB 234	2605	4241	6846
V2–HHB 299	2246	3498	5744
V3–Raj.171	2378	3871	6249
SEm ±	66.16	175.31	160.11
CD (P=0.05)	201.33	531.32	487.21

Effect of sowing dates and varieties on farm profitability

Economic analysis revealed that sowing dates and varieties had a significant influence on the profitability of pearl millet cultivation (Table 4). Among the different sowing dates, the crop sown on 15 July (D2) recorded the highest gross return (` 71,362 ha$^{-1}$), net return (` 51,362 ha^{-1}) and benefit–cost ratio (3.5), followed by 5 July (D1) with gross return of ` 58,441 ha$^{-1}$, net return of ` 38,441 ha^{-1} and B:C ratio of 3.0. The lowest economic returns were observed under delayed sowing on 25 July (D3), with gross return of ` 51,038 ha^{-1}, net return of ¹ 31,038 ha^{-1} and B:C ratio of 2.6. The higher profitability under optimum sowing time may be attributed to higher grain and straw yields, efficient utilization of resources and better synchronization of crop growth with favorable environmental conditions (Singh and Kumar, 2019; Patel *et al*., 2017). Similar results were reported by Yadav *et al*. (2020), who emphasized that timely sowing plays a crucial role in maximizing economic returns in pearl millet under semi-arid regions. Among the varieties, RHB 234 recorded the highest gross return (` 77,848 ha$^{-1}$), net return (` 57,848 ha^{-1}) and B:C ratio (3.9), followed by Raj.171 and HHB 299. The superior economic performance of RHB 234 may be attributed to its higher yield potential, better dry matter accumulation and efficient partitioning of assimilates towards grain yield (Reddy and Reddy, 2015; Nagaraja *et al*., 2020). The

Table 4 : Effect of different dates of sowing and varieties on farm profitability with common Cost of cultivation (` 20000/ha) (pooled over 2 years).

Treatments	Gross return (` /ha)	Net return (` /ha)	B:C ratio
Date of sowing			
D1 (05 July)	58441	38441	3
D2 (15 July)	71362	51362	3.5
D3 (25 July)	51038	31038	2.6
Varieties			
V1–RHB 234	77848	57848	3.9
V2–HHB 299	66644	46644	3.3
V3–Raj.171	71063	51063	3.5

variation in profitability among varieties is mainly due to differences in genetic potential and adaptability to prevailing agro-climatic conditions (Kumar *et al*., 2018). The interaction effect indicated that the combination of 15 July sowing (D2) with RHB 234 (V1) resulted in maximum gross and net returns as well as the highest B:C ratio, whereas 25 July sowing (D3) with HHB 299 (V2) recorded comparatively lower returns. This clearly indicates that adoption of an optimum sowing date along with a high-yielding and well-adapted variety is essential for achieving higher profitability in pearl millet cultivation under semi-arid conditions (Singh *et al*., 2017).

Conclusion

The present investigation established that both sowing dates and varietal selection exert a significant influence on growth dynamics, yield attributes, productivity and economic returns of pearl millet under semi-arid conditions. Sowing around mid-July (15 July) provided a favourable agro-climatic window that enhanced crop establishment, tiller production and reproductive development, ultimately resulting in higher grain (2395 kg ha^{-1}), straw (3829 kg ha^{-1}) and biological yield (6224 kg ha^{-1}). Although, early sowing (5 July) promoted greater plant height and dry matter accumulation at later stages, it did not translate into maximum yield, indicating that synchronization of phenological stages with rainfall distribution and temperature regimes is more critical than early vegetative vigor. Delayed sowing (25 July) significantly reduced growth and yield due to shortened crop duration and exposure to terminal moisture stress. Among the tested genotypes, RHB 234 demonstrated superior performance in terms of yield attributes, productivity and profitability, suggesting better resource-use efficiency and assimilates partitioning towards economic yield. The interaction effects further confirmed that the combination of 15 July sowing with RHB 234 was the most productive and economically viable, highlighting the importance of integrating optimum sowing time with suitable genotype selection for maximizing pearl millet performance under rainfed conditions.

Future Research scope

Despite the clear advantages observed under the present study, further research is warranted to refine and sustain pearl millet production under changing climatic scenarios:

- Long-term multi-location trials should be conducted to validate the stability and adaptability of promising varieties like RHB 234 across diverse agro-ecological zones of Rajasthan.
- Detailed studies on climate-resilient sowing windows are needed, particularly under erratic monsoon patterns and rising temperatures.
- Integration of precision nutrient management strategies, including site-specific nutrient management and use of biofertilizers, may further enhance productivity and soil health.
- Exploration of water-use efficiency and moisture conservation practices, such as mulching and conservation tillage, could improve crop performance under limited rainfall conditions.
- Advanced physiological and molecular studies focusing on stress tolerance mechanisms may help in developing improved genotypes with higher yield stability.
- Economic analysis incorporating market fluctuations and input cost variability would provide more robust recommendations for farmers.

Overall, a holistic approach combining improved varieties, optimized sowing time and sustainable agronomic practices is essential for enhancing pearl millet productivity and resilience in semi-arid regions.

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