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Research Article

Influence of Sowing Dates and Cultivars on Growth, Yield, and phenology of Proso Millet (*Panicum miliaceum* L.) in Punjab, India

JAGDISH SINGH[1], AMIT KAUL[2] AND NAVNEET KAUR[3]*

[1]*Punjab Agricultural University Regional Research Station, Gurdaspur-143521, Punjab*
[2]*Department of Agronomy, Punjab Agricultural University, Ludhiana-141004, Punjab*
[3]*Punjab Agricultural University Regional Research Station, Ballowal Saunkhari-144521, Punjab*

ABSTRACT

The rice-wheat cropping system in Punjab has resulted in declining water table, soil health degradation and climate change. To address such issues, diversification of some area under rice wheat to low water requiring crops such as millets is need of hour. Proso millet (*Panicum miliaceum* L.) has emerging as climate resilient crop, with short growing period, minimal water and nutrient requirements, and able to grow under marginal soil fertility levels. Thus, the field study assessed the impact of sowing dates and cultivar selection on the growth, maturity, and yield of proso millet in Punjab. The experiment involved three cultivars; TNAU-145, Punjab Cheena-1, and PM-2 sown on six different dates viz., 26th April, 11th May, 26th May, 10th June, 25th June and 11th July during the year 2023 and 2024. The results revealed that early sowing, particularly on April 26 and May 11, produced the tallest plants, maximum tiller numbers, longest panicles and overall biomass. Among the cultivars, Punjab Cheena-1 consistently outperforming other varieties for grain (3.67 q/acre) and biological yield (32.1 q/acre) followed by PM-2 and TNAU-145. Delay in sowing (11th July) led to shorter crop duration and crop acquired less accumulated growing degree days (1140.2 °C day) which ultimately lower grain yields (2.11 q/acre) compared to normal and early sowings. The findings highlight the potential of proso millet to fits well into Punjab's water-stressed and ecologically vulnerable landscapes. Tailoring sowing schedules and genotype choice can significantly boost productivity, offering a sustainable pathway for crop diversification and resource conservation in the region.

Key words: *Panicum miliaceum*, Sowing date, Phenology, Climate resilience, Crop diversification, Resource-use efficiency

Introduction

Proso millet is cultivated in about 35 countries, with nearly 90% of the global area concentrated in Russia, the USA, Ukraine, North Korea, and Kazakhstan, which together contribute about 86% of total production (FAO, 2018). It is mainly used as bird and livestock feed and is also grown in countries such as China, Mongolia, India, and parts of southern Europe. In India, it is primarily cultivated in Uttar Pradesh, Tamil Nadu, Bihar, Karnataka, Andhra Pradesh, Madhya Pradesh, and the North Eastern states (Anonymous, 2023). Despite its wide distribution, the global area under proso millet has declined due to its low average yield (890 kg ha^{-1}) compared to other cereals (FAO, 2018). To encourage millet production and consumption, the Government of India declared year 2018 as the National Year of Millets and 2023 as the International Year of Millets, highlighting their nutritional importance.

*Corresponding author,
Email: navneetkaur@pau.edu

Proso millet is a climate-resilient crop with strong potential to address Punjab's agronomic and ecological challenges (Gregory *et al*., 2019). Punjab, once the hub of the Green Revolution, now faces severe groundwater depletion and soil degradation due to the dominance of the rice–wheat cropping system, which occupies about 86% of the cultivated area (Anonymous, 2023). Groundwater extraction has reached 156.87% of annual recharge, with over 75% of blocks classified as overexploited (Anonymous, 2024). Intensive monoculture, heavy tubewell irrigation, and chemical inputs have further reduced soil fertility and organic carbon (Chauhan *et al*., 2012; Singh *et al*., 2017). In this context, proso millet offers a viable alternative owing to its short duration, low water and nutrient requirements, and adaptability to marginal conditions (Seghatoleslami *et al*., 2008). Its C,, photosynthetic pathway ensures high water-use efficiency, requiring nearly half the water of wheat (Baltensperger *et al*., 1995). Additionally, proso millet is nutritionally rich, supporting both food and nutritional security (Saleh *et al*., 2013).

Diversifying cropping systems with robust, resource efficient grains like proso millet can reduce pressure on depleting water tables, restore degraded soils, and mitigate the risks associated with input-intensive agriculture (Cavers and Kane, 2016). However, successful integration of this crop relies on optimizing agronomic practices particularly the selection of appropriate sowing window and cultivars. The sowing time for proso millet varies across Indian states, typically sown in the July with the onset of the monsoon, while in Karnataka and other southern states, sown during late June to mid-July, and in Bihar, sowing is done from mid-March to mid-May (Chapke *et al*., 2020). The yield study of different cultivars in different states has revealed that the Proso millet varieties such as Prasad and TNAU 145 performed better for Tamil Nadu and southern India due to their early maturity and yield stability, while CO(Pv) 3 and GPU 67 yielded good in northern zones including Uttarakhand, and Rajasthan, showing their adaptability to diverse agro-climatic conditions. Thus, best sowing time in combination with best cultivar further enhance crop adaptation to local agro-climatic variations, allowing for optimized growth, improved yields, and resource use efficiency (Bandyopadhyay *et al*., 2017; Ali *et al*., 2022; Ma *et al*., 2024). Additionally, improved understanding of genotype and environment interactions help farmers to adopt management practices best suited to local conditions, thus maximizing returns and minimizing risks.

This study investigates the interactive effect of sowing dates and proso millet cultivars on growth, phenology and productivity under the field conditions of Punjab. By aligning millet production with principles of resource conservation and sustainable management, the study aims to provide pathways to revitalize soil health, conserve groundwater, and support resilient and secure food systems in the state.

Material and methods

Location details

The field experiment was conducted at the research farm of Punjab Agricultural University, Regional Station, Gurdaspur during the year 2023 and 2024. The soil at the experimental site was classified as fine loamy, non-calcareous, mixed, hypertermic typic Haplustalfs with silt loam texture (41 % sand, 40.5 % silt and 18.5% clay) (Singh and Sharma 2021). The soil has 7.5 pH, 0.13 dSm^{-1} electrical conductivity, 0.52 % organic carbon, 37.5 kg ha^{-1} available phosphorus, and 62.5 kg ha^{-1} available potassium. The collected soils from the field were composited and homogenized, air-dried and sieved through a 1-mm sieve to get representative soil sample for pre-sowing soil analysis in the laboratory.

Weather of the experimental site

The average annual rainfall of the region is 700 mm, where mean maximum temperature reaches as high as 42°C in the month of May-June while close to freezing temperatures (around 2.9 °C) along with ground frost spells during the months of December-January. The mean minimum and maximum temperature, and daily rainfall were recorded manually at agrometeorological observatory about 200 m away from the experimental site.

Treatment details

The three cultivars of proso millet namely TNAU-145, PM-1 (variety released as Punjab Cheena-1), and PM-2 (coded varieties under testing by Punjab Agricultural University) were sown on six sowing dates namely S_1: 26th April, S_2: 11th May, S_3: 26th May, S_4: 10th June, S_5: 25th June, S_6: 11th July. The experiment was laid out in randomized complete block design with two factors i.e. date of sowing and cultivar, were replicated three times.

Crop management

The pre-sowing irrigation was applied before preparation of fine seed bed. The proso millet cultivars namely TNAU-145, PM-1 (variety released as Punjab cheena-1), and PM-2 were sown as per treatment using seed rate of 3.0 kg/hectare with row spacing of 22.5 cm. The fertilizers were applied as urea at the rate of 60 kg ha^{-1} and SSP at the rate of 60 kg/hectare. The whole of the phosphorus was applied at the time of sowing and nitrogen fertilizer in the form of urea was applied in two equal splits i.e. half of urea at time of sowing and remaining half after 15-20 days after sowing. Two hand hoeings were done to manage weeds in the field first at 15-20 days after sowing and second 40-45 days after sowing. The irrigation was applied as per the crop need and weather conditions so that crop does not suffer any moisture stress.

Observations record

The maximum plant height, number of tillers, number of days taken to flowering and maturity were recorded from the randomly selected five plants from each plot.

The growing degree days as a measure of thermal time, were calculated by simple arithmetic accumulation of daily mean temperature above the base temperature. The growing degree days for each stage were calculated as (Nuttonson, 1955):

$$\text{Growing degree days (°C days)} = \Sigma_{i=1}^{n} T_i - T_b \quad (1)$$

Where, i is the ith day from sowing, T_i is mean temperature for that day, n is the number of days in the growing season (Ellis *et al*., 1990) and T_b is Base temperature and was taken equal to 10°C. The heat use efficiency was calculated using the following formula:

Heat use efficiency (kg/ha/°C days) =

$$\frac{\text{Grain or dry matter yield (kg/ha)}}{\text{AGDD (°C day)}} \quad (2)$$

AGDD is Accumulated growing degree days (°C Day) is sum of growing degree days acquired by crop during life cycle.

Statistical analysis

The pooled data of two year was subjected to ANOVA for randomized complete block design with two factors (Gomez and Gomez, 1984) using R (R core team 2025) to evaluate differences between treatments. Treatment mean separation was done by using Fishers LSD at 5% significance level (P≤0.05).

Results and Discussion

A significant influence of sowing time on plant was observed in proso millet (Table 1). The maximum plant height was observed under S_1 treatment, which was at par with S_2 and S_3 sowing date while further delay in sowing resulted in progressive reduction in plant height. Among the genotypes, significantly higher plant height was observed under TNAU-145 as compared to all other varieties. The results also corroborate with the findings of Deshmukh *et al*. (2013), Mubeena *et al*. (2019) and Nandini and Sridhara (2019), where taller plants were observed in early sown crop due to favourable climatic conditions during the crop growth period, resulting in higher rate of photosynthesis which directly influenced the plant height.

The highest number of tillers per unit area (242 tiller m^{-2}) were observed under crop sown on 26th April 2023 (S_1 treatment), where the number of tillers reduces with the delay in sowing and found lowest (175.8 tiller m^{-2}) in the treatment where crop was sown in the month of July (11th July). Among the varieties, the Punjab Cheena-1 variety produced significantly higher number of tillers (232.2 tiller m^{-2}) of tillers compared to TNAU 145 and PM 2 (Table 1). The results revealed that the sowing in the

Table 1. Effect of date of sowing and different varieties on plant height and no. of tillers m^{-2} in proso millet

Treatments	Plant height (cm)	No. of tillers m^{-2}	Days to flowering	Days to physiological maturity	Panicle length (cm)	AGDD (°C day)
S_1: 26th April	7502	242.0	61.3	75.7	23.4	1,493.7
S_2: 11th May	73.2	238.4	60.3	73.3	23.2	1,527.8
S_3: 26th May	72.6	231.9	58.6	72.6	23.0	1,462.3
S_4: 10th June	72.8	217.7	56.0	72.3	22.7	1,512.9
S_5: 25th June	68.8	202.6	53.9	70.2	22.7	1,430.7
S_6: 11th July	67.8	178.5	54.7	69.8	22.1	1,140.2
LSD (p=0.05)	3.8	10.3	2.7	3.8	NS	83.3
TNAU-145	74.9	203.8	60.6	75.5	20.2	1,498.4
Punjab Cheena 1	70.9	232.2	53.8	71.5	24.7	1,401.8
PM-2	69.4	219.6	57.1	69.9	23.6	1,383.6
LSD (p=0.05)	2.69	7.2	1.9	2.7	1.37	58.9
Interactions (S×V)	NS	NS	NS	NS	3.35	NS

month of April resulted in maximum number of tillers m^{-2} due to the fact that early sown crop had experienced longer period of vegetative growth coupled with favourable weather conditions. Mubeena *et al*., (2019) reported significant reduction in number of tillers m^{-2} with delay in sowing which might be due to delay in germination.

The duration to flowering and physiological maturity was markedly influenced by sowing time and variety (Table 1). The crop sown in 26th April (S_1) took more number of days to flowering (61.3 days) and physiological maturity (75.7 days) while the late sown crop i.e 11th July (S_6) took 54.7 days to attain flowering and 69.8 days to physiological maturity. This reduction in crop duration with delayed sowing indicates accelerated phenological progression under increasing temperature regimes. Among varieties, the maximum number of days to flowering (60.6 days) and physiological maturity (75.5 days) was observed in TNAU-145 which was significantly higher as compared to Punjab Cheena 1. Earlier sown crop took more time to achieve maturity, which progressively decreased with delay in sowing. Reddy *et al*., (2016) reported that with delay in sowing, flowering may induce earlier, resulting in less vegetative growth and earliness in maturity. The results obtained in the present investigation corroborate with the findings of Ashoka and Halikatti (1997), who observed earlier flowering with delayed sowing. Physiological maturity in proso millet crop proceeds from top to the bottom of the panicle. The ripening of the seed was not uniform throughout panicle and delay in harvesting may cause losses due to shattering (Baltensperger *et al*., 1995). So, synchronizing maturity through appropriate sowing time is critical for minimizing yield losses.

The longest panicles (23.4 cm) were observed under S_1 (26th April) sowing which remained statistically at par with S_2 (11th May) and S_3 (26th May) date of sowings. The maximum panicle length (24.7 cm) was observed under Punjab Cheena-1, the longer panicles represent a greater number of grains per panicle that may results in higher grain yield. Longer panicles under early sown crop might be owing to higher dry matter accumulation in the panicle and better translocation of assimilates from source to the sink. Above results were similar with the findings of Nandini and Sridhara (2019). The variety Punjab Cheena-1 consitantly produced longer panicles during all the sowing dates, where as PM-2 produced panicle comparable to Punjab cheena-1 during all sowing dates except crop sown on 25th June compared to TNAU-145 cultivar.

The grain yield was strongly influenced by sowing time and varietal performance (Table 2). The maximum grain yield (3.56 q/acre) was observed under 11th May (S_2) sown crop that was statistically at par with 26th May (S_3), 10th June (S_4) and 26th April

Table 2. Effect of date of sowing and different varieties on Grain yield of proso millet

	Grain yield (q/acre)			
	TNAU-145	PM-1 (Punjab Cheena 1)	PM-2	Mean S
S_1: 26th April	2.39	4.09	3.13	3.20
S_2: 11th May	3.28	4.02	3.37	3.56
S_3: 26th May	3.18	3.98	3.36	3.50
S_4: 10th June	3.29	3.73	3.58	3.53
S_5: 25th June	1.94	3.58	2.93	2.82
S_6: 11th July	2.02	2.60	1.71	2.11
Mean V	2.68	3.67	3.01	
LSD (0.05) S= 0.16, LSD (0.05) V= 0.12, LSD S × V= 0.28				

Table 3. Effect of date of sowing and different varieties on biological yield of proso millet

	Biological yield (q/acre)			
	TNAU-145	Punjab Cheena 1	PM-2	Mean S
S_1: 26th April	27.1	30.2	28.9	28.7
S_2: 11th May	27.3	30.7	29.1	29.0
S_3: 26th May	29.3	30.6	32.4	30.8
S_4: 10th June	26.9	34.2	32.5	31.2
S_5: 25th June	31.4	32.4	32.1	32.0
S_6: 11th July	30.4	34.4	32.5	32.4
Mean V	28.7	32.1	31.2	
LSD (0.05) S= 1.92, LSD (0.05) V= 1.36, LSD S × V= NS				

(S_1) treatments, representing that the optimum sowing window for proso millet in Punjab lies between late April to first week of June. The yield was significantly declined under late June and July sowings, likely due to suboptimal temperature and moisture conditions during reproductive phases. Among varieties, the maximum grain yield (3.67 q/acre) was observed under Punjab Cheena 1 which was significantly higher than TNAU 145 and PM 2. The interaction between sowing date and variety was also found significant, where Punjab Cheena 1 sown during S_1, S_2 and S_3 sowing dates produces significantly higher grain yield compared to all other treatment combinations. Early sown crop might have experienced favourable weather conditions coupled with prolonged photoperiod which enhanced photosynthetic activity and assimilate accumulation. These assimilates were efficiently translocated towards the developing panicles resulted in greater panicle length, and ultimately higher grain yield. The results of present investigation are in agreement with the findings of Maurya *et al*. (2016) and Mubeena *et al*. (2019).

The biological yield of the crop sown on 11th July (S_6) was significantly higher (32.4 q/acre) than other treatments, but statistically at par with S_4 (25th June) and S_5 (11th July) sown crops. This indicates that the late sowing of crop produces more biomass, that may be possible as it coincides with the monsoon rainfall, which may have provided favourable soil moisture condition for higher biomass production. Among the varieties, the maximum biological yield (32.1 q/acre) was observed under Punjab Cheena 1, that was statistically at par with PM 2, but significantly higher biological yield as compared to TNAU 145 culitvar. Higher biological yield might be due to favourable weather conditions like bright sunshine hours and adequate soil moisture supply that has resulted in better growth parameters like plant height, leaf area index and dry matter accumulation which have directly influenced straw yield. These results were similar with the findings

Table 4. Effect of date of sowing and different varieties on heat use efficiency of proso millet

Time of sowing	Heat use efficiency (kg ha^{-1} °C Day^{-1})			
	TNAU-145	Punjab Cheena 1	PM-2	Mean S
S_1: 26th April	0.35	0.68	0.52	0.52
S_2: 11th May	0.50	0.65	0.53	0.56
S_3: 26th May	0.50	0.66	0.56	0.57
S_4: 10th June	0.50	0.59	0.59	0.56
S_5: 25th June	0.31	0.59	0.50	0.47
S_6: 11th July	0.36	0.56	0.37	0.43
Mean V	0.42	0.62	0.51	
LSD (0.05) S= 0.04, LSD (0.05) V=0.03, LSD S × V= 0.06				

of Mubeena *et al*. (2019) and Nandini & Sridhara (2019).

The heat use efficiency (HUE) of proso millet varies with different sowing dates and varieties (Table 4). Heat use efficiency reflects how well a crop converts accumulated heat units (growing degree days) into yield, making it a critical trait for adaptation and productivity in varying thermal regimes. The highest HUE value (0.57) were recorded for the crop sown on 26th May (S_3) followed by 11th May (S_2) and 10th June (S_4) sown crops while a notable reduction was recorded under late sowing (S_5 and S_6). The excessive heat, shortened grain filling periods, or the onset of moonson, which are known to severely affect reproductive processes in millets, has resulted in the lower HUE and yield under S_5 and S_6 sowing dates.

The proso millet variety Punjab Cheena 1 has significantly higher HUE (0.62), compared to TNAU-145 (0.42) and PM 2 (0.51), indicating superior thermal adaptability and better resource use efficiency for yield formation. The interaction effect for date of sowing and variety was statistically significant, where Punjab Cheena 1 attains higher HUE on the April 26 sown crop (0.68) and maintains superior HUE across most sowing dates, further confirming its suitability for variable conditions. The selection of optimal sowing dates (early to mid-May or early June) and high-efficiency varieties (such as Punjab Cheena 1**)** can substantially boost proso millet yield potential, exhibit resilience to heat and limited water, particularly under climate vulnerable agro-ecosystems (Calamai *et al*., 2020). Samineni *et al*. (2025) also reported that genotype by environment interactions strongly affects yield potential of proso millet, corroborating the findings, where HUE falls sharply in late sowings. The results revealed significant linear relationship (R^2 = 0.82) was observed between yield and heat use efficiency (Fig. 1), emphasizing that higher thermal utilization efficiency directly translated into greater productivity. The relationship supports that the HUE as a reliable tool for selecting optimal variety and sowing time, as the variety Punjab Cheena-1, consistently recorded higher HUE, and grain yields.

Conclusion

The Punjab Cheena-1 cultivar produced the tallest plants, highest tiller counts, higher grain and biological yield compared to other cultivars. The results confirm that sowing of proso millet variety Punjab Cheena 1 during mid-May significantly improves plant growth and grain yield. Early sowing enabled efficient utilization of temperature and solar radiation during key phenophases, leading to better crop growth, higher yield components, and improved thermal productivity. The selection of suitable sowing time and improved cultivars not only enhances yield but also contributes to resource conservation, offering farmers a resilient solution in the face of groundwater depletion. Integrating millet into local crop rotations can help revive soil health, lower water use, and build climate resilience, guiding Punjab towards sustainable agriculture amid mounting environmental challenges.

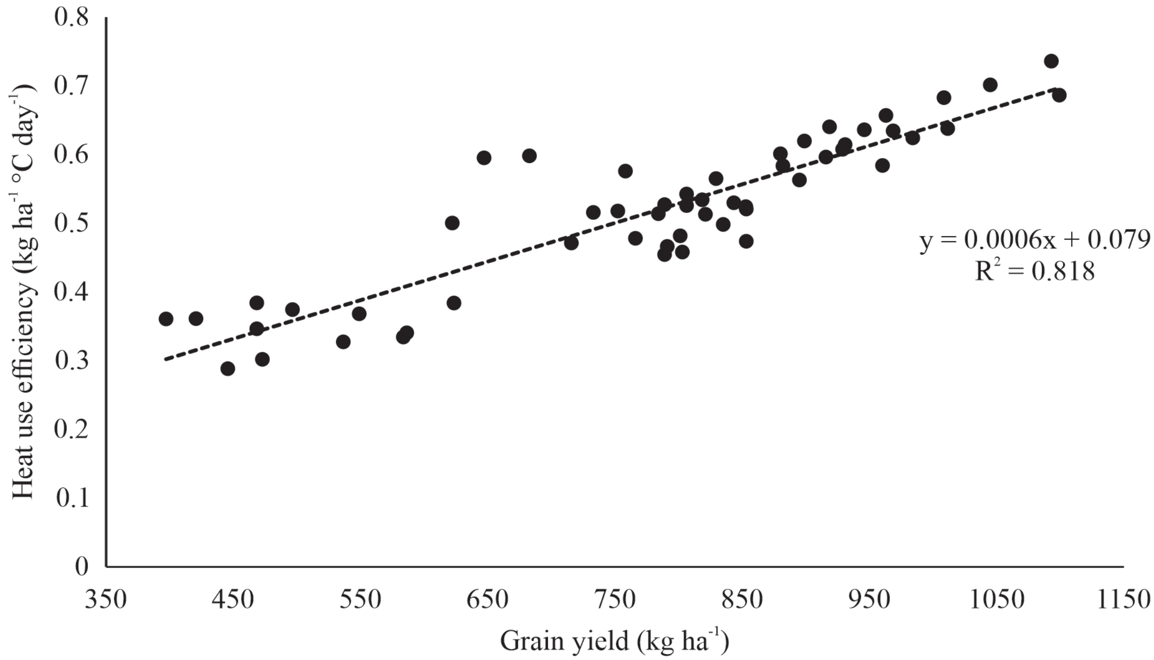

Fig. 1. Relationship of heat use efficiency and grain yield of proso millet

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