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Research Paper

Growth dynamics, yield and economic response of pearl millet (*Pennisetum glaucum*) hybrids to row spacing adjustments under hyper arid condition of Rajasthan

M.L. REAGER[1], SUBHASH CHANDRA[2], B.S. KHERAWAT[3], NAVAL KISHOR[4], P.R. RAIGER[5], RICHA PANT[6], DASHARATH PRASAD[7], KIRAN KUMARI[8] AND ANIRUDH CHOUDHARY[9]

Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan 334 006

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ABSTRACT

An experiment was conducted during the *Kharif* season of 2021–2022 at Krishi Vigyan Kendra, Bikaner-II (Lunkaransar), Rajasthan, with the treatment combination of three row spacings (30 cm × 15 cm, 45 cm × 15 cm and 60 cm × 15 cm) and seven hybrids of pearl millet 'HHB-67' improved, 'HHB-197', 'HHB-299', 'MPMH-17', 'HHB-273', 'HHB-226' and 'BHB-1602'). The experiment was carried out in split plot design with three replications. The result reveled that yield attributes, yield, net returns and B:C ratio were recorded significantly higher in the wider spacing (60×15 cm) statistically showed maximum seed yield (2.40 t/ha), net returns (36,324 Rs ha^{-1}) with B:C ratio (3.07) followed by 45×15 cm space sowing seed yield (2.25 t ha^{-1}), net returns (33,856 Rs ha^{-1}) with B:C ratio (2.93) and third sowing spacing (30×15 cm) seed yield (1.92 t ha^{-1}), Net Returns (27,086 Rs ha^{-1}) with B:C ratio (2.55) respectively. Similarly, hybrid MPMH-17 recorded significantly higher grain yield 2.50 t ha^{-1} followed by hybrid HHB-299 (2.39 t ha^{-1}), HHB-273 (2.22 t ha^{-1}), HHB-197 (2.21 t ha^{-1}), HHB-67 imp (2.08 t ha^{-1}), HHB-226 (1.97 t ha^{-1}) and BHB-1602 (1.96 t ha^{-1}) respectively. In interaction of row spacing with different hybrids showed that pearl millet hybrid MPMH-17 sowing at spacing 45×15 cm, being statically at par with HHB-299 sowing at spacing 45×15 cm and HHB-67 imp. sowing at spacing 60×15 cm recorded maximum seed yield, stover yield and biological yield, which was significantly higher over all other hybrids of pearl millet with sowing all row spacing.

Key words: Benefit: cost ratio, Hybrids, Yield, Pearl millet

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is important millet crops grown in India (Satyavathi *et al.,* 2021). Pearl millet belongs to family *poaceae* and genus *pennisetum*, originated in central tropical Africa and widely distributed in hot arid India. Pearl millet is the major *kharif* grain and fodder crops in the arid and semi-arid regions of India (Sanjana Reddy *et al*., 2021). The major producing state are Rajasthan (46%), Maharashtra (19%), Gujarat (11%), Uttar Pradesh (8%) and Haryana (6%) in India and it is fourth most important cereal crop after rice, wheat and sorghum (Saroy *et al.,* 2024). In the majority of the world's poorest nations, pearl millet is an integral part of the diet for agricultural families. India is the largest producer of pearl millet in the world (Satyavathi *et al.*, 2021). Nutritionally, the pearl millet grains are rich source of protein (9-15 %), fat (5 %), carbohydrates (67 %), mineral matters (2-7 %), high energy value (>360 Kcal/100g) and high Fe, Zn and Ca compared to other cereals. Millet produces high quality grains than any other cereals under extreme conditions: like unfertile soil, intense heat and prolong drought (Jan *et al*., 2015) and it is primary cause for pearl millet's widespread cultivation in arid and semi-arid situations (Yadav *et al.,* 2017).

Row spacing is the most important non-monetary input influencing crop yield. Sowing at optimum spacing improves the productivity by providing suitable environment at all the growth stages (Bamboriya *et al.,* 2017). The optimum plant density varies depending on genotypes or environmental factors such soil fertility, moisture supply and planting date (Seleiman *et al.,* 2021). Berenguer and Faci (2001) reported that an increase in plant density can reduce water availability to the individual plant and lead to water deficiency, followed by yield decrease. Generally, previous results worthy cleared that yield per single plant decreases as the plant density per unit area increase, also plant density can affect plant morphology and dry matter content

[1]**Corresponding author's Email:** drmadanagro@gmail.com
[1]Associate Professor, [3,4,6]SMS, [7]Senior Scientist and Head, KVK, [2]Director, DEE, [8]M.Sc. Scholar, [9]Ph.D. Scholar, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan; [5]Assistant Professor, Agriculture University, Jodhpur, Rajasthan

(Lafrage and Hammer, 2002). Ali (2010) showed that sowing pearl millet at the medium plant density (250 thousand/plantha) gave the highest values of most studied traits.

The productivity of any crop depends on its genetic potential, soil and climate (Raza *et al.,* 2019). Since genotype is fixed character, growth and yield of a crop is influenced by environmental and cultural practices (Chetan *et al.,* 2017). But until now very fewer literatures are available on cultivation of new pearl millet hybrids with suitable row spacing for the region, keeping in view of the importance, the study aimed to investigate the growth dynamics, yield and economic response of pearl millet (*Pennisetum glaucum* L.) hybrids to row spacing adjustments under hyper arid conditions of Rajasthan.

MATERIALS AND METHODS

Two years field experiments were conducted at Krishi Vigyan Kendra, Bikaner-II (Lunkaransar), Swami Keshwanand Rajasthan Agricultural University, Bikaner during *Kharif* season of year 2021–2022. Lunkaransar is located on 28.01° N latitude and 73.22° E longitude at an altitude of 234.7 m above mean sea level. The trials were conducted under irrigated (three irrigations applied to cope drought stress) conditions during both the years. The experiment was laid out in a split plot design consisting 21 treatment combinations comprised of three rows spacing 30 cm × 15 cm, 45 cm × 15 cm and 60 cm × 15 cm and seven pearl millet hybrids were 'HHB-67' (Improved), 'HHB 197', 'HHB-299', 'MPMH-17', 'HHB-273', 'HHB-226' and 'BHB-1602' in three replications. Pre-sowing irrigation was applied for uniform germination because no rainfall was received at the time of sowing. The crop was maintained weed free by hand weeding twice at 30 and 45 days after sowing. The recommended dose of nitrogen (100 kg N/ha) and phosphorus (40 kg P_2O_5/ha) were applied with urea (46% N) and diammonium phosphate (46% P_2O_5 and 18% N), respectively. The entire phosphorus and half of the nitrogen doses was applied at the time of sowing, and the remaining half of the nitrogen dose was given as a top dressing 30 days after sowing.

The observation methods used ensured precise and reliable data collection for evaluating the performance of different pearl millet genotypes. These standardized techniques help in assessing growth, maturity, and yield-related traits, which are crucial for agronomic improvement programs. Plant Height (cm) measurements were taken from the base of the plant (soil surface) to the tip of the highest leaf or panicle at physiological maturity. Observations were recorded from a randomly selected sample of 5–10 plants per plot, and the average height was calculated. Daily field monitoring was conducted to track the flowering stages of plants. The date when 50% of the plants in a plot showed visible stigma emergence was recorded. The number of days from sowing to this stage was noted as Days to 50% flowering. Maturity was confirmed when grains hardened, and the panicle turned yellowish-brown. The number of days from sowing to maturity was recorded. Tillers were counted manually per plant at the reproductive stage. Only productive tillers (those bearing a fully developed panicle) were considered. The diameter of the panicle was measured at its thickest part using a Vernier caliper. A random grain sample was collected from harvested panicles. 1000 grains were counted using an electronic seed counter. The grains were then weighed using a digital balance, and the weight was recorded in grams. Harvest index is the ratio of economic yield to the biological yield which was calculated by using formula given by Donald and Hamblin (1976). Experimental data were statistically analyzed by using the methods of analysis of variance (ANOVA) as described by Gomez and Gomez (1984).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (kg ha}^{-1})}{\text{Biological yield (kg ha}^{-1})} \times 100$$

Post-harvest observation net returns (₹/ha) and B:C Ratio were recorded and analyzed separately according to procedure given by Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

Plant growth and development

Row spacing and different hybrids had significant effect on days taken to 50% flowering and maturity for pearl millet during 2021, 2022 and in pooled data of the year 2021 and 2022. The data demonstrate that the mean values for days to 50% flowering and maturity under various row spacing differed significantly (Table 1). Pearl millet grown on 60 cm × 15 cm spacing being statistically at par with 45 cm × 15 cm, significantly increased days to 50 % flowering and maturity over 30 cm × 15 cm sowing. However, 45 cm × 15 cm spacing being statistically at par with pearl millet grown at both spacing 45 cm × 15 cm and 60 cm × 15 cm during the year of 2021 and 2022 as well as pooled mean of both years. The magnitude of increase in pooled mean with pearl millet grown on 60×15 cm spacing was 6.36 and 3.78 per cent days to 50% flowering and days to maturity, respectively as compared to grown on 30 cm × 15 cm spacing. A possible reason for increased days to 50% flowering and maturity upon wider the row spacing is that the lesser number of plants per unit area increased both the photosynthesizing area and the volume of roots per unit soil surface, allowing the crop to improve the exploitation of environmental resources. Lower light interception, might be due to less inter-plant competition for light at wider row spacing, could have reduced assimilate production (Bana *et al.* 2023). The increased growth in wide row

Table 1. Effect of row spacing on growth, crop development stages and yield attributes of different pearl millet hybrids (pooled of 2021 and 2022)

Treatment	Plant height (cm)	Days to 50 % flowering	Days to maturity +	Effective tillers/ plant	Ear head length (cm)	Ear head diameter (cm)	1,000-grain weight (g)
Row spacing							
30 cm × 15 cm	149.14	45.07b	80.57b	1.65c	18.32b	2.27b	9.16b
45 cm × 15 cm	148.24	47.32a	81.36a	3.01b	19.39a	2.29b	9.24a
60 cm × 15 cm	146.41	47.94a	83.62a	3.84a	19.79a	2.40a	9.33a
SEm±	1.35	0.64	0.89	0.08	0.20	0.02	0.04
CD (P=0.05)	NS	2.08	2.91	0.25	0.66	0.05	0.11
Pearl millet hybrids							
'HHB-67' imp.	145.53c	44.23c	78.66c	2.72b	19.25b	2.05c	9.21b
'HHB-197'	160.08a	44.00c	78.03c	2.73b	20.06a	2.57a	9.47a
'HHB-299'	152.73b	52.85a	89.70a	3.12a	19.21b	2.61a	9.12b
'MPMH-17'	143.91c	48.06b	83.87b	3.30a	18.85b	2.25b	9.21b
'HHB-273'	143.17c	47.82b	83.38b	2.59b	18.74b	2.24b	9.20b
'HHB-226'	145.23c	46.58b	81.43b	2.70b	19.04b	2.27b	9.25b
'BHB-1602'	144.88c	43.90c	77.90c	2.68b	18.99b	2.26b	9.24b
SEm±	1.81	0.93	1.20	0.10	0.27	0.02	0.05
CD (P=0.05)	5.12	2.62	3.38	0.29	0.76	0.06	0.13

spacing treatment was due to higher soil moisture conservation and better growth of plants. Pool data of plant density at 40 DAS demonstrate that increasing row to row spacing from 30 cm × 15 cm to 60 cm × 15 cm, it was recorded decreased, significantly. Effect of different row spacing was non-significant on plant height at harvest during pooled mean of both years.

Days to 50% and days to maturity among the seven pearl millet hybrids was significantly different as sown in table 1. Pearl millet hybrid 'HHB-299' recorded maximum days to 50% flowering (52.85) as well as days to maturity (89.70) and significantly higher over other pearl millet hybrids. After that, 'MPMH-17', 'HHB-273' and 'HHB-226' being at par to each other statistically superior over pearl millet hybrid 'HHB-67' imp., 'HHB-197' and 'BHB-1602', which have lesser number of days to 50% flowering and maturity. The results on the number of days to 50% flowering show that late maturing varieties having longer period of growth yield more. Similar results have been reported by (Carrera *et al.,* 2024). Pearl millet hybrid HHB-197 recorded maximum plant height (160.1 cm) at harvest over all pearl millet hybrids, followed by 'HHB-299' (152.7 cm) this was due to differential maturity duration of genotypes (Kumar, 2001 and Parihar, 2005). The difference in plant height between the hybrids might due to genetic and morphological characteristic of varieties in exploiting climatic optima at important crop growth stages (Chetan *et al.,* 2017). The effect on plant density of different pearl millet hybrid was non-significant during pooled mean of both years.

Yield attributes

The analysis of yield attributes for different pearl millet hybrids under varying row spacings revealed significant differences in effective tillers per plant, ear head length, ear head diameter, and 1,000 grain weight across the years 2021 and 2022 (Table 1). The data indicate that plants grown at a row spacing of 60 cm × 15 cm produced the highest number of effective tillers (3.84), ear head length (19.79 cm), and ear head diameter (2.40 cm), significantly surpassing the narrower 30 cm × 15 cm spacing, which recorded the lowest values across all attributes. Specifically, the 60 cm × 15 cm treatment increased effective tillers by 132% and ear head length by 7.48% compared to the 30 cm × 15 cm spacing. This enhancement in yield attributes can be attributed to reduced inter-plant competition and improved resource allocation, facilitating better growth conditions (Amjad and Anderson, 2006; Yogi *et al.,* 2023). Among the hybrids, 'HHB-197' showed superior performance in ear head length (20.06 cm pooled) and 1,000-grain weight (9.47 g pooled), while 'HHB-299' had the highest number of effective tillers (3.12 pooled). These findings emphasize that both agronomic practices such as row spacing and the selection of high-performing hybrids are crucial for maximizing yield potential in pearl millet cultivation. This may be due to crop depends on its genetic potential, soil and climate (Ankit *et al.,* 2022). Since genotype is fixed character, growth and yield of a crop is influenced by environmental and cultural practices (Chetan *et al.,* 2017). Such effect was due to the genetic variability between the pearl millet genotypes (Kumar *et al.,* 2014).

Yield

Yield is economic return of a crop and outcome of yield attributes. The highest seed, stover and biological yield as well as harvest index was recorded with the spacing of 60×15 cm which was significantly greater than row spacing of 30 and 45 × 15 cm (Table 2). It was found that seed, stover and biological yield as well as harvest index of pearl millet significantly increased with wider the row space from 30 cm to 45 cm × 15 cm and 45 cm to 60 cm × 15 cm. However, 45 cm × 15 cm spacing being statistically at par with pearl millet grown at both spacing 45 cm × 15 cm and 60 cm × 15 cm during pooled mean of year 2021 and 2022. The magnitude of increase in pooled mean with pearl millet grown on 60 cm × 15 cm spacing was 25.48, 12.04 and 17.11% seed, stover and biological yield, respectively as compared to grown on 30 cm × 15 cm and 45 cm × 15 cm spacing. Further, seed, stover and biological yield among the seven pearl millet hybrids was significantly different as sown in Table 2. Pearl millet hybrid 'MPMH-17' and 'HHB-299' being at par to each other recorded maximum (2.50 and 2.40 t/ha) seed yield, (3.79 and 3.66 t/ha) stover yield and (6.29 and 6.05 t/ha) biological yield, significantly higher over other pearl millet hybrids. Followed by, pearl millet hybrids 'HHB-273' and 'HHB-197' being at par to each other and significantly superior over 'HHB-67' imp., 'HHB-226' and 'BHB-1602' in respect to seed, stover and biological yield.

The interaction effects of row spacing and different hybrids showed statistically significant during pooled mean of the years 2021 and 2022 (Table 3). Pearl millet hybrid MPMH-17 sowing at spacing 45 cm × 15 cm, being statically at par with 'HHB-299' sowing at spacing 45 cm × 15 cm and 'HHB-67' imp. sowing at spacing 60 cm × 15 cm recorded maximum seed yield (2.66, 2.56 and 2.66 t/ha, respectively), stover yield (4.02, 3.89 and 3.85 t/ha, respectively) and biological yield (6.68, 6.45 and 6.50 t/ha, respectively), as well as harvest index (39.78 and 39.55, respectively), which was significantly higher over all other hybrids of pearl millet with sowing all row spacing during pooled mean of the year 2021 and 2022. However, pearl millet hybrid 'HHB-197', 'HHB-273', 'HHB-226' and 'BHB-1602' sowing with 60 cm × 15 cm spacing perform better than 30 cm ×15 cm and 45 cm × 15 cm spacing in respect to seed, stover and biological yield. Such effect was due to the genetic variability between the pearl millet hybrids (Carrera *et al.,* 2024). Similarly significant differences in pearl millet genotypes with respect to grain yield under different condition were also reported by Patil (2005); Maqsood and Ali (2007).

Economics

Net returns and B:C ratio are economic return of a crop and outcome of yield attributes. It's miles a prime problem of farmers community. The highest Net Returns and B:C ratio was recorded with row spacing of 60 × 15 cm which was significantly greater than row spacing of 30×15 cm and 45×15 cm (Table 2). It was found that net returns and B:C ratio of pearl millet significantly increased with wider

Table 2. Effect of row spacing on yield and economics of different pearl millet hybrids (pooled of 2021 and 2022)

Treatment	Seed yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ha)	Harvest index (%)	Net Returns (₹/ha)	Benefit: cost ratio
Row spacing						
30 cm × 15 cm	1.92c	3.16b	5.08b	37.62c	27,086c	2.55c
45 cm × 15 cm	2.25b	3.52a	5.77a	38.89b	33,856b	2.93b
60 cm × 15 cm	2.41a	3.55a	5.95a	40.43a	36,324a	3.07a
SEm±	0.03	0.03	0.06	0.06	571	0.03
CD (P=0.05)	0.09	0.11	0.19	0.19	1861	0.11
Pearl millet hybrids						
'HHB 67' imp.	2.08c	3.27c	5.35c	38.55c	30,085d	2.72d
'HHB 197'	2.21b	3.43b	5.64b	39.10b	32,737c	2.87c
'HHB 299'	2.40a	3.66a	6.05a	39.55a	36,693b	3.09b
'MPMH 17'	2.50a	3.79a	6.29a	39.78a	38,943a	3.22a
'HHB 273'	2.22b	3.45b	5.67b	39.13b	33,077c	2.89c
'HHB 226'	1.98c	3.15c	5.13c	38.40c	27,863d	2.59d
'BHB 1602'	1.96d	3.13c	5.09d	38.35c	27,557e	2.57e
SEm±	0.04	0.05	0.09	0.10	813	0.05
CD (P=0.05)	0.11	0.13	0.24	0.29	2,293	0.13

Table 3. Interactions effect of row spacing and hybrids on yield of pearl millet (pooled of 2021 and 2022)

Pearl millet hybrids	Seed yield (t/ha)			Stover yield (t/ha)			Biological yield (t/ha)		
	Row spacing (cm)			Row spacing (cm)			Row spacing (cm)		
	30 × 15	45 × 15	60 × 15	30 × 15	45 × 15	60 × 15	30 × 15	45 × 15	60 × 15
'HHB 67 imp.	1.55	2.04	2.66a	2.69	3.27	3.85a	4.24	5.31	6.50a
'HHB 197'	1.99	2.24	2.38b	3.26	3.51	3.52	5.26	5.75	5.90b
'HHB 299'	2.22	2.56a	2.41b	3.53	3.89a	3.55	5.75	6.45a	5.95b
'MPMH 17'	2.41b	2.66a	2.44b	3.76b	4.02a	3.59	6.16b	6.68a	6.03b
'HHB 273'	1.99	2.25	2.43b	3.26	3.53	3.57	5.25	5.78	5.99b
'HHB 226'	1.64	2.02	2.26	2.84	3.24	3.37	4.49	5.26	5.63
'BHB 1602'	1.62	1.99	2.28	2.81	3.20	3.39	4.42	5.19	5.67
	Row spacing within hybrid	Hybrids within row spacing		Row spacing within hybrid	Hybrids within row spacing		Row spacing within hybrid	Hybrids within row spacing	
SEm±	0.04	0.03		0.05	0.03		0.09	0.06	
CD (P=0.05)	0.12	0.09		0.15	0.11		0.27	0.19	

the row space from 30 cm × 15 cm to 45 cm × 15 cm and 45 cm × 15 cm to 60×15 cm. The magnitude of increase in pooled mean with pearl millet grown on 60 cm × 15 cm spacing was 34.11 and 7.29% net returns and 20.39 and 4.78% Benefit: cost ratio, respectively as compared to grown on 30 cm × 15 cm and 45 cm × 15 cm spacing.

Net returns and B:C ratio among the seven pearl millet hybrids were significantly different as sown in table 2. Pearl millet hybrid 'MPMH-17' recorded maximum (₹38,943/ha) Net Returns and (3.22) B:C ratio and significantly higher over other pearl millet hybrids. Followed by, pearl millet hybrids 'HHB-299' significantly superior over 'HHB-67' imp., 'HHB-197', 'HHB-273', 'HHB-226' and 'BHB-1602' in respect to net returns and B:C ratio. Minimum net returns (₹27,557ha) and B:C ratio (2.57) was recorded with pearl millet hybrid 'BHB-1602'.

The interaction effects of row spacing and different hybrids showed statistically significant during pooled mean of the years 2021 and 2022 (Table 4). Pearl millet hybrid 'MPMH-17' sowing at spacing 45 cm × 15 cm, being statically at par with HHB-299 sowing at spacing 45 cm × 15 cm and 'HHB-67' imp. sowing at spacing 60 cm × 15 cm recorded maximum net returns (42,462, 40,303 and 41,560 ₹/ha, respectively) and B:C ratio (3.42, 3.30 and 3.37, re-

Table 4. Interactions effect of row spacing and hybrids on economics of pearl millet (pooled of 2021 and 2022)

Pearl millet hybrids	Net returns (₹/ha)			Benefit: cost ratio		
	Row spacing (cm)			Row spacing (cm)		
	30 × 15	45 × 15	60 × 15	30 × 15	45 × 15	60 × 15
'HHB-67' imp.	19,236	29,460	41,560a	2.10	2.68	3.37a
'HHB-197'	28,756	33,599	35,856b	2.64	2.92	3.05b
'HHB-299'	33,463	40,303a	36,312b	2.91	3.30a	3.07b
'MPMH-17'	37,358	42,462a	37,007b	3.13b	3.42a	3.11b
'HHB-273'	28,640	33,886	36,706b	2.63	2.93	3.10b
'HHB-226'	21,363	28,980	33,247	2.22	2.65	2.90
'BHB-1602'	20,788	28,305	33,577	2.19	2.62	2.92
	Row spacing within hybrid	Hybrids within row spacing		Row spacing within hybrid	Hybrids within row spacing	
SEm±	843	571		0.05	0.03	
CD (P=0.05)	2,576	1,861		0.15	0.11	

spectively), which was significantly higher over all other hybrids of pearl millet with sowing all row spacing during pooled mean of the year 2021 and 2022. However, pearl millet hybrid 'HHB-197', 'HHB-273', 'HHB-226' and 'BHB-1602' sowing with 60 cm × 15 cm spacing perform better than 30 cm × 15 cm and 45 cm × 15 cm spacing in respect to net returns and B:C ratio.

The experiment conducted during the *kharif* seasons of 2021 and 2022 at Krishi Vigyan Kendra, Bikaner-II (Lunkaransar), Rajasthan, demonstrated that wider row spacing (60×15 cm) resulted in significantly higher yield attributes, seed yield, net returns, and benefit: cost (B:C) ratio. Among the tested hybrids, 'MPMH-17' recorded the highest grain yield (2.50 t/ha), followed by 'HHB-299' and 'HHB-273'. Interaction analysis revealed that the combination of hybrid 'MPMH-17' with a row spacing of 45 cm × 15 cm was statistically at par with HHB-299 (45×15 cm) and 'HHB-67' improved (60 cm × 15 cm), yielding the highest seed, stover, and biological yields. These findings suggest that optimizing row spacing and hybrid selection can significantly enhance the productivity and profitability of pearl millet cultivation in the region.

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