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Assessment of growth dynamics and phenological development of rainfed pearl millet under different growing environments in semi-arid region of Haryana

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Abstract
The field experiment entitled "Assessment of growth dynamics and phenological development of rainfed pearl millet under different growing environments in semi-arid region of Haryana" was conducted during *Kharif* season (2022) at research farm of Department of Agricultural Meteorology, CCS HAU, Hisar. The study was comprised of three growing environments as factor (A) namely (DI) 24th June, (D2) 18th July and (D3) 10th August, comprising three varieties as factor (B) *viz*., (V1) GHB 558, (V2) HHB 67 Improved and (V3) HHB 197 laid out in factorial RBD with four replications. The objectives of the study undertaken are to determine the effect of different growing environment and various varieties on growth and phenology of pearl millet. The results revealed that the 24th June sown crop recorded highest plant height (225.5 cm) followed by 18th July (217.6 cm) at physiological maturity stage. First date of sowing (24th June) has produced higher dry matter than remaining two dates of sowing (18th July and 10th August. Similarly crop sown on 24th June attained higher LAI at 36 DAS to maturity and the maximum LAI (5.06) was attained at 50 DAS followed by 18th July (4.63). Among three varieties, long duration variety GHB 558 took maximum time to attain various phenological stages due to long duration variety (74-78 days) as compared to other short duration varieties *viz*., HHB 67 Improved and HHB 197 (68-72 days). The sowing of GHB 558 on 24th July leads to better growth and phenological parameters in semi-arid conditions of Haryana.

Keywords: Growing environment, growth, phenology, pearl millet, rainfed

1. Introduction
Pearl millet (*Pennisetum glaucum* L.R.Br) is a diploid species, which belongs to family Gramineae (Poaceae). It is believed to be originated in West Africa and three forms of pearl millet species are found there: the wild progenitor, the cultivated form and an intermediate form (Abuali *et al*., 2012) [1]. India is the largest pearl millet growing country contributing 50 per cent of production in the world. In India, mostly pearl millet is grown in rainy (*Kharif*) season (June-September) but in some parts of Gujarat, Rajasthan and Uttar Pradesh it is being increasingly cultivated during the summer season (February-May); and at a small scale in Maharashtra and Gujarat it is also grown during the post-rainy (*Rabi*) season (November-February) (Yadav and Rai, 2013) [16]. In India, it occupies an area of 6.57 million ha with an average production of 9.64 million tones and productivity of 1471 kg/ha, whereas it is grown over an area of 5.13 lakh ha with total production of 13.43 lakh tonnes with productivity of 2618 kg/ha in the state of Haryana (Indiastat, 2025) [8].
It is appropriately referred to as a "nutricereal" because it is high in energy, carbohydrate, protein, fat, ash, dietary fibre, iron and zinc. It has a high fibre content (1.2g/100g) and amylase activity. Protein content *i.e.*, 11.6 g/100 g, is comparable to wheat but higher than rice. It has a remarkable ability to withstand stresses particularly drought and has the ability to revive when moisture is applied by irrigation or by rain and therefore, per day productivity is higher than any other cereal. Productivity depends largely on the prevailing weather conditions during crop growth period and sensitive to waterlogging.
Weather recommendations for pearl millet are typically determined based on the calendar date or soil temperature (Andrews *et al*., 1998) [3]. Prompt sowing of crops usually guarantees adequate

time for root establishment and vegetative growth, facilitating the optimal harvest of available soil nutrients and radiant energy (Soler *et al*., 2008) [14]. Sowing at the optimal time enhances productivity by creating a favorable environment throughout all growth stages. Climate change is expected to impact agriculture and food security. Currently, there is a pressing need to standardize sowing times due to irregular rainfall patterns, terminal heat, the frequent occurrence of extreme weather events, and limited water resources (Singh *et al*., 2010) [13]. Varieties also have profound effect on different phenological stages (Bishnoi *et al*., 1985) [5]. So, Identifying the most appropriate sowing time and choosing suitable pearl millet varieties is essential for improving resource-use efficiency and unpredictable weather conditions.

2. Materials and Methods

2.1. Site description: The field experiment was conducted at Research Farm, Dept of Agricultural Meteorology, CCS HAU, Hisar (Haryana), India. It is situated at 29° 10'N latitude and 75° 46' E longitude with an elevation of 215.2 meters above the mean sea level. Hisar is situated in the sub-tropical, semi-arid climatic zone of India. The station lies under the Eastern Agroclimatic Zone of Haryana. The experiment was comprised of three dates of sowing (24th June, 18th July and 10th August) and three varieties (GHB 558, HHB 67 Improved, and HHB 272) and laid out in factorial RBD with four replications.

According to meteorological data depicted in figure 1 and figure 2 in three different growing environments i.e. date of sowing treatments highest mean maximum temperature was recorded in crop sown on 24th June (35.1 ^{0}C) followed by 10th August (34.4 ^{0}C) and 18th July (33.9 ^{0}C), sown crop. Whereas, the highest mean minimum temperature was recorded in crop sown on 24th June (26.7 ^{0}C) followed by 18th July (26.2 ^{0}C) and 10th August (25.9 ^{0}C) sown crop, respectively. The total amount of rainfall received during crop season was 356.1 mm, 479.6 mm and 247 mm during crop sown on 24th June, 18th July and 10th August, respectively. The second and third dates of sowing crops received heavy rainfall during the last phase of crop and recorded 190.8 mm of rainfall during 21-25 Sept., 2022 which proved detrimental particularly to third date of sowing sown crop.

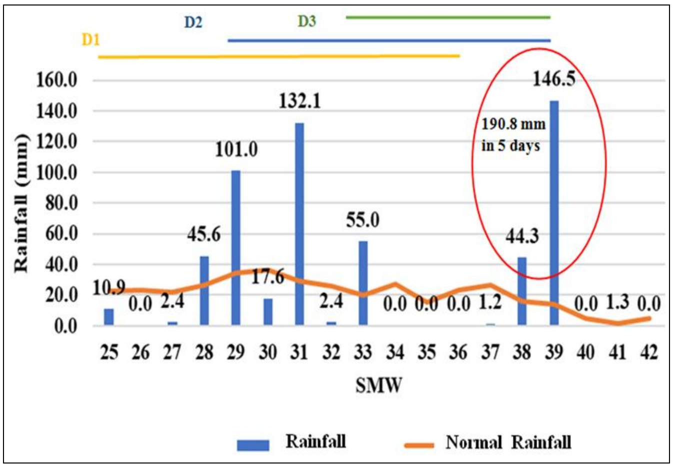

Fig 1: Mean weekly values of Rainfall during *Kharif* 2022

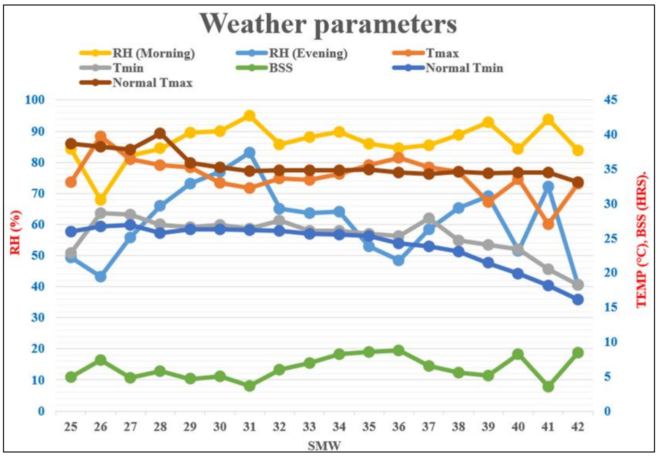

Fig 2: Mean weekly values of important weather parameters during *Kharif* 2022

2.2 Growth parameters

2.2.1 Plant Height: Three plants were selected randomly from each plot and tagged permanently. Plant height is measured from point of root-shoot intersection to the highest terminal point with the help of a wooden meter rod at seven days interval. The mean plant height (cm) at each growth stage was worked out and recorded as plant height (cm) at respective stage.

2.2.2 Leaf area index (LAI): Three plants from each plot were selected for the green leaf area at 7 days intervals. All the green leaves from these plants were counted and averaged as number of leaves/plant. Leaf Area Meter (LI-COR Model LAI-2000) used for the measurement of green leaf area (cm^2) and then leaf area/plant was computed (Williams *et al.*, 1984) [15].

LAI = L/S

Where, L = Leaf area (m^2)
S = Land area (m^2)

2.2.3. Dry matter accumulation and its partitioning (g /plant): Dry matter production was recorded at 7 days interval from crop establishment to the harvest. For this, one plant was uprooted randomly from sample rows of each plot and separated into stem, panicle and leaf. The samples were first air dried for some days and finally dried in an electric oven at 70 °C. The weight was recorded and expressed as average dry matter per plant (g).

2.3 Phenological Observations

Phenological stages of pearl millet were recorded through regular visual field observations. Emergence was noted when coleoptiles appeared above the soil. The five-leaf stage was identified by the visibility of the fifth leaf and initial tiller emergence. Days to tillering were recorded from sowing to the appearance of first tillers. Booting was marked by the panicle enclosed within the fully expanded flag leaf sheath. The 50% flowering stage was recorded when half of the panicle showed visible stigmas. Milking was identified 6-7 days after fertilization when grains contained watery to milky endosperm, followed by the dough stage as grain consistency shifted from soft to firm. Physiological maturity was confirmed by the formation of a black layer in the hilar region, indicating completion of dry matter accumulation.

2.4 Data Analysis
The observations recorded for growth parameters and phenophases were put to statistical analysis in accordance with the analysis of variance technique as suggested by Fisher (1950) [7] for factorial RBD. The critical difference was calculated to assess the significance of treatment means with the help of 'F' test at 5% level of significance.

3. Results and Discussion
3.1 Growth parameters
3.1.1 Plant height
Different dates of sowing significantly influenced the plant height (Table 1). Maximum plant height was recorded in 24th June sown crop (225.5 cm) followed by 18th July (217.6 cm) at physiological maturity stage. The possible reason could be that early sown crop had availed prolonged photoperiod for vegetative growth as a result plant attained maximum plant height as compared to late sown crop. The findings of Maurya *et al*. (2016) [10], Nwajei *et al*. (2019) [12] and Aggarwal *et al.* (2016) [2] also supported the result related to plant height and varieties. Different varieties significantly influenced the plant height. Among the varieties lot of variation was observed in the height with growth and development but at physiological maturity the maximum plant height was recorded in GHB 558 (231.3 cm) followed by HHB 197 (221.0 cm) and HHB 67 Improved (212.5 cm).

Table 1: Effect of different growing environments on plant height (cm) of rainfed pearl millet varieties

Treatment	DAS								
	15	22	29	36	43	50	57	64	PM
Factor A (Sowing dates)									
24th June	21.9	44.9	69.3	103.0	162.1	186.8	204.9	218.9	225.5
18th July	22.6	50.9	71.2	101.4	158.3	181.0	198.8	211.9	217.6
10th Aug	20.2	42.4	62.0	86.8	141.1	Water stagnation			
SE(m)	0.66	0.46	2.14	2.55	2.02	0.75	2.23	2.20	2.14
CD at 5%	1.93	1.34	6.29	7.48	5.93	2.28	6.77	6.68	6.50
Factor B (Varieties)									
GHB 558	19.1	43.6	67.6	88.2	158.2	189.6	208.9	223.5	231.3
HHB 67 Improved	22.6	48.4	63.1	95.2	148.9	178.7	196.0	207.3	212.5
HHB 197	23.0	46.3	71.8	107.8	154.4	183.4	200.6	215.5	221
SE(m)	0.66	0.46	2.14	2.55	2.02	0.92	2.73	2.69	2.62
CD at 5%	1.93	1.34	6.29	7.48	5.93	2.79	8.29	8.18	7.96

3.1.2 Dry matter accumulation (g/plant) and its partitioning
Different dates of sowing significantly influenced the total dry matter production. It was evident from Table 2 and 3 that at physiological maturity 24th June sown crop produced maximum amount of total dry matter (90.7 g/plant) followed by 18th July sown crop (79.10 g/plant). Hence, delay in sowing reduced the dry matter significantly at all growth intervals. The difference in total dry matter accumulation became increase with the crop age. From 15 DAS to 29 DAS dry matter increased with slower rate and thereafter it starts increasing with faster rate. The highest dry matter allocation was observed in leaf followed by stem during early vegetative phase *i.e.*, 15 to 36 DAS in all dates of sowing. Stem of plant was attained the highest dry matter from 43 to 63 DAS, and thereafter panicle gained the highest weight till harvest. Favourable weather conditions in the early sown crop led to higher total dry matter, attributed to increased plant height, leaf area index, soil moisture availability, and accumulation of heat units. This result was also supported by the finding of Maiti and Bidinger (1981) [9], Bacci *et al*. (1998) [4]. Different varieties significantly influenced the total dry matter production. Among all the varieties GHB 558 produced maximum total dry matter (93.9 g/plant) followed by HHB 197 (82.5 g/plant) and HHB 67 Improved (78.4 g/plant).

Table 2: Dry matter accumulation (g/plant) and its partitioning under different growing environments in different varieties of pearl millet from 15 to 43 DAS

DAS	15			22			29			36			43		
	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total
Factor A (Sowing dates)															
24th June	1.0	0.6	1.6	3.0	1.4	4.4	8.4	5.8	14.2	13.4	12.6	26.0	20.4	21.1	41.5
18th July	1.1	0.6	1.7	3.1	1.5	4.6	9.2	6.3	15.5	12.1	10.5	22.6	17.6	19.7	37.3
10th Aug	0.8	0.4	1.2	2.9	1.0	3.9	8.0	5.5	13.5	11.8	8.9	20.7	14.2	14.4	28.6
SE(m)	0.01	0.02	0.02	0.01	0.01	0.02	0.05	0.03	0.05	0.07	0.07	0.09	0.11	0.12	0.16
CD at 5%	0.01	0.07	0.07	0.04	0.02	0.05	0.13	0.09	0.16	0.20	0.20	0.27	0.32	0.35	0.48
Factor B (Varieties)															
GHB 558	0.9	0.6	1.5	2.7	1.5	4.2	7.8	5.3	13.1	12.3	9.8	22.1	18.3	19.9	38.2
HHB 67 Improved	1.0	0.4	1.4	3.1	1.1	4.2	8.8	6.0	14.8	12.2	10.8	23.0	16.4	16.9	33.3
HHB 197	1.0	0.6	1.6	3.1	1.3	4.4	9.0	6.3	15.3	12.8	11.4	24.2	17.5	18.4	35.9
SE(m)	0.01	0.02	0.02	0.01	0.01	0.02	0.05	0.03	0.05	0.07	0.07	0.09	0.11	0.12	0.16
CD at 5%	0.01	0.07	0.07	0.04	0.02	0.05	0.13	0.09	0.16	0.20	0.20	0.27	0.32	0.35	0.48

Table 3: Dry matter accumulation (g/plant) and its partitioning under different growing environments in different varieties of pearl millet under from 50 DAS to maturity

DAS	50				57				64				PM			
	Leaf	Stem	Panicle	Total	Leaf	Stem	Panicle	Total	Leaf	Stem	Panicle	Total	Leaf	Stem	Panicle	Total
Factor A (Sowing dates)																
24th June	20.4	23.2	7.1	50.7	15.2	25.8	15.6	56.6	11.0	29.5	28.0	68.5	7.8	31.1	51.8	90.7
18th July	19.5	21.8	6.9	48.2	13.6	24.4	13.4	51.4	9.2	26.5	24.2	59.9	6.6	27.5	45.0	79.1
SE(m)	0.13	0.11	0.03	0.18	0.09	0.16	0.07	0.21	0.04	0.15	0.15	0.23	0.05	0.21	0.26	0.34
CD at 5%	0.40	0.34	0.10	0.55	0.28	0.48	0.21	0.63	0.11	0.45	0.45	0.70	0.17	0.64	0.80	1.03
Factor B (Varieties)																
GHB 558	22.0	24.4	7.7	54.0	15.8	26.8	17.1	59.6	11.7	30.3	29.2	71.1	8.4	31.6	53.9	93.9
HHB 67 Improved	18.4	21.3	6.0	45.6	13.7	23.5	11.3	48.4	9.2	25.8	23.4	58.3	6.8	27.4	44.2	78.4
HHB 197	19.6	21.9	7.4	48.9	13.8	25.1	15.2	54.1	9.5	28.0	25.8	63.3	6.5	28.9	47.2	82.5
SE(m)	0.16	0.14	0.04	0.22	0.11	0.20	0.09	0.25	0.05	0.18	0.18	0.28	0.07	0.26	0.32	0.41
CD at 5%	0.50	0.42	0.12	0.67	0.35	0.59	0.26	0.77	0.14	0.55	0.55	0.85	0.20	0.78	0.97	1.26

3.1.3 Leaf Area Index
Sowing dates as well as varieties significantly influenced the leaf area index. The crop sown on 24th June attained higher LAI values at 36 DAS to physiological maturity and the maximum LAI attained was 5.06 at 50 DAS followed by 18th July (4.63). During early growth stages, the LAI increased at a faster rate *i.e.*, upto 36 DAS and then with slower rate. The crop attained maximum LAI at around 50 DAS coinciding with flowering stage and then declined (Table 4). The reason could be that early sowing crop which has prolonged photoperiod as a result of more assimilates was utilized by plant to exhibited more LAI as compared to late sown crop. These results were in conformity with the findings of Andrews *et al.* (1998) [3]. Among the varieties GHB 558 has highest LAI (5.39) at 57 DAS followed by HHB 197 (4.81) and HHB 67 Improved (4.57) at 50 DAS. Up to 36 DAS, HHB 197 variety had higher LAI as compared to GHB 558 and HHB 67 Improved.

Table 4: Effect of different growing environments on LAI in rainfed pearl millet varieties

Treatment	DAS								
	15	22	29	36	43	50	57	64	PM
Factor A (Sowing dates)									
24th June	0.06	0.81	1.83	3.53	4.37	5.06	5.00	4.53	3.81
18th July	0.06	0.84	1.91	3.37	4.11	4.63	4.55	4.25	3.61
10th Aug	0.05	0.70	1.35	2.45	2.86	Water stagnation			
SE(m)	0.001	0.005	0.010	0.014	0.026	0.017	0.029	0.018	0.020
CD at 5%	0.004	0.014	0.029	0.041	0.077	0.051	0.088	0.055	0.061
Factor B (Varieties)									
GHB 558	0.05	0.75	1.67	2.91	3.83	5.15	5.39	5.07	4.22
HHB 67 Improved	0.06	0.78	1.70	3.17	3.70	4.57	4.38	3.97	3.39
HHB 197	0.06	0.81	1.72	3.26	3.81	4.81	4.56	4.14	3.52
SE(m)	0.001	0.005	0.010	0.014	0.026	0.020	0.035	0.022	0.024
CD at 5%	0.004	0.014	0.029	0.041	0.077	0.062	0.107	0.067	0.074

3.2 Phenological parameters
Phenological observations were recorded by observing the crop at regular interval of 2 to 3 days in different treatments and the results are shown in Table 5. Different dates of sowing significantly influenced the phenological development. Crop sown on 24th June took longer time (75.2 days) to attain physiological maturity followed by 18th July (70.5 days) sown crop. The 10th August sown crop was damaged after 47 DAS due to heavy rainfall and prolonged water stagnation. The 10th August sowing crop took the lowest number of days for different phenological stages and recorded 50% flowering at 46.2 DAS. These results match with the findings of Aggarwal *et al.* (2016) [2] and Nwajei *et al*. (2019) [12]. Bisht *et al*. (2019) [6] reported that delay in sowing causes reduction in days to attain physiological maturity Among the three varieties, GHB 558 took longer time (74.8 days) followed by HHB 197 (72.9 days) and HHB 67 Improved (70.9 days), respectively to attain the physiological maturity during the crop season. After flowering HHB 67 Improved attained physiological maturity 2-3 days faster than HHB 197 because of fast grain filling feature. Due to increase in temperature, development stage time period decreased which leads ultimate decreased biomass and yield. McIntyre *et.al*. (1993) [11] also supported the result and concluded that each one degree rise in temperature decreases the length of the development period by about two days.

Table 5: Effect of different sowing environments on phenophase development (No. of days taken) of rainfed pearl millet varieties

	DAS							
Stage Treatment	Emergence	Five leaf stage	Tillering stage	Boot stage	50% flowering	Milk stage	Dough stage	PM
Factor A (Sowing dates)								
24th June	4.3	13.1	18.7	45.5	53.9	59.8	66.4	75.2
18th July	4.3	14.3	19.5	44.0	52.3	57.7	63.7	70.5
10th Aug	4.1	10.5	15.7	39.0	46.2	Damaged		
SE(m)	0.12	0.10	0.11	0.06	0.09	0.11	0.13	0.12
CD at 5%	NS	0.28	0.33	0.16	0.26	0.33	0.38	0.36

Factor B (Varieties)								
GHB 558	4.5	13.1	18.5	44.2	52.2	60.5	66.1	74.8
HHB 67 Improved	3.8	12.0	17.1	41.7	49.6	57.4	63.4	70.9
HHB 197	4.4	12.8	18.3	42.7	50.6	58.4	65.6	72.9
SE(m)	0.12	0.10	0.11	0.06	0.09	0.13	0.15	0.14
CD at 5%	0.34	0.28	0.33	0.16	0.26	0.41	0.46	0.44

4. Conclusion
Plant height, total dry matter and leaf area index were significantly higher in 18th July sown crop followed by the crop sown on 24th July and 10th August at early stages. The crop sown on 24th June attained was significantly higher values at 36 DAS to maturity. Among the varieties, GHB 558 produced significantly higher plant height, total dry matter accumulation and leaf area index at physiological maturity followed by HHB 197 and HHB 67 Improved. Among different sowing dates, 24th June sown crop took maximum number of days to attain physiological maturity followed by 18th July and. Among the varieties GHB 558 took maximum days as compared to HHB 197 and HHB 67 improved. The heavy rainfall *i.e.,* 190 mm during 38th and 39th week caused water stagnation in crop field and may result crop failure if water drainage facility is not available.

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6. Conflict of Interest
I declared that no conflict of interest related to my research. No any external funding involve during the course of experiment and analysis and publication decision

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