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Physiological evaluation of promising pearl millet (*Pennisetum glaucum* (L.) R. Br) Hybrids

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Abstract
Five promising pearl millet [*Pennisetum glaucum* (L.) hybrids *viz*., DHBH-1203, 86M33, RHRBH-9808, PROAGRO-9450 and DHBH-9071 were evaluated for physiological analysis of growth and yield variation in RBD with four replications at MPKV, Rahuri, Dist. Ahmednagar during *kharif*, 2014. The data on morpho-physiological parameters was recorded periodically, while yield and yield contributing characters were recorded at harvest. Physiological basis for grain yield differences amongst the high and low yielding hybrids was mainly due to the variation in morpho-physiological traits *viz*. plant height, number of tillers plant^{-1}, leaf area plant^{-1}, leaf area index, flag leaf area, stomatal conductance, total dry matter plant^{-1}, ear head length, ear head girth, number of productive tillers plant^{-1}, grain yield plant^{-1}, biomass production, and harvest index. Most of the characters showed positive relation to the mean grain yield. It was observed that initial growth was rather slow and was rapid between 30 and 60 DAS, thereafter it increased at static phase. These periods confirms the lag, log and senescence phases of growth, respectively. The leaf area was highest at 60 DAS and it declined with time. The hybrids RHRBH-9808 and DHBH-1203 were found superior for morpho-physiological traits and for yield and yield contributing characters. Therefore, emphasis would be given on these morpho-physiological characters for developing of high yielding hybrids. The correlation coefficient (r) calculated in this study revealed highly positive significant correlation among yield and yield contributing parameters such as number of productive tillers, ear head length, ear head girth, biological yield, harvest index and grain yield (kg plot^{-1}).

Keywords: Morpho-physiological traits, physiological analysis, pearl millet hybrids, growth attributes

Introduction
Pearl millet (*Pennisetum glaucum* (L.) R. Br) is also known as bajra, candle millet, cat-tail millet, bulrush millet, spiked millet and locally known as bajri. It has significant potential as a food and fodder crop and also ability to give good yields with high nutritive value even under hot dry conditions on infertile soils of low water holding capacity, where other cereal crop fails (Hulse *et al.* 1980 and Khairwal and Yadav, 2005) [13, 16]. Nutritionally, it is a rich source of dietary protein, fat, calcium, phosphorus, iron and zinc and essential amino acids in comparison to other cereals such as maize, rice, sorghum and wheat (Davis *et al.* 2003; Filardi *et al.* 2005 and Deshmukh *et al.*, 2010) [4, 7, 5]. The energy value of pearl millet grain is relatively higher compared to maize, wheat or sorghum (Hill and Hanna, 1990) [12]. In India, area under pearl millet is 9.3 million ha with a production of 9.5 million tones and productivity of 1044 kg ha^{-1} (Rai *et al.*, 2009; Anonymous, 2011) [19, 2]. In Maharashtra, pearl millet is grown on 6.23 lakh hectare of land with 3.8 lakh million tons of grain production with productivity of 600 kg ha^{-1} (2011-12). Various morpho-physiological characters have correlation with yield. These characters directly or indirectly affects various physiological processes such as photosynthesis, transpiration, translocation of assimilates etc. yield contributing characters such as ear head length, number of productive tillers plant^{-1}, grain yield plant^{-1} influences the yield. The crop physiological studies on source-sink relationship help breeders to select desirable plant types or ideotypes which are high yielding, drought resistant, responsive to lower fertilizer doses having high water use efficiency and solar energy utilization and wider adaptability. In view of these considerations the present investigation on physiological evaluation of promising pearl millet (*Pennisetum glaucum* (L.) R. Br) hybrids were undertaken to study the morpho-physiological parameters of promising hybrids.

Material and Methods
Five promising pearl millet [*Pennisetum glaucum*(L.) hybrids *viz*., DHBH-1203, 86M33, RHRBH-9808, PROAGRO-9450 and DHBH-9071 were evaluated for physiological analysis of growth and yield variation in RBD with four replications at MPKV, Rahuri, Dist. Ahmednagar during *kharif*, 2014.

The pre-sowing operations like ploughing, Harrowing and Stubble collection were done before sowing of crop. At the time of sowing a basal dose of 25 kg N and 25 kg P_2O_5 hectare^{-1} was applied by placement method and remaining 25 kg of N was applied as top dressing after one month. The gross and net plot sizes were 4.00 x 3.00 and 3.10 x 2.70 m^2. The spacing was 45 x 15 cm. Two to three seeds were dibbled per hill and thinning was done ten days after sowing by keeping one healthy seedling. One hoeing and one hand weeding was given after 21 DAS for keeping experimental plot for weed free. The observations on morphological traits and dry matter production were recorded periodically at 30 days interval till harvest. The stomatal frequencies and stomatal conductance was recorded at the time of 50% flowering. The yield and yield contributing characters were recorded at the time of harvest. The net assimilation rate (NAR) and crop growth rate (CGR) were calculated as per the formulae given by Gardner *et al.* (1988) [8] and Duncan *et al.* (1978) [6]. The statistical analysis of data was carried out by the method suggested by Panse and Sukhatme (1985) [18]. Simple correlation of various morpho-physiological and yield contributing characters were calculated as per the formula suggested by Snedecor and Cochran (1967) [23].

Results and Discussion

The vegetative phase governs the overall phenotypic expression of the plant and prepares the plant for next important reproductive phase. The root, stem, branches and leaves, all these parts constitute vegetative phase and perform specific functions. Early vegetative development of crop regulates the reproductive capacity (Awal and Ikeda, 2003) [3]. The hybrids were significantly differed for morpho-physiological parameters at various stages of growth indicated wide range of variability amongst the hybrids (Table 1).

In the present investigation, the plant height was increased with advancing age of the crop to the tune of 66.70, 164.15, 183.95 and 184.95 cm. The hybrids, RHRBH 9808 and Proagro-9450 maintained the highest and lowest plant height at 30 (74.10 and 60.41 cm), 60 (174.65 and 153.77 cm), 90 DAS (195.33 and 173.60 cm) and at harvest (196.30 and 174.53 cm), respectively. The number of tillers plant^{-1} was ranged between 2.21 and 3.06, 3.86 and 4.88, 4.22 and 5.07 and 4.22 and 5.07 at 30, 60 and 90 DAS and at harvest, respectively. The hybrids, RHRBH 9808 and Proagro-9450 recorded the highest and the lowest number of tillers plant^{-1}, respectively**.** It is to be noted that, the plant height and number of tillers plant^{-1} were increased rapidly between 30 and 60 DAS and thereafter the growth was steadily increased upto 90 DAS. After 90 DAS to harvest, the plant height and number of tillers plant^{-1} was nearly constant. Therefore, the crop growth before 30 DAS and 30 to 60 DAS might be considered as lag phase and log phase of crop growth in pearl millet, respectively.

The leaf area, leaf area index and flag leaf area was increased upto 60 DAS and thereafter it was declined toward maturity due to defoliation of leaves and diversion of assimilates towards reproductive organ. Therefore, growth after 60 to 90 DAS and 90 DAS to maturity considered as static and senescence phase, respectively. In the present investigation, the hybrids, RHRBH 9808 and Proagro-9450 recorded the highest and lowest leaf area at 30 (11.51 and 8.27 dm^2), 60 (22.74 and 18.12 dm^2), 90 DAS (9.46 and 5.18 dm^2) and at harvest (7.72 and 4.33 dm^2), respectively. Simultaneously, these hybrids maintained the highest and lowest leaf area index at 30 (1.70 and 1.22), 60 (3.37 and 2.68), 90 DAS (1.40 and 0.77) and at harvest (1.14 and 0.64), respectively. The flag leaf area plant^{-1} was maximum at 60 DAS and declined towards maturity. The hybrids, RHRBH 9808 and Proagro-9450 recorded the highest and lowest leaf area at 60 (39.93 and 30.16 cm^2), 90 DAS (19.69 and 11.19 cm^2) and at harvest (19.19 and 10.70 cm^2), respectively.

The pattern of the dry matter production and its distribution into component plant parts has been of phenomenal interest to the research workers engaged in yield analysis. This method has been accepted as one of the standard method of yield analysis. All the physiological processes results into a net balance and accumulation of dry matter and hence, the biological productivity of plant is judged from their actual ability to produce and accumulate dry matter. Rate of growth and growth duration are integrated into conceptual variables largely correlated with yield or total biomass accumulation (Yin *et al.*, 2004; Andrade *et al.*, 2005; Hammer *et al.*, 2005) [24, 1, 10]. In the present study, on an average, the dry matter production plant^{-1} was increased to the tune of 35.52, 112.10, 113.64 and 115.73 g at 30, 60 and 90 DAS and at harvest, respectively. The hybrids, RHRBH 9808 and Proagro-9450 recorded the highest and lowest dry matter production plant^{-1} at 30 (39.75 and 32.16 g), 60 (119.20 and 103.54 g), 90 DAS (120.46 and 105.32 g) and at harvest (122.64 and 107.46 dm^2), respectively.

The knowledge of crop physiology through growth analysis technique, which involves tracing the history of growth and identifying the growth and yield factors contributing for yield variation, is a vital tool in understanding the crop behavior. This would be vital to the breeder as well as agronomist in tailoring suitable genotype or management technology for boosting up the growth and yield factors of the crop. Briggs *et al.* (1926) defined absolute growth rate (AGR) as daily increment in dry matter over a given period. The AGR gives general idea regarding the pattern of growth at different growth stages. Gregory (1926) [9] had given the idea about net assimilation rate (NAR) is the rate of increase in dry weight per unit leaf area, assuming that both dry matter and leaf area increase exponentially.

In the present investigation, the absolute growth rate (AGR) was higher during 30 to 60 DAS which was declined during 60 to 90 DAS and 90 DAS to harvesting (Table 2). The hybrids, DHBH-1203 (2.6940 g day $^{-1}$) and RHRBH 9808 (2.6940 g day $^{-1}$) at 30 to 60 DAS, 86M33 (0.0807 g day $^{-1}$) and DHBH-9071 (0.0720 g day $^{-1}$) at 60 to 90 DAS and DHBH-1203 (0.0837 g day $^{-1}$) and RHRBH 9808 (0.0727 g day $^{-1}$) at 90 DAS to harvest recorded higher absolute growth rate (Table 2). Similarly, the net assimilation rate (NAR) was higher between 30 to 60 DAS and it was declined between 60 to 90 DAS. After 90 DAS it was increased towards maturity (Table 2). The hybrids, Proagro-9450 (0.0823 g dm^{-2}day^{-1}) and 86M33 (0.0803 g dm^{-2}day^{-1}) at 30 to 60 DAS, 86M33 (0.0030 g dm^{-2}day^{-1}) and Proagro-9450 (0.0025 g dm^{-2}day^{-1}) at 60-90 DAS) and Proagro-9450 (0.0065 g dm^{-2}day^{-1}) and DHBH-1203 (0.0050 g dm^{-2}day^{-1}) recorded higher net assimilation rate (NAR). Rajput (2001) [20] observed that maximum NAR and CGR were recorded between 30 and 45 DAS in all pearl millet genotypes and declined thereafter. Kadam (2002) [14] observed significant difference in CGR and NAR in pearl millet as these functions vary with genotypes.

Stomatal frequency has been associated together with photosynthate pathways to higher water use efficiency in C_4 plants, compared to C_3 plants (Hardy *et al.*, 1995) [11]. Among all the hybrids, more number of stomata was observed on lower surface as compared to upper surface (Table 3). Hybrid

PROAGRO-9450 recorded significantly the highest number of stomata per unit leaf area (95.68 mm^{-2}), while hybrid DHBH-1203 recorded significantly the lowest (67.78 mm^{-2}) number of stomata per unit leaf area. Hybrid PROAGRO-9450 recorded significantly the highest number of stomata per unit leaf area (115.12 mm^{-2}), while hybrid DHBH-1203 recorded significantly the lowest (88.77 mm^{-2}) number of stomata per unit leaf area. Singh and Singh (1989) [22] reported that, the adaxial leaf surfaces had less stomatal frequency than abaxial leaf surfaces in *Sorghum bicolor*. The hybrid RHRBH-9808 recorded significantly highest stomatal conductance (0.048 mol m^{-2} s^{-1}), while hybrid PROAGRO-9450 recorded significantly lowest stomatal conductance (0.033 mol m^{-2} s^{-1}). Zhang *et al.* (2007) [25] reported that the stomatal frequency is closely linked to water use efficiency through its influence on stomatal conductance.

The generative growth constitutes the development and growth of reproductive parts. From yield point of view, this phase assumes significance as the sink lies in the reproductive parts. Hence, the detailed observations were made on various aspects of generative growth at the stage of maturity. The Ear head length (cm), Ear head girth (cm), Number of productive tillers $plant^{-1}$, Grain yield (g $plant^{-1}$, kg $plot^{-1}$, q ha^{-1}), Biomass production (kg $plot^{-1}$) and Harvest index (%) are the most important yield components that affect the yield potential of pearl millet. In the present investigation, hybrid RHRBH-9808 recorded the highest ear head length (22.88 cm) and ear head girth (11.68 cm) and number of productive tillers $plant^{-1}$ (2.74). However, 86M33 recorded the lowest (19.70 cm) ear head length and PROAGRO-9450 recorded the lowest (10.60 cm) ear head girth least number of productive tillers $plant^{-1}$ (2.2). The hybrid RHRBH-9808 maintained highest grain yield $plant^{-1}$ (27.72 g), grain yield $plot^{-1}$ (3.44 kg) and highest grain yield ha^{-1} (41.06 q). However, the hybrid PROAGRO-9450 recorded minimum grain yield $plant^{-1}$ (20.25 g), grain yield $plot^{-1}$ (2.51 kg) and grain yield ha^{-1} (30 q). The hybrid, RHRBH-9808 recorded significantly highest (14.45 kg $plot^{-1}$) biomass among all the hybrids except hybrid DHBH-1203 which was at par with it, while hybrid PROAGRO-9450 (12.65 $plot^{-1}$) recorded significantly the lowest biomass yields $plot^{-1}$. The hybrids, RHRBH-9808 (23.78%) and PROAGRO-9450 (19.84%) recorded significantly the highest and lowest harvest index $plot^{-1}$, respectively (Table 4). On the basis of above results, the pearl millet hybrid RHRBH-9808 is found better for yield and yield contributing characters.

Correlation between yield and yield attributing parameters were presented in Table 5. All the parameters were positively correlated with each other. Number of productive tillers per plant at harvest showed a highly significant positive correlation with ear head length (r = 0.569), ear head girth (r = 0.700), biological yield (r = 0.781), harvest index (r = 0.465) and grain yield (r = 0.686). Ear head length showed significant positive correlation with grain yield (r = 0.583), biological yield (r = 0.627) and harvest index (r = 0.522). Ear head girth (cm) was found to be significantly and positively correlated with grain yield (r = 0.641) and biological yield (r = 0.536). Biological yield (r = 0.584) and harvest index (r = 0.946) showed highly positive significant correlation with grain yield. The results were in accordance with that of Sagar (1992) [21], Mukharji *et al.* (1982) [17] and Karthigeyan *et al.* (1995) [15].

Table 1: Morpho-physiological characters influenced by pearl millet hybrids at various stages of growth

Hybrids	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
	Plant height (cm)				Number of tillers $plant^{-1}$			
DHBH-1203	69.43	167.48	187.33	188.32	2.92	4.64	4.83	4.83
86M33	62.56	160.73	177.92	178.97	2.59	4.37	4.66	4.66
RHRBH 9808	74.10	174.65	195.33	196.30	3.06	4.88	5.07	5.07
Proagro-9450	60.41	153.77	173.61	174.53	2.21	3.86	4.22	4.22
DHBH-9071	67.03	164.11	185.56	186.62	2.76	4.49	4.70	4.70
Mean	66.70	164.15	183.95	184.95	2.71	4.45	4.69	4.69
S.E. (±)	1.07	3.33	3.60	3.45	0.12	0.14	0.13	0.13
CD @5%	3.31	10.27	11.09	10.62	0.37	0.42	0.41	0.41
	Leaf area $plant^{-1}$ (dm^2)				leaf area index			
DHBH-1203	10.80	20.13	8.04	6.58	1.60	2.98	1.19	0.97
86M33	8.68	19.49	6.35	5.03	1.29	2.89	0.94	0.75
RHRBH 9808	11.51	22.74	9.46	7.72	1.70	3.37	1.40	1.14
Proagro-9450	8.27	18.12	5.18	4.33	1.22	2.68	0.77	0.64
DHBH-9071	10.00	19.74	7.96	6.53	1.48	2.92	1.18	0.97
Mean	9.85	20.04	7.40	6.04	1.46	2.97	1.10	0.89
S.E. (±)	0.25	0.41	0.23	0.23	0.04	0.06	0.03	0.03
CD @5%	0.76	1.26	0.70	0.72	0.11	0.18	0.10	0.10
	Flag leaf area (cm^2)				Total dry matter $plant^{-1}$ (g)			
DHBH-1203	--	35.93	16.16	15.74	36.65	117.47	117.53	120.04
86M33	--	32.49	12.58	12.14	33.71	107.86	110.28	111.91
RHRBH 9808	--	39.93	19.69	19.19	39.75	119.20	120.46	122.64
Proagro-9450	--	30.16	11.19	10.70	32.16	103.54	105.32	107.46
DHBH-9071	--	33.14	14.19	13.80	35.36	112.45	114.61	116.61
Mean	--	34.33	14.76	14.31	35.52	112.10	113.64	115.73
S.E. (±)	--	0.43	0.39	0.38	0.51	2.31	2.47	2.38
CD @5%	--	1.34	1.21	1.17	1.56	7.11	7.60	7.34

Table 2: Growth parameters influenced by pearl millet hybrids at various stages of growth

Hybrids	30-60 DAS	60-90 DAS	90 DAS- At harvest	30-60 DAS	60-90 DAS	90 DAS- At harvest
	AGR (g day $^{-1}$)			NAR (g dm^{-2}day^{-1})		
DHBH-1203	2.6940	0.0020	0.0837	0.0781	0.0001	0.0050
86M33	2.4717	0.0807	0.0543	0.0803	0.0030	0.0042
RHRBH 9808	2.6483	0.0420	0.0727	0.0697	0.0012	0.0037
Proagro-9450	2.3793	0.0593	0.0713	0.0823	0.0025	0.0065
DHBH-9071	2.5697	0.0720	0.0667	0.0779	0.0024	0.0040
Mean	2.5527	0.0513	0.0697	0.0773	0.0018	0.0045
S.E. (±)	0.250	0.060	0.006	0.0045	0.0003	0.0074
CD @5%	0.730	0.174	0.017	0.0132	0.0010	NS

Table 3: Stomatal frequency and stomatal conductance influenced by bajra hybrids

Hybrids	Stomatal frequency		Stomatal conductance (mol m^{-2} s^{-1})
	Adaxial side	Abaxial side	
DHBH-1203	67.78	88.77	0.043
86M33	80.49	99.94	0.036
RHRBH 9808	81.16	94.86	0.048
Proagro-9450	95.68	115.12	0.033
DHBH-9071	83.88	99.99	0.040
Mean	81.80	99.74	0.040
S.E. (±)	1.49	1.77	0.001
CD @5%	4.59	5.44	0.003

Table 4: Yield and yield contributing characters influenced by bajra hybrids

Hybrids	Prod-uctive tillers plant^{-1}	Ear-head length (cm)	Ear-head girth (cm)	Grain yield (g plant^{-1})	Grain yield (kg plot^{-1})	Grain yield (qt ha^{-1})	Biomass production (kg plot^{-1})	Harvest index
DHBH-1203	2.65	21.90	11.45	22.84	2.83	33.84	14.19	19.97
86M33	2.41	19.70	11.03	21.48	2.66	31.82	13.43	19.87
RHRBH-9808	2.74	22.88	11.68	27.72	3.44	41.06	14.45	23.78
Proagro-9450	2.20	21.40	10.60	20.25	2.51	30.00	12.65	19.84
DHBH-9071	2.56	20.85	11.14	22.86	2.84	33.87	13.77	20.57
Mean	2.51	21.35	11.18	23.03	2.86	34.12	13.70	20.80
S.E. (±)	0.05	0.39	0.06	0.77	0.10	1.14	0.30	0.68
CD @5%	0.17	1.19	0.18	2.39	0.30	3.54	0.93	2.10

Table 5: Association of morpho-physiological parameters with grain yield

Hybrids	No. of productive tillers	Ear head length (cm)	ear head girth (cm)	Biological yield (kg plot^{-1})	Harvest index	Grain yield (kg plot^{-1})
No. of productive tillers	1	0.569**	0.700**	0.781**	0.465*	0.686**
Ear head length (cm)		1	0.379	0.627**	0.522*	0.583**
Ear head girth (cm)			1	0.536**	0.400	0.641**
Biological yield (kg plot^{-1})				1	0.390	0.584**
Harvest index					1	0.946**
Grain yield (kg plot^{-1})						1

** Significant at 1%, r at 1% = 0.561

It is concluded, that the plant height, number of tillers, ear head length, ear head girth, number of productive tillers plant^{-1}, harvest index, total dry matter production, grain yield plant^{-1} are found to be the desirable characters for developing the ideal plant type in pearl millet. The yield contributing parameters *viz.*, number of productive tillers, ear head length, ear head girth, biological yield and harvest index showed significant positive correlation with yield. The high yielding hybrids, RHRBH-9808 and DHBH-1203 found superior in respect to plant height, leaf area, number of productive tillers plant^{-1}, total dry matter, ear head length, ear head girth and biomass production. Therefore, emphasis would be given on these morpho-physiological characters for developing of high yielding hybrids and these hybrids can be used for further breeding programme.

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