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Assessment of Physiological Basis of Yield Variation in Small Millets under Rainfed Condition

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A B S T R A C T

Physiological traits play an important role in crop growth and development. Comparative investigation on small millets, with respect different physiological traits such as leaf area index, leaf area duration, specific leaf weight, chlorophyll content, gas exchange parameters etc. and their relationship with grain yields were meager, and will be useful in small millets improvement. Therefore, this study aims to investigate the physiological traits and their relationship with grain yields five small millets (foxtail millet, proso millet, kodo millet, little millet and barnyard millet). Physiological traits such as leaf number, leaf area, specific leaf weight, chlorophylls a, b, and total chlorophyll, SPAD reading, photosynthetic rate and transpiration rate have reached their maximum value at grain development stage in all the crops, while leaf area index was the maximum at grain development stage, highest root length was achieved at maturity stage, and highest stomatal conductance was at flowering stage. Among different cultivars within the each crop, a cultivar having high leaf number, leaf area, leaf area index, leaf area duration, specific leaf weight, chlorophyll a, b, and total chlorophyll, chlorophyll fluorescence ratio, SPAD reading, photosynthetic rate, transpiration rate, stomatal conductance and root length, had produced higher grain yield. This shows importance of these traits in for enhanced yields in small millets.

Introduction

Small millets such as finger millet, foxtail millet, proso millet, kodo millet, little millet and barnyard millets are considered as important nutri-rich and climate-smart crops and are adapted to diverse environments (Vetriventhan *et al*., 2015 and Upadhyaya *et al*., 2008). Small millets play an important role in diversifying agriculture, supporting traditional farming systems and improving food and nutritional security particularly in marginal lands. Small millets are grown in India, China, Russia, Japan., USA and other African and East Asian countries. In India, the cultivation of small millets are cultivated in limited area of 2.32 m ha and occupy about 9.7 lakhs ha with a production of 4.67 lakhs tons, with a productivity of 480 kg/ha (averaged between 2006-2010).

Potential yields of up to 3 tons in small millets were reported (http://www.aicrpsm.res.in/Reports.html), indicating a large yield gaps, and great opportunity to enhance productivity following improved crop management practices and cultivation high yielding cultivars. Comparative investigation on small millets, with respect different physiological traits such as leaf area index, leaf area duration, specific leaf weight, chlorophyll content, etc. and their relationship with grain yields were meager, and will be useful in small millets improvement. Therefore, this study aims to investigate the physiological traits and their relationship with grain yields.

Materials and Methods

The experiment was conducted at Tamil Nadu Agricultural University, Coimbatore situated at 11N° and 77E° longitude with at an altitude of 426.7 m above mean sea level. This study included two cultivars each of barnyard millet (Co 1 and Co 2) and kodo millet (Co 3, APK), three cultivars each of proso millet (Co 3, Co 4 and Co 5), little millet (Co 2, Co 3 and Co 4) and foxtail millet (Co 5, Co 6 and Co 7). Together, 13 cultivars of five small millets were planted in randomized complete block design with three replications. The experiment received NPK in the form of urea, single super phosphate and muriate of potash, respectively at the rate of 44: 22: 15 kg/ha. Full dose of P was applied as basal, whereas, N was applied in two splits, one as basal and another at 30 days after sowing (DAS). Potassium in the form of Muriate of potash was applied at 20th and 40th DAS. The observations on physiological traits and Gas exchange parameters were recorded at seedling (20-25 DAS), vegetative (30-35 DAS), flowering (40-55 DAS), grain development (60-70 DAS) and grain maturation (75-85 DAS) stages of the crop. All the observations were made from ten randomly selected plants from each replication of all the treatments. The physiological traits such as number of leaves, leaf area, leaf area index (LAI), leaf area duration (LAD), specific leaf weight (SLW), root length**,** Chlorophyll a, b and total chlorophyll content were estimated. The number of leaves per plant was determined by counting the leaves from the base to the tip of the plant. Leaf area for the whole sampling unit was measured by using Leaf Area Meter (Licor Model 3100) and expressed as cm^2 plant^{-1}. The Leaf Area Index (LAI) was calculated by employing the formula of Williams (1946).

LAI =

$$leaf\ area\ per\ plant / ground\ area\ occupied\ by\ the\ plant$$

Leaf Area Duration (LAD =

$$\frac{L1+L2}{2}(t2 - t1)$$

where, L_1 = LAI at first stage, L_2 = LAI at second stage, t1 – t2 = Time interval in days) was determined using the formula of Power *et al.* (1967) and expressed in days. Specific leaf weight (SLW=$leaf\ dry\ weight/leaf\ area$) was determined by using the formula given by Pearce *et al*. (1968) and expressed as mg cm^{-2}.

The plant was uprooted with minimum damage to the roots and the root length from the cotyledonary node to the root tip was measured and expressed as cm. Chlorophyll a, b and total chlorophyll content, were estimated in a fully expanded young leaf as per the method of Arnon (1949) and expressed as mg g^{-1} fresh weight. Chlorophyll index in leaves was measured using SPAD meter. Photosynthetic rate, transpiration rate and stomatal conductance was measured following portable Photosynthesis System (PPS) (Model LI-6400 of LICOR Inc., Lincoln, Nebraska, USA) equipped with a halogen lamp (6400-02B LED) positioned on the cuvette. Totally, three measurements were taken in the same leaf. The fully expanded young leaf was inserted in a 3 cm^2 leaf chamber and PPFD at 1200 µmol photons m^{-2} s^{-1} and relative humidity (50-55%) were set. The readings were taken between 11.00 am to 12.30 pm. Using PPS, the following gas exchange parameters were recorded and the values expressed as in parentheses.

Transpiration rate (mmol H_2O m^{-2} s^{-1})

Stomatal conductance (mmol H_2O m^{-2} s^{-1})

Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})

The data collected on the different parameters were statistically analyzed by the 'F' test for significance as suggested by Gomez and Gomez (2010). The critical difference (CD) was computed at 5% probability. Biochemical traits at different crop growth stages were compared following Newman and Keul's test (Newman 1939; Keuls 1952) using the GenStat 17th edition (http://www.genstat.co.uk).

Results and Discussion

Physiological traits

Physiological traits such as leaf number, leaf area, leaf area index, leaf area duration, specific leaf weight, chlorophyll a, chlorophyll b and total chlorophyll content and SPAD reading (Soil Plant Analysis Development) were recorded at five different growth stages of small millets (Table 1). Leaf number of was the highest in little millet at grain development (13.20), grain maturation (11.93) and harvest (6.90) stages while barnyard millet had the maximum number of leaf at flowering (7.60) and grain development (8.20) stages. Among five crop growth stages, the maximum leaf was reached at grain development stage (5.60 in kodo millet to 13.20 in little millet) in all small millets investigated (Table 2). Leaf area, leaf area index and leaf area duration ware maximum in barnyard millet in four out of five growth stages compared to other crops investigated (Table 1), and reached the highest leaf area during grain development stage, leaf area index at grain maturation stage and leaf area duration in either of grain development or grain maturation stages. Specific leaf weight was the highest in foxtail millet at all five growth stages, and it has reached the maximum at grain developmental stage in all the crops. Chlorophyll a, b and total chlorophyll contents reached the maximum at grain development stage in all the crops.

Chlorophyll b was the maximum in finger millet in first four stages while kodo millet had the highest chlorophyll b content at maturity. Chlorophyll a was the maximum at vegetative stage in barnyard millet, flowering stage in kodo millet, grain development and maturation stages in proso millet and at harvest in little millet. Total chlorophyll content was the maximum in kodo millet in all crop growth stages except at grain maturation stage and reached the maximum at flowering stage in all five crops. Foxtail millet had slightly higher chlorophyll fluorescence (Fv/Fm ratio) and in all crops, it is maximum at grain development stage and low at maturity stage. The SPAD reading was maximum in foxtail millet in vegetative to grain maturation stage while barnyard millet had the maximum SPAD value at harvest.

Gas exchange parameters

Gas exchange parameters such as photosynthetic rate, transpiration rate and stomatal conductance were recorded at vegetative, flowering, panicle initiation and maturation stages in 13 cultivars of five small millets. Photosynthetic rate was the maximum in proso millet at vegetative, flowering and grain maturity stage compared to other crops, and it reached highest at grain development stage and significantly differed with other stages in all the crops. Transpiration rate was the maximum at vegetative stage and grain development stage in proso millet, flowering stage in barnyard millet and maturity stage in little millet, and it reached the maximum at grain development stage in all the crops and differed significantly. Stomatal conductance was maximum in proso millet at vegetative, grain development and maturity stages and was reached the highest at flowering stage in all five small millets studied.

Relationship of physiological traits with grain yield

Two cultivars each in barnyard and kodo millets, and three cultivars each in foxtail millet, proso, and little millets were used in this study. Flowering duration of these cultivars varied from 40 to 65 DAS. Except kodo millet, remaining four crops' cultivars flowered within 52 DAS, and matured in less than 95 DAS. Grain yields of small millets cultivars varied from 1133 kg/ha (APK of kodo millet) to 3499 kg ha^{-1} (Co 7 of foxtail millet), and straw yield varied from 5083 kg ha^{-1} to 7666 kg/ha. Harvest index varied from 0.27 to 4.10 among cultivars. Harvest index was highest in kodo millet (0.39 to 0.41, mean 0.40) and was lowest in foxtail millet (0.27 to 0.32, mean of 0.28). The foxtail millet cultivars yielded an average of 3033 kg/ha followed by proso millet (2877 kg/ha), and least was in kodo millet (1575 kg/ha). Within each crop, a cultivar having high leaf number, leaf area, leaf area index, leaf area duration, specific leaf weight, chlorophyll a, b, and total chlorophyll, chlorophyll florescence ratio, SPAD reading and root length had produced higher grain yield (Table 3 to 7).

Table.1 Gas exchange parameters of small millets at different growth stages

Crop	Growth stage			
	Vegetative state	Flowering	Grain development	Grain maturity
Photosynthetic rate				
Barnyard millet	29.90a	35.45b	41.38c	27.85a
Foxtail millet	22.90a	35.67c	43.56d	27.30b
Proso millet	30.97a	35.80ab	38.41c	31.50ab
Kodo millet	24.35a	28.70a	38.12b	26.09a
Little millet	27.67a	31.37b	39.74	31.36b
TranspirationRate				
Barnyard millet	5.25a	11.40b	12.77c	11.61b
Foxtail millet	5.00a	7.20b	13.07d	11.22c
Proso millet	6.40a	9.60b	14.74d	10.71c
Kodo millet	5.10a	8.00b	13.02d	10.88c
Little millet	5.40a	8.13b	13.74d	12.02c
Stomatal conductance				
Barnyard millet	0.32a	1.42d	0.49b	0.79c
Foxtail millet	0.24a	1.09d	0.65b	0.80c
Proso millet	0.32a	1.36d	1.11b	1.23c
Kodo millet	0.26a	1.13d	0.58b	0.77c
Little millet	0.27a	1.12d	0.82b	1.03c

#Growth Stages: Mean values of a trait at different growth stages were compared using Neman and Kuel's test (Newman 1939; Keuls1952). The means followed by different letter for a given trait and crop at different stages indicating significant difference at 5% probability.

Table.2 Mean performance of small millets for different physiological traits at different growth stages

Crop and trait	Crop Stages#				
	Vegetative	**Flowering**	**Grain development**	**Grain maturation**	**Harvest**
Leaf number					
Barnyard millet	3.60a	7.60b	8.20b	7.85b	6.45b
Foxtail millet	4.80a	5.8bc	6.4c	5.9abc	5.1ab
Proso millet	6.00ab	6.93ab	7.63b	6.53ab	5.5a
Kodo millet	4.52a	4.85a	5.60a	5.30a	4.80a
Little millet	4.80a	7.40b	13.20c	11.93c	6.90b
Leaf Area					
Barnyard millet	540a	673b	819c	767bc	653b
Foxtail millet	335a	520b	756d	652c	587bc
Proso millet	342a	571b	790b	715b	581b
Kodo millet	252a	535b	818c	705bc	598b
Little millet	334a	423ab	861d	689c	547bc
Leaf area Index (LAI)					
Barnyard millet	2.41a	2.99ab	3.42bc	3.64c	2.91b
Foxtail millet	1.49a	2.31b	2.90c	3.36d	2.61bc
Proso millet	1.52a	2.54b	3.18b	3.52b	2.58b
Kodo millet	1.13a	2.38b	3.13bc	3.64c	2.655v
Little millet	1.48a	1.88ab	3.06c	3.83d	2.43bc
Leaf area duration (LAD)					
Barnyard millet	27.00a	32.05ab	32.73ab	35.28b	31.76b
Foxtail millet	19.00a	26.03b	31.28c	29.83bc	26.54b
Proso millet	20.28a	28.58ab	28.58ab	33.47b	30.48ab
Kodo millet	17.52a	27.55b	33.83b	31.45b	27.59b

Little millet	16.82a	24.70b	34.43b	31.30b	26.81b
Specific leaf weight (SLW)					
Barnyard millet	7.22a	7.65ab	22.48d	16.31c	11.76a
Foxtail millet	7.25a	8.19a	25.28d	18.59c	13.33b
Proso millet	6.98a	8.10a	24.70d	17.52c	12.65b
Kodo millet	6.27a	7.45a	23.87c	16.07b	11.73ab
Little millet	7.14a	7.61a	22.79d	16.94c	7.61a
Chlorophyll 'a'					
Barnyard millet	1.47ab	1.54ab	1.73b	1.34a	1.26a
Foxtail millet	1.45b	1.60c	1.75c	1.33ab	1.23a
Proso millet	1.357a	1.60b	1.78c	1.37a	1.233a
Kodo millet	1.43b	1.62b	1.72c	1.25a	1.19a
Little millet	1.41ab	1.51bc	1.60c	1.29a	1.28a
Chlorophyll 'b'					
Barnyard millet	0.35ab	0.42ab	0.56b	0.46ab	0.29a
Foxtail millet	0.40a	0.44a	0.78a	0.61a	0.30a
Proso millet	0.18a	0.42a	0.52a	0.38a	0.18a
Kodo millet	0.31a	0.42a	0.54a	0.49a	0.39a
Little millet	0.25a	0.36a	0.36a	0.50a	0.30a
Total Chlorophyll					
Barnyard millet	1.66ab	1.78ab	1.92b	1.80ab	1.55a
Foxtail millet	1.67ab	1.77bc	1.93c	1.74bc	1.53a
Proso millet	1.53ab	1.80cd	1.91d	1.7bc	1.4a
Kodo millet	1.70a	1.83a	2.03a	1.72a	1.58a
Little millet	1.63ab	1.82b	1.92b	1.63ab	1.48a
Chlorophyll fluorescence (Fv/Fm ratio)					
Barnyard millet	0.58b	0.72d	0.77e	0.68c	0.55a

Foxtail millet	0.59b	0.71d	0.77e	0.69c	0.57a
Proso millet	0.55a	0.69b	0.75c	0.67b	0.54a
Kodo millet	0.58b	0.68d	0.75e	0.67c	0.55a
Little millet	0.58b	0.72d	0.76e	0.68c	0.56a
SPAD					
Barnyard millet	37.20b	43.60c	52.70d	35.50b	25.65a
Foxtail millet	38.70b	46.93c	54.53d	38.47b	23.07a
Proso millet	34.07b	43.47c	51.87d	33.70b	16.30a
Kodo millet	35.20b	42.45bc	49.60c	33.60b	22.65a
Little millet	35.47b	44.77c	52.77d	35.03b	25.43a
Root length (cm)					
Barnyard millet	6.00a	17.10b	17.60b	17.95b	18.05b
Foxtail millet	5.73a	9.87b	15.80c	16.50c	16.60c
Proso millet	6.67a	14.23b	16.10c	16.27c	16.43c
Kodo millet	5.75a	11.65b	14.70c	15.35c	16.00c
Little millet	5.55a	12.40b	15.40c	15.50c	15.80c

Growth Stages: Mean values of a trait at different growth stages were compared using Neman and Kuel's test (Newman 1939; Keuls1952). The means followed by different letter for a given trait and crop at different stages indicating significant difference at 5% probability.

Table.3 Physiological traits - Number of leaves, Leaf area (cm^2) and Leaf area index of small millets at different growth stages

Crop	Number of leaves					Leaf area (cm^2)					Leaf area index				
	I	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**
Banyard millet															
CO 1	3.4	7.2	7.6	7.0	6.3	510.43	656.29	790.66	744.21	614.54	1.35	2.17	2.54	3.04	2.46
CO 2	3.8	8.0	8.8	8.7	6.6	570.88	689.77	849.18	791.49	691.88	1.43	2.63	3.10	3.37	2.60
Foxtail millet															
CO 5	4.4	5.4	6.3	6.0	4.8	305.12	470.96	729.44	610.73	588.15	1.77	2.82	3.89	4.14	2.68
CO 6	4.7	5.6	6.0	5.9	5.0	330.15	499.61	740.61	651.83	579.38	1.36	2.09	2.71	3.24	2.61
CO 7	5.4	6.6	6.8	5.8	5.6	370.65	588.11	797.14	694.32	594.88	1.47	2.22	2.90	3.29	2.58
Proso millet															
CO 3	5.7	6.6	7.3	5.3	5.1	304.24	489.33	683.44	570.82	554.12	1.65	2.61	3.09	3.54	2.64
CO 4	5.9	6.8	7.1	6.6	5.3	322.11	591.02	757.61	697.25	585.65	1.25	2.58	3.26	3.94	2.69
CO 5	6.5	7.4	8.5	7.7	6.1	399.34	633.91	930.57	875.96	603.59	1.00	2.18	3.00	3.33	2.62
Kodo millet															
CO 3	4.6	5.5	6.6	6.2	5.4	280.19	580.51	887.11	733.77	606.29	1.49	1.69	2.63	3.48	2.20
APK	3.9	4.2	4.6	4.4	4.2	225.33	489.77	749.82	675.48	590.19	1.40	1.78	2.84	3.56	2.31
Little millet															
CO 2	4.1	7.1	12.0	10.5	6.1	335.61	380.14	783.59	590.77	494.11	1.56	2.17	3.71	4.44	2.79
CO 3	3.7	7.4	13.2	12.3	6.9	315.19	399.46	800.11	640.08	519.36	2.27	2.92	3.31	3.51	2.73
CO 4	6.6	7.7	14.4	13.0	7.7	350.15	488.27	999.87	835.14	627.37	2.54	3.07	3.52	3.77	3.08
Mean	**4.8**	**6.6**	**8.4**	**7.6**	**5.8**	**355.33**	**535.17**	**807.62**	**700.91**	**588.42**	**1.58**	**2.38**	**3.12**	**3.59**	**2.61**
SED	0.017	0.018	0.048	0.044	0.015	1.521	1.567	1.437	1.518	0.794	0.006	0.007	0.006	0.006	0.003
CD (0.05)	0.036	0.037	0.100	0.091	0.032	3.139	3.234	2.967	3.134	1.640	1.35	2.17	2.54	3.04	2.46

I - Vegetative stage ; II – Flowering stage ; III – Grain development stage ; IV – Grain maturation stage ; V – Harvest stage

Table.4 Physiological traits - Leaf area duration (days), Specific Leaf Weight (mg /cm^{-2}) and Root length (cm) of small millets at different growth stages

Crop	Leaf area duration (days)				Specific Leaf Weight (mg /cm^{-2})					Root length (cm)				
	I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**
Banyard millet														
CO 1	17.60	23.55	27.90	27.50	3.7	7.4	13.2	12.3	6.9	5.5	16.5	16.7	17.3	17.4
CO 2	20.30	28.65	32.35	29.85	6.6	7.7	14.4	13.0	7.7	6.5	17.7	18.5	18.6	18.7
Foxtail millet														
CO 5	22.95	33.55	40.15	34.10	4.7	5.6	6.0	5.9	5.0	5.2	7.2	15.5	16.6	16.7
CO 6	17.25	24.00	29.75	29.25	5.4	6.6	6.8	5.8	5.6	5.5	8.9	15.6	16.4	16.5
CO 7	18.45	25.60	30.95	29.35	5.7	6.6	7.3	5.3	5.1	6.5	13.5	16.3	16.5	16.6
Proso millet														
CO 3	21.3	28.50	33.15	30.90	3.4	7.2	7.6	7.0	6.3	5.9	13.2	15.5	15.7	15.9
CO 4	19.15	29.20	36.00	33.15	3.8	8.0	8.8	8.7	6.6	6.5	13.9	16.3	16.4	16.6
CO 5	15.9	25.90	31.65	29.75	4.4	5.4	6.3	6.0	4.8	7.6	15.6	16.5	16.7	16.8
Kodo millet														
CO 3	15.9	21.60	30.55	28.40	5.9	6.8	7.1	6.6	5.3	5.9	11.9	15.6	16.2	16.5
APK	15.9	23.10	32.00	29.35	6.5	7.4	8.5	7.7	6.1	5.6	11.4	13.8	14.5	15.5
Little millet														
CO 2	18.65	29.40	40.75	36.15	4.6	5.5	6.6	6.2	5.4	5.6	11.5	12.2	15.5	15.8
CO 3	25.95	31.15	34.10	31.20	3.9	4.2	4.6	4.4	4.2	5.4	12.3	15.3	15.4	15.8
CO 4	28.05	32.95	36.45	34.25	4.1	7.1	12.0	10.5	6.1	5.7	12.5	15.5	15.6	15.8
Mean	**19.79**	**27.47**	**33.52**	**31.02**	**4.8**	**6.6**	**8.4**	**7.6**	**5.8**	**355.33**	**535.17**	**807.62**	**700.91**	**588.42**
SED	0.063	0.062	0.063	0.042	0.017	0.018	0.048	0.044	0.015	1.521	1.567	1.437	1.518	0.794
CD (0.05)	0.130	0.129	0.131	0.088	0.036	0.037	0.100	0.091	0.032	3.139	3.234	2.967	3.134	1.640
I - Vegetative stage ; II – Flowering stage ; III – Grain development stage ; IV – Grain maturation stage ; V – Harvest stage														

Table.5 Physiological traits - Chlorophyll 'a' (mg g^{-1}), Chlorophyll 'b' (mg g^{-1}) and Total Chlorophyll (mg g^{-1}) content of small millets at different growth stages

Crop	Chlorophyll 'a' (mg g^{-1})					Chlorophyll 'b' (mg g^{-1})					Total Chlorophyll (mg g^{-1})				
	I	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**
Banyard millet															
CO 1	1.43	1.47	1.62	1.32	1.20	0.31	0.36	0.50	0.42	0.28	1.63	1.73	1.88	1.74	1.48
CO 2	1.51	1.60	1.83	1.37	1.32	0.39	0.48	0.61	0.49	0.30	1.69	1.82	1.95	1.86	1.62
Foxtail millet															
CO 5	1.39	1.51	1.65	1.28	1.19	0.37	0.41	0.58	0.57	0.31	1.60	1.72	1.89	1.85	1.50
CO 6	1.45	1.55	1.78	1.31	1.22	0.38	0.45	0.70	0.31	0.20	1.66	1.78	1.92	1.62	1.42
CO 7	1.51	1.75	1.83	1.41	1.28	0.44	0.45	1.05	0.95	0.39	1.75	1.82	1.97	1.74	1.67
Proso millet															
CO 3	1.34	1.66	1.73	1.33	1.22	0.17	0.46	0.51	0.32	0.11	1.51	1.72	1.87	1.65	1.33
CO 4	1.39	1.40	1.78	1.37	1.20	0.18	0.41	0.25	0.24	0.18	1.57	1.81	1.91	1.61	1.38
CO 5	1.34	1.73	1.82	1.41	1.28	0.17	0.46	0.51	0.32	0.11	1.52	1.88	1.95	1.72	1.61
Kodo millet															
CO 3	1.41	1.66	1.76	1.30	1.18	0.35	0.51	0.64	0.59	0.48	1.68	1.77	1.95	1.85	1.66
APK	1.45	1.57	1.68	1.20	1.20	0.27	0.33	0.43	0.38	0.30	1.72	1.90	2.11	1.58	1.50
Little millet															
CO 2	1.31	1.48	1.56	1.22	1.21	0.21	0.30	0.37	0.16	0.10	1.52	1.78	1.93	1.38	1.31
CO 3	1.43	1.50	1.54	1.29	1.31	0.25	0.34	0.60	0.46	0.17	1.68	1.84	1.90	1.75	1.48
CO 4	1.49	1.56	1.70	1.36	1.31	0.28	0.45	0.79	0.88	0.34	1.74	1.83	1.94	1.76	1.65
Mean	**1.41**	**1.57**	**1.71**	**1.32**	**1.04**	**0.29**	**0.41**	**0.60**	**0.49**	**0.27**	**1.64**	**1.80**	**1.94**	**1.70**	**1.51**
SED	0.0011	0.0017	0.0016	0.0011	0.0008	0.0015	0.0010	0.0034	0.0038	0.0018	0.0014	0.0009	0.0010	0.0022	0.0021
CD (0.05)	0.0022	0.0035	0.0033	0.0022	0.0017	0.0030	0.0021	0.0071	0.0078	0.0078	0.0029	0.0019	0.0020	0.0045	0.0042

I - Vegetative stage ; II – Flowering stage ; III – Grain development stage ; IV – Grain maturation stage ; V – Harvest stage

Table.6 Chlorophyll fluorescence (Fv/Fm ratio) ,SPAD values, Yield potential and harvest index of small millets

Crop	Chlorophyll fluorescence (Fv/Fm ratio)					SPAD values					Yield potential and Harvest index				
	I	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**	**Days to 50% flowering**	**Plant height**	**Days to maturity (days)**	**Grain yield (Kg/ha)**	**Harvest index**
Banyard millet															
CO 1	0.581	0.723	0.774	0.679	0.552	36.2	41.5	50.6	34.7	24.8	52	113	95	2197	0.35
CO 2	0.583	0.725	0.778	0.682	0.555	38.2	45.7	54.8	36.3	26.5	48	120	92	3091	0.38
Foxtail millet															
CO 5	0.586	0.708	0.770	0.692	0.569	35.2	45.1	51.1	38.8	22.1	43	106	89	2716	0.27
CO 6	0.589	0.715	0.772	0.695	0.572	38.4	47.2	54.0	37.5	20.4	43	106	87	2883	0.28
CO 7	0.592	0.714	0.775	0.697	0.574	42.5	48.5	58.5	39.1	26.7	40	111	83	3499	0.31
Proso millet															
CO 3	0.526	0.663	0.731	0.675	0.521	32.8	44.2	49.6	30.4	17.2	47	105	94	2883	0.39
CO 4	0.562	0.669	0.748	0.664	0.537	33.1	40.6	51.3	34.5	16.4	45	106	93	2666	0.39
CO 5	0.567	0.674	0.769	0.673	0.558	36.3	45.6	54.7	36.2	15.3	44	113	90	3083	0.4
Kodo millet															
CO 3	0.575	0.681	0.752	0.674	0.543	37.4	46.4	52.5	35.9	22.1	60	96	115	2016	0.41
APK	0.577	0.683	0.755	0.677	0.546	33.0	38.5	46.7	31.3	23.2	65	94	122	1133	0.39
Little millet															
CO 2	0.575	0.720	0.760	0.675	0.558	34.2	42.2	50.7	33.5	24.7	48	103	86	2466	0.35
CO 3	0.578	0.723	0.764	0.679	0.560	35.1	44.5	52.4	36.2	25.4	47	105	83	2499	0.36
CO 4	0.581	0.726	0.769	0.682	0.561	37.1	47.6	55.2	35.4	26.2	43	106	80	2774	0.38
Mean	**0.574**	**0.701**	**0.763**	**0.680**	**0.554**	**36.11**	**44.43**	**52.47**	**35.37**	**22.38**	**48**	**107**	**93**	**2608**	**0.36**
SED	0.0003	0.0004	0.0002	0.0002	0.0002	0.044	0.048	0.049	0.041	0.064	0.117	0.113	0.201	9.630	0.001
CD (0.05)	0.0006	0.0008	0.0004	0.0004	0.0005	0.091	0.099	0.101	0.086	0.113	0.241	0.234	0.413	19.87	0.002

I - Vegetative stage ; II – Flowering stage ; III – Grain development stage ; IV – Grain maturation stage ; V – Harvest stage

Table.7 Gas exchange parameters of small millets at different growth stages

Stages	Vegetative stage			Flowering stage			Grain development stage			Maturity stage		
Crop	**PR**	**TR**	**SC**	**PR**	**TR**	**SC**	**PR**	**TR**	**SC**	**PR**	**TR**	**SC**
Barnyard millet												
CO1	29.3	5.1	0.31	34.2	11.3	1.4	40.1	12.66	0.47	27.16	11.53	0.78
CO2	30.5	5.4	0.33	36.7	11.5	1.43	42.66	12.88	0.52	28.54	11.68	0.8
Foxtail millet												
CO5	21.5	4.8	0.21	33.7	6.7	1.09	42.13	12.84	0.56	25.21	10.87	0.71
CO6	22.7	5	0.23	36.6	7.2	1.08	43.46	13.14	0.62	26.81	11.23	0.81
CO7	24.5	5.2	0.27	36.7	7.7	1.11	45.1	13.94	0.68	29.87	11.55	0.88
Proso millet												
CO3	30.2	6.3	0.31	34.3	9.1	1.31	35.32	14.11	1.05	30.8	10.31	1.21
CO4	30.8	6.4	0.32	35.6	9.4	1.35	37.41	14.67	1.1	31.53	10.56	1.22
CO5	31.9	6.5	0.32	37.5	10.3	1.41	42.5	15.45	1.19	32.17	11.26	1.27
Kodo millet												
APK	23.5	5	0.25	27.6	7.8	1.1	37.13	12.81	0.54	25.67	10.45	0.73
CO3	25.2	5.2	0.27	29.8	8.2	1.16	39.1	13.23	0.62	26.5	11.32	0.81
Little millet												
CO2	26.5	5.2	0.26	30.4	7.8	1.08	38.22	12.64	0.76	30.14	11.65	1.01
CO3	27.5	5.4	0.27	31.5	8.1	1.1	39.41	13.65	0.82	31.64	11.74	1.03
CO4	29	5.6	0.3	32.2	8.5	1.19	41.58	14.95	0.89	32.3	12.67	1.05
Mean	**27.16**	**5.5**	**0.28**	**33.6**	**8.74**	**1.22**	**40.32**	**13.61**	**0.75**	**29.1**	**11.29**	**0.94**
SED	0.056	0.009	0.0006	0.051	0.025	0.002	0.046	0.015	0.004	0.042	0.01	0.003
CD (0.05)	0.115	0.019	0.0013	0.105	0.05	0.005	0.096	0.031	0.008	0.086	0.021	0.007
PR - Photosynthetic Rate				**TR – Transpiration rate**					**SC – Stomatal conductance**			

Small millets are climate resilient crops, and are less affected by insect pests and diseases and abiotic stress. However, small millets cultivation and consumption has been declined mainly due to limited productivity, high drudgery involved in their processing and negative perceptions of small millets as a food for the poor. In this study, we assessed the physiological traits at different growth stages and their relationship with grain yield. Understanding the physiological traits in crops plants at different stages helps to understand their adaptations and crop characteristics. Leaf area is the fundamental determinant of the rate of photosynthesis of any plant and the optimum leaf area development aids in effective interception of light energy and facilitates higher dry matter production.

The nature of the foliage cover is an important factor in determining the efficiency with which the available solar radiation is used in primary production (Loomis and Williams, 1969). The leaf area index is an important measure of canopy structure because crop morphology, leaf orientation and distribution influence LAI. Leaf area duration is the integral of leaf area index over time. Formation of optimum photosynthetic area and maintenance of photosynthetically active leaves for a longer duration, especially during the reproductive phase of crop, are essential for increasing the photosynthetic rate, dry matter accumulation and grain yield (Watson, 1958). Specific leaf weight plays an important role in leaf and plant functioning and is related to species strategies of resource acquisition and use. Specific leaf weight, a measure of leaf thickness, has been reported to have a strong positive correlation with leaf photosynthesis of several crops as reported by Bowes *et al.* (1972).

Photosynthetic pigments are composed of chlorophylls a, b and total and the main functions are interception and storage of light energy by inductive resonance through antenna complexes and consequent electron transport carried out by the Photosystem II (Taiz and Zeiger, 2002). The efficiency of leaves to produce assimilates and its persistence depends largely on photosynthetic pigments, of which, the leaf chlorophyll content is of the prime importance, which is directly associated with the increase in PSII photochemistry, photosynthate production and dry matter accumulation. Hence, measurement of chlorophylls indirectly explains the efficiency of the photosynthesis and photosynthates production. The chloroplast in green plants constitutes the photosynthetic apparatus. Chlorophylls and other photosynthetic pigments are found in the form of protein pigment complexes mainly in thylakoid membranes of grana. Photosynthetic pigments play major role in plant productivity, as they are responsible for capturing light energy and using it as a driving force for producing the assimilates. Chlorophyll index permits a rapid and non-destructive determination of leaf chlorophyll content by measuring leaf transmittance using SPAD meter.

Reduction in transpiration rate under water deficit conditions leads to reduce the photosynthetic rate by inhibition of CO_2 entry into the chloroplast through the stomata. The chlorophyll fluorescence is an important measurement of photosynthetic efficiency of crops. The high Fv/ Fm ratio is proportional to quantum yield and showing high degree of photosynthesis (Gitelson *et al*., 1999). Fluorescence yield will be high when PS II reaction centre is least damaged by photoinhibition. In this study, Several physiological traits such as leaf number, leaf area, specific leaf weight, chlorophylls a, b, and total chlorophyll, SPAD reading, photosynthetic rate and transpiration rate have reached their maximum value at grain development stage in all the crops, while leaf area index was the maximum at grain development stage, highest root length was achieved at maturity stage, and highest stomatal conductance was at flowering stage. Among different cultivars within the each crop, a cultivar having high leaf number, leaf area, leaf area index, leaf area duration, specific leaf weight, chlorophyll a, b, and total chlorophyll, chlorophyll florescence ratio, SPAD reading, photosynthetic rate, transpiration rate, stomatal conductance and root length, had produced higher grain yield. This shows importance of these traits in for enhanced yields in small millets.

References

Arnon, I. 1949. Crop production in dry regions . Background and principles. Leonard Hill books. London. 650p

Bowes, G.W., L. Orgen and R.H. Hageman. 1972. Light saturated photosynthesis rate, RuBP carboxylase activity and specific leaf weight in soybeans grown under different light intensities. Crop Science.12: 77-79.

Gitleson, A.A., C. Buschmann and H.K. Lichtenthaler. 1999. Leaf chlorophyll fluorescence corrected for reabsorption by means of absorption and reflectance measurements. Journal of Plant Physiology. 152: 283-296.

Gomez, K.A. and A.A. Gomez. 2010. Statistical procedure for agricultural research. New York, Wiley Inter-Science Publications.

Keuls, M. 1952. The use of the "Studentized range" in connection with an analysis of variance. Euphytica 1:112–122.

Loomis, R. S., and W. A. Williams. 1969. Productivity and the morphology of crop stands: patterns with leaves. In Eastin, J. D., et al., eds., Physiological aspects of crop yield. American Society of Agronomy. Madison: 27-47.

Newman, D. 1939. The distribution of range in samples from a normal population expressed in terms of an independent estimate of standard deviation. Biometrika. 31:20–30.

Pearce, R.B., R.H. Brown and R.E. Blaster. 1968. Photosynthesis of alfalfa leaves as influenced by age and environment. Crop Science. 8: 677-680.

Power, J.E., W.O. Wills, D.L. Granes and G.A. Reichman. 1967. Effect of soil temperature, phosphorus and plant age on growth analysis of barley. Agronomy Journal. 59: 231-234.

Taiz, L., and Zeiger, E., (2002). Plant physiology, third ed. Sinaur, sunderland.

Upadhyaya, H.D., C.L.L Gowda, V.G. Reddy and S. Singh. 2008. Diversity of small millets germplasm in genebank at ICRISAT. In: 5th International Symposium on New Crops and Uses: their role in a rapidly changing world, 3-4 September, 2007, University of Southampton, Southampton, UK.

Vetriventhan, M., H.D.Upadhyaya, S.L. Dwived, S.K. Pattanashetti, and S.K. Singh. 2015. Finger and foxtail millets. p. 291–319. In Singh, M., Upadhyaya, H.D. (eds.), Genetic and Genomic Resources for Grain Cereals Improvement. Oxford: Academic Press.

Watson, D.J. 1952. The physiological basis for variation in yield. Advances in Agronomy. 4: 101-145.

Williams, R.F. 1946. The physiology of plant growth with special referance to the concept of net assimilation rate. Annals of Botony. 10: 41-71.

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