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Resourceful Photosynthesis System and Stem Reserve Accumulation Plays Decisive Role in Grain Yield of Kodo Millet (*Paspalum scrobiculatum*)

P. Kumar* • A. Sao • A. K. Thakur • S. C. Yadav • P. Sahu

S. G. College of Agriculture and Research Station, Jagdalpur- 494001, Chhattisgarh
Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh

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ABSTRACT

Looking for climate resilient potential, experimental analysis was made among forty three advanced breeding lines to interpret the stress tolerance mechanism and homogenize crop improvement parameters for widespread economic domestication of the hill crop. The maximum canopy length was observed in genotype BK 31 (74 cm) followed by BK 6 (73 cm), BK 48 (68), BK 2 and BK 23 (64 cm each). Perusal of flowering span revealed that entries exhibiting 50 percent flowering by 65-75 DAS, beard good crop yield. In contrast, vary early blooming genotype (PCGK-18, 50 DAS; PCGK-8 & 19, 50 DAS; PCGK-13, 59 DAS) exhibited comparative lower yield owing to exceedingly short vegetative phase. Among early maturing accessions, PCGK-18 (81 DAS); PCGK-8, PCGK-16 and BK-60 (94 DAS) and others in similar category suffered from yield penalty. Hence, genotypes should be bred for 100-105 DAS to optimize yield potential. PCGK-18 (5.50 kg/ha), BK-81 (8.50 kg/ha), PCGK-15, BK-23, BK-28 (9.0 kg/ha each) and other similar genotypes with lower biomass did not attain optimum yield bar. Conclusively, optimal vegetative growth is fundamental for grain yield physiology and yield increases in accordance to total biomass following normal distributional curve. Analysis of harvestable yield interprets that, higher the canopy length higher the yield. Genotype BK 48 with 70.50 cm plant height, turned to reproductive phase by 76 DAS, accomplished crop cycle by 111 DAS, produced significant higher biomass and maximum yield. During primary development phase, the plant generative organs are well protected by vegetative tissues and unless the stress is semilethal or lethal, the reproductive cells and or structures respond to unfavorable conditions indirectly, as mediated by the vegetative plant organs.

1. Introduction

Kodo millet (*Paspalum scrobiculatum*), widely grown in hilly and plateau regions, is a member of Family *Poaceae* and commonly known as Scrobic, kodo millet, koda millet, kodra, ditch millet, ricegrass, Indian paspalum, creeping paspalum, water couch, Indian crown grass. Among cultivated and wild species, *Paspalum scrobiculatum var. scrobiculatum* is widely cultivated in India and other parts of the world as an important semi food crop, while *Paspalum scrobiculatum var. commersonii* is the wild variety indigenous to Africa (Heuze et al. 2015). Kodo originated from Africa and is now widespread in the Old World tropics. It was first introduced to India 3000 years ago and domestication process is still ongoing. Kodo is very common in rainfed and upland ecology in India where no alternate *Kharif* crop is possible. Kodo Millet is gaining importance due to dual reasons like nutritional properties and stress tolerance (Kumar et al. 2016a). Being main source of protein and minerals it is part daily diets of tribal and weaker section rural inhabitant. The millet contains a high proportion

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*Corresponding author: prafull397@gmail.com of complex carbohydrate and dietary fiber which helps in prevention of constipation and slow release of glucose to the blood stream. Millets including Kodo contain water soluble fiber and this property may be utilized for maintaining or lowering blood glucose response among diabetic and CVD patients (Riccardi *et al*., 2008). Glycemic load (GL) representing both quality and quantity of carbohydrate in a food and allows comparison of the likely glycemic effect of realistic portion of the different foods and low glycemic index foods like Kodo, have been shown to improve the glucose tolerance in both healthy and diabetic subjects (Chandel et al. 2014). Among stress tolerant attributes, Kodo is quite promising crop of rainfed and upland agriculture. In rainfed areas, where crop species required with less than 100 DAS growth cycle and traditional cereal i.e*.,* rice cannot be grown, it providesan excellent crop source of sustainability. Similarly in upland ecology, which is characterized by low input cultivation in infertile soil, *Scorbic* can be grown successfully. Looking for these background information, experiment was framed to set experimental protocol for improvement of this emerging stress cereal crop.

2. Materials and Methods

The bireplicated rainfed experiment was conducted at Millet Research Block of S. G. College of Agriculture and Research Station, Jagdalpur, IGKV, Raipur. Forty three genotypes (Table 1) were selected based on initial yield evaluation trails conducted previous years. The plot size was at 2.25 x 5.00m and maintained entirely rainfed across the experiment session. Observations were recorded for eight quantitative parameters viz., plant height (cm), tillers per plant, numbers per ear, finger length (cm), days to 50 percent flowering (DAS), days to maturity (DAS), fodder yield (kg/ha) and grain yield (kg/ha). Trial was sown at onset of monsoon and standard agronomic package of practice was followed to raise the crop. Plant height, tillers count, ear count and finger length measurement was done on five plant average basis while blooming and durational observation was recorded on days after sowing basis. For fodder yield, upper canopy (excluding root) of entire plot was cut and weighed. The pooled replicated data was subjected to statistical analysis using software SPARK 2.

3. Results and Discussion

Water stress, both vegetative and terminal, impacts include growth, yield, membrane integrity, pigment content, osmotic adjustment, water relations and photosynthetic activity (Anjum et al. 2011; Kumar et al. 2016b) which further becomes complicated by climatic, edaphic and agronomic factors. The susceptibility varies with stress degree dependence, accompanying stress factors, plant species and genotype and their developmental stages. Plants' Acclimation to water deficit is multi episodic result, leading to adaptive changes in plant growth and physio-biochemical processes, such as changes in plant structure, growth rate, tissue osmotic potential and antioxidant defenses (Kumar et al. 2015a). Present era crop improvement focused to elucidate the responses and crops adaption to water deficit for improving the crop plants resistance and to ensure higher crop yields against unfavorable environmental stresses. This article attempted to provide an overview of morphological responses of Kodo millet genotypes to stressed environment. Among the 43 genotypes evaluated, average plant height was 59cm. The maximum canopy length was observed in genotype BK 31 (74 cm) followed by BK 6 (73 cm), BK 48 (68), BK 2 and BK 23 (64 cm each) (Table 01). However, Genotype BK 50 (45cm), PCGK 13 (46cm) and BK 49 (46cm) exhibited significantly higher yield than tall statured one. In contrast to other cereal crop like rice, where 80-90cm height is considered to be critical to harvest good crop, Kodo millet should be bred 45-65cm canopy length. The physiological explanation is that, the culm strength of Kodo millet is very poor due to lower silica content which causes lodging just concluding the maturity. Tillering nature is not much promising in upland crop, and similar pattern was observed in present experiment. Productive tillers ranged from 3-6 per plant and maximum value was documented in genotype BK 60 (6) but overall appraisal of data revealed that it did not contribute significant towards seed yield. Similarly fingers per plant were spotted as standard and non-significant factor for distinguishing the test entries. As per cereal crop hypothesis, finger length was found to quite crucial in yield determination. The experimental mean value was recorded to be 6.5cm and it ranged between 3.7 to 9.7cm. Genotype PCGK-16 exhibited maximum value for finger length (9.7cm) followed by PCGK-23 and BK-31 (8.6cm), PCGK -3 (8.5cm) and PCGK-26 (8.4cm). However, genotype PCGK-2 and PCGK-13 exhibited noticeable grain yield (5600kg/ha and 4888kg/ha) with 5.7cm and 4.7cm finger length against the generalized perception which may attribute to crop genetics and morphology. According crop genetics theory larger finger size reduces and hampers the availability photosynthates to each grain and or small quantity assimilates eventually shrink the finger. In continuation, bold grain size and tripartite or irregular grain distribution in rachis provides the minimum length advantages to genotype or vice versa. Hence, merely scaling the length is not suggested in this newly emerging cereal but grain distribution should be observed critically to formulize the yield equation. The maximum days to flowering was recorded to be 81 DAS (PCGK-23 and BK-40). The subsequent genotypes are PCGK

-12 (80 DAS) and PCGK-3 (79 DAS). Perusal of flowering span revealed that entries exhibiting 50 percent flowering by 65-75 DAS, beard good crop yield. In contrast, vary early blooming genotype (PCGK-18, 50 DAS; PCGK-8 & 19, 50 DAS; PCGK-13, 59 DAS; BK-16, 59 DAS) exhibited comparative lower yield owing to exceedingly short vegetative phase. Days to maturity i.e. total crop duration or complete growth period was recorded to be 104 DAS for entire experiment. The genotype PCGK-23 was found as most late maturing (116 DAS) followed by PCGK-3, PCGK-12 and PCGK-23 (115 DAS); PCGK-2, BK-35, BK-36, BK-45, BK-46 and BK-48 (110 DAS). Among early maturing accessions, PCGK-18 (81 DAS); PCGK-8, PCGK-16, BK-60 (94 DAS); PCGK-13, PCGK-19, PCGK-43, BK-14, BK-19 (96 DAS) and others in similar category suffered from yield penalty. Hence, in support to experimental outcome, it is concluding that genotypes should be bred for 100-105 DAS to optimize yield potential. Grain development begins with very important process of double fertilization that leads to development of male and female gametes, their fusion and the development of the embryo and endosperm which should take place undisturbed. Abiotic stress, various kind and severity, poses differential but always negative effect on reproductive development process and yield declines (Kumar et al. 2014a; 2015b). Breeding for specific cultivation conditions (life habitats), here rainfed ecology, as well as for developmental synchrony further exacerbates the effects of adverse environmental conditions on the yield of modern cultivars.

Figure 1. LSD comparison and Normal Distribution Curve of Significant Parameters

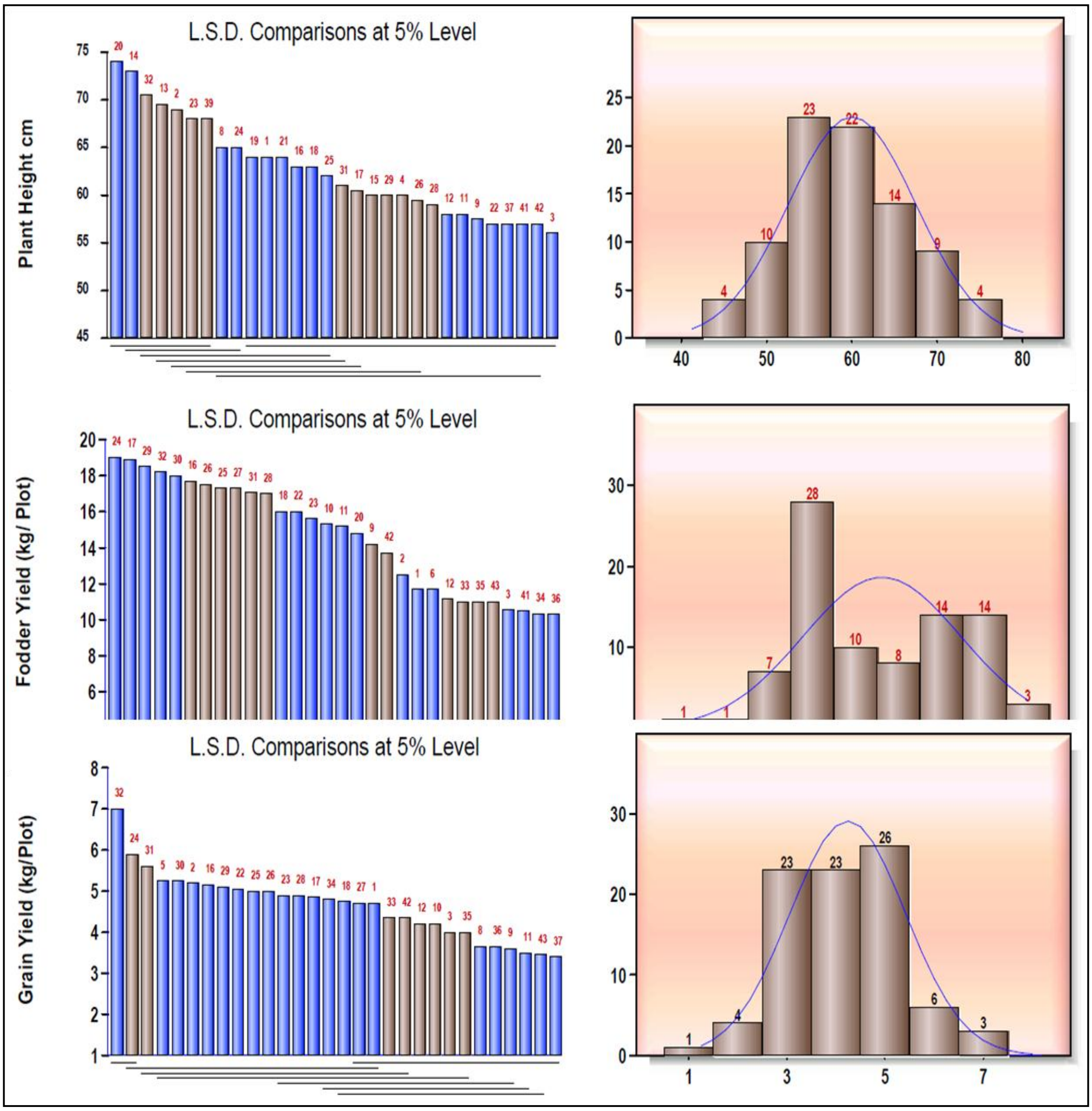

Table 1. Phenological response to Rainfed Treatment under field condition

S. No	**Genotypes**	**Plant Height (cm)**	**Tillers/ Plant**	**Fingers/ Ear**	**Finger Length (cm)**	**Days to 50 % Flowering (DAS)**	**Days to Maturity (DAS)**	**Fodder Yield (kg/ Plot)**	**Grain Yield (kg/Plot)**
01	PCGK - 2	64.00	3.50	4.50	5.70	75.50	110.50	11.70	4.70
02	PCGK - 3	69.00	5.00	3.50	8.50	79.00	115.00	12.50	5.20
03	PCGK - 19	56.00	3.50	4.00	6.55	58.50	96.00	10.55	4.00
04	PCGK - 12	60.00	4.00	4.50	6.90	80.00	114.00	9.00	3.30
05	PCGK - 13	46.50	3.00	3.50	4.75	59.00	96.00	10.05	5.25
06	PCGK - 43	51.00	4.00	4.00	6.70	59.50	98.00	11.70	3.25
07	PCGK - 18	54.00	4.50	4.00	4.20	51.00	81.00	5.50	1.45
08	PCGK - 8	65.00	4.50	3.50	7.10	59.00	96.00	10.00	3.65
09	PCGK - 16	57.50	3.00	4.50	9.65	59.00	94.00	14.20	3.60
10	PCGK - 23	55.00	5.00	4.00	8.60	81.50	116.00	15.30	4.20
11	PCGK - 26	58.00	4.00	4.50	8.40	79.00	116.00	15.20	3.50
12	IK – 1*	58.00	4.00	3.50	4.45	63.00	101.00	11.15	4.20
13	BK - 2	69.50	4.50	4.00	7.20	63.50	102.50	9.00	2.80
14	BK - 6	73.00	4.50	4.50	4.50	63.00	103.00	9.90	3.10
15	BK - 14	60.00	4.00	5.50	4.85	60.00	98.00	10.05	3.05
16	BK - 19	63.00	4.00	4.00	6.60	60.50	98.00	17.70	5.15
17	BK - 20	60.50	5.50	3.00	7.50	69.00	106.00	18.90	4.85
18	BK - 21	63.00	5.00	4.00	8.10	74.50	108.00	16.00	4.75
19	BK - 30	64.00	6.00	3.00	3.70	67.00	106.00	9.50	2.90
20	BK - 31	74.00	4.50	4.00	8.60	67.00	105.00	14.80	3.30
21	BK - 32	64.00	4.00	3.00	5.40	60.50	97.00	9.50	2.55
22	BK - 34	57.00	3.50	5.00	8.20	75.00	109.00	16.00	5.05
23	BK - 35	68.00	4.00	2.50	5.80	74.50	110.00	15.60	4.90
24	BK - 36	65.00	3.00	3.00	8.35	74.00	111.00	19.00	5.90
25	BK - 38	62.00	4.00	3.50	6.70	68.00	108.00	17.30	5.00
26	BK - 39	59.50	3.50	3.00	8.10	74.00	109.00	17.50	5.00
27	BK - 40	54.00	3.50	3.00	6.60	80.00	113.00	17.30	4.70
28	BK - 42	59.00	4.00	4.50	7.40	71.00	110.50	17.00	4.90
29	BK - 43	60.00	4.50	3.00	7.90	71.50	109.00	18.50	5.10
30	BK - 45	55.00	3.00	5.00	7.40	75.00	110.00	18.00	5.25
31	BK - 46	61.00	5.50	3.00	7.20	74.50	112.00	17.05	5.60
32	BK - 48	70.50	4.00	3.50	6.90	76.00	111.00	18.20	7.00
33	BK - 49	46.00	4.50	3.00	7.25	67.00	105.00	11.00	4.35
34	BK - 50	45.50	4.00	3.00	7.10	69.00	110.50	10.35	4.80
35	BK - 52	56.00	5.50	4.00	5.30	70.00	109.00	11.00	4.00
36	BK - 62	50.00	3.50	3.00	4.10	61.00	97.00	10.30	3.65
37	BK - 81	57.00	4.00	3.00	5.15	60.00	98.00	10.00	3.40
38	BK - 81	54.00	5.50	4.00	5.60	60.50	96.00	8.50	3.25
39	BK - 23	68.00	3.00	3.00	5.90	61.50	97.00	9.00	2.85
40	BK - 28	53.50	5.00	4.00	4.15	63.00	101.00	9.15	2.65
41	BK - 60	57.00	4.00	3.00	7.20	59.00	94.00	10.50	3.15
42	BK - 64	57.00	6.00	4.00	5.95	65.00	103.00	13.70	4.35
43	BK - 82	54.00	3.50	3.00	5.40	62.50	98.00	11.00	3.45
Mean		**59.40**	**4.21**	**3.70**	**6.55**	**67.47**	**104.14**	**12.98**	**4.12**
C.V.		7.22	20.15	24.41	8.78	1.79	2.38	6.53	15.81
F ratio		5.10	1.83	1.20	13.27	80.23	18.84	37.05	5.61
F Prob.		0.00	0.03	0.28	0.00	0.00	0.00	0.00	0.00
S.E.		3.03	0.60	0.64	0.41	0.85	1.75	0.60	0.46
C.D. 5%		8.65	1.71	1.82	1.16	2.43	5.00	1.71	1.31
C.D. 1%		11.57	2.29	2.43	1.55	3.25	6.68	2.29	1.76
Range Lowest		45.50	3.00	2.50	3.70	51.00	81.00	5.50	1.45
Range Highest		74.00	6.00	5.50	9.65	81.50	116.00	19.00	7.00

Fodder yield was ranged between 5.5 kg/plot (PCGK-18) to 19.0 kg/plot (BK-36) and the testing mean was documented as 13.0 kg/ha. Parallel to previous reports, vegetative biomass (referred fodder yield) is imperative, up to certain extent, to maintain plant productivity as it imparts major role in photosynthesis. BK-43 (18.50 kg/ha), BK-48 (18.20), BK-45 (18.0 kg/ha), BK-39 (17.50 kg/ha) and BK-38 and BK-40 (17.30 kg/ha) were found as high fodder yielder genotypes and in correspondence to biomass significant higher end product was also achieved (discussed later) (Fig 01). In contrary, PCGK-18 (5.50 kg/ha), BK-81 (8.50 kg/ha), PCGK-15, BK-23, BK-28 (9.0 kg/ha each) and other similar genotypes with lower biomass did not attain optimum yield bar. Conclusively, optimal vegetative growth is fundamental for grain yield physiology and yield increases in accordance to total biomass following normal distributional curve. Grain yield was phenotypically positively associated with plant height, finger length, days to 50 percent flowering, days to maturity and fodder yield signifying the suitability of selection indices. Plot grain yield was highest in genotype BK-48 (7.0 kg) followed by BK-36 (5.90 kg) and BK-46 (5.60 kg) and the yield trend lied at 4.12 kg/plot. Analysis of harvestable yield interprets that, higher the canopy length higher the yield. Genotype BK 48 with 70.50 cm plant height, turned to reproductive phase by 76 DAS, accomplished crop cycle by 111 DAS, produced significant higher biomass and maximum yield. During primary development phase, the plant generative organs are well protected by vegetative tissues. Unless the stress is semilethal or lethal, the reproductive cells and or structures respond to unfavorable conditions indirectly, as mediated by the vegetative plant organs. Parallel to present findings, Channappagoudar *et al.* (2008), Nirmalakumari and Vetriventhan (2010), Ganesamoorthi (2012), Prasanna *et al.* (2013) and Prakash and Vannirajan (2015) have observed that straw yield per plant, single earhead weight, plant height, flag leaf width, 1000 grain weight, earhead length, flag leaf length and earhead width and the major stem reserve mobilizations causes that eventually standardizes crop yield.

Conclusions

The success of cereal reproduction as well as the realization of yield potential of a given genotype, however, is dependent not only on the stress sensitivity of the reproductive and grain-filling stages but on overall plant growth and development. Resourceful photosynthesis system and stem reserve accumulation throughout the vegetative development segment has a decisive role on the formation of generative organs and thus may directly affect final yield. Therefore, in order to improve yield wellbeing in cereal species, the whole developmental process, from grain to grain, needs to be considered and appropriate strategies must target several developmental stages.

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