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Effect of Light Intensity on the Morpho-physiological Traits and Grain Yield of Finger Millet

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Authors' contributions

Author YANR designed, analysed, interpreted and prepared the manuscript. Author KTKG advised in formulating the experiment. Both authors read and approved the final manuscript.

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ABSTRACT

The normal light intensity during monsoon season in rainfed finger millet cultivation regions in particular, Bangalore, is around 1200 $uMm^{-2}s^{-1}$; the effect of reduction in light intensity on physiological parameters and grain yield of finger millet was studied. The experiment was laid out in split plot design with four light intensity treatments and three varieties in three replications. Each replication had four lines of 1.5 m row length (1.5 m x 1.0 m). The crop was directly sown on 03-08-2007 with the spacing of 22.5 cm between rows and 10 cm between the hills, using three varieties namely, GPU-48 (early maturing variety, 100 days), GPU-28 (medium maturing variety, 110 days), and L-5 (late maturing variety, 120 days). Decreased light intensity at canopy level decreased the leaf area, specific leaf weight, net assimilation rate and biomass production, which resulted in decreased grain yield in all varieties. Mean grain yield decreased by 16.4, 34.7 and 55.7% respectively with 75, 50 and 25% light intensity. Low light intensity decreased the biomass, which is important in regional fodder security. Early maturing variety had lesser percent reduction in grain yield (1.68%) as compared to the medium (9.5%) and late maturing (29.0%) varieties at low light intensity of 75 % natural light. Therefore, the critical lower limit of light intensity could be nearly 1200 $uMm^{-2}s^{-1}$ for finger millet potential yield. The results obtained in this study also suggests that genotypic variability for low light adaptation of early maturing genotype (GPU-48) can be exploited for intercropping systems in rainfed mango plantations up to 4-5 years.

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1. INTRODUCTION

Finger millet is known for its drought tolerance and; is cultivated in arid and semi-arid regions of more than 25 countries. Finger millet grain has good nutritional composition with protein (7.3%), fat (1.3%), carbohydrates (72.6%), dietary fiber (18%), ash (3.0%), high calcium and leucine contents [1,2,3,4,5,6]. It has high soluble fiber, polyphenols and resistant starch, thus slow hydrolysis of starch and; helpful for diabetic people [7]. In India as a staple food and fodder crop, cultivated in an area of 1.19 million hectares with a production of 1.98 million tones and productivity of 1661 kg ha^{-1}, Karnataka being the major producer to the extent of 58 per cent % [8,9].

More than 90% of finger millet area in India is cultivated as rainfed crop during monsoon season [10] wherein, cloudiness was high during reproductive phase and grain filling period (September to November, 3 Okta) as compared to low cloudiness of 2 Okta during vegetative phase in July and August months, thus reduces incident solar radiation during reproductive phase [11]. Low light intensity is one of the important abiotic limitations to realize the potential yield during monsoon seasons [12,13]. Light is the driving force for chlorophyll synthesis and subsequent photosynthesis, biomass production and grain yield [14]. Low light intensity (cloudiness / shading) affect the spikelet fertility, photosynthetic rate etc. thus decreases the grain yield [15]. Studying the influence of light intensity in finger millet would have practical significance especially as an intercrop in mango orchards of 4-5 years age where shade by the mango plants limits the photosynthesis and productivity. Therefore, the present study, effect of low light intensities (shading) on morpho-physiological parameters and grain yield of finger millet of different duration groups could be pertinent and; provides the information on the extent of reduction in grain yield and suitable crop duration to low light condition.

2. MATERIALS AND METHODS

2.1 Crop Management

Experiment was conducted at the field unit of Department of Crop Physiology, University of Agricultural Sciences, GKVK, Bengaluru situated at 12°58¹ North latitude and 77°35¹ East longitude at an altitude of 930 meter above the Mean Sea Level with red sandy loam soil. The experiment was laid out in split plot design with four light intensity treatments and three varieties in three replications. Each replication had four lines of 1.5 m row length (1.5 m x 1.0 m). The crop was direct sown on 03-08-2007 with the spacing of 22.5 cm between rows and 10 cm between the hills, using three varieties namely, GPU-48 (early maturing variety, 100 days), GPU-28 (Medium maturing variety, 110 days), and L-5 (late maturing variety, 120 days). One seedling per hill was maintained within 15 days after sowing (DAS). Two hand weedings were taken up within 30 DAS. The crop was raised using recommended package of practices for finger millet by applying 50:40:25 kg NPK per hectare in split dose. Entire dose of P, K and half dose of N at the time of sowing and; the remaining 50% N was applied at 45 DAS. Protective irrigations were provided during rain-free period. Once the crop was well established (30 DAS), different light intensity treatments were imposed.

2.2 Treatment imposition

Four light intensities (shading) at the canopy level namely, 100, 75, 50 and 25 per cent in comparison with normal 100 per cent light intensity (1212 uM m^{-2}s^{-1}) were imposed using a structure made of wooden reepers and black polythene strips (Fig. 1). Treatment adoption was, (1) 100% light intensity, open condition, (2) 75% light intensity, by fitting hard black polythene strips, which could resist the breakage against wind (2.5 cm width) leaving the gap of 7.5 cm between the two strips, (3) 50 per cent light intensity, by fixing black strip (5.0 cm width) leaving 5.0 cm gap between two strips and (4) 25 per cent light intensity, fixing two strips of 5.0 cm and 2.5 cm leaving the gap of 2.5 cm in between two black strips. These four treatments provided through structures gave 100, 80, 53 and 33% of natural light intensities at the time of treatment imposition.

2.3 Observations

Observations were made on light intensity at ground level at the time of treatment imposition (30 DAS). At the time of 50% flowering in control

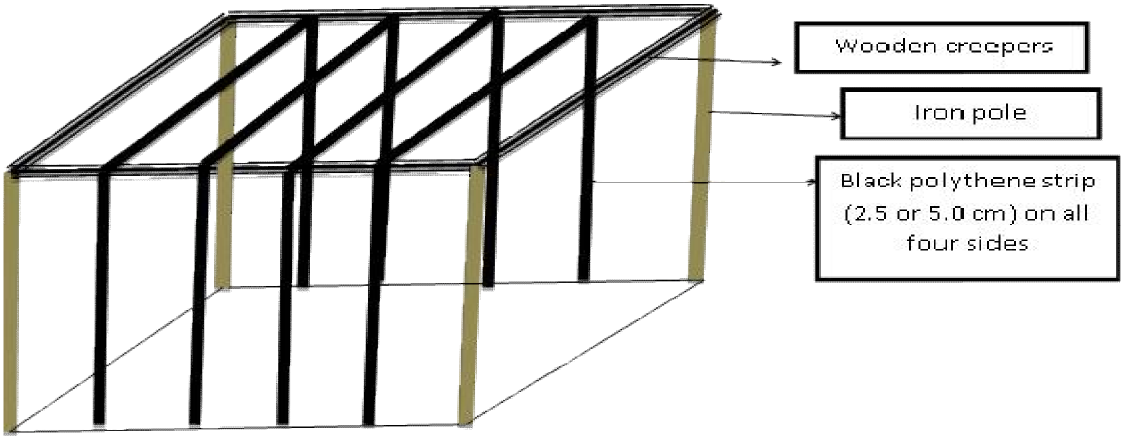

Fig. 1. Diagram showing wooden creeper structure (2 m height) raised in the field to provide different light intensities

treatments, the leaf area (LA) and dry matter (TDM) in 1.5 m row length (mrl) having 15 plants in one of the middle rows of the plot were measured. The leaf area was measured by sampling method, wherein in each replication, 15 leaves were measured for leaf length x leaf width at middle x 0.75 factor to arrive at sample leaf area, these leaves were oven dried to constant weight. Then total leaf area per plant (cm^2 $plant^{-1}$) was arrived by the ratio of sample leaf area divided by it leaf dry weight and; multiplied by total leaf dry weight per plant. The specific leaf weight (SLW, $mg.cm^{-2}$) was calculated as the leaf dry weight divided by its leaf area. The net assimilation rate (DM/LA, $mg.cm^{-2}$) was computed as dry matter per plant at flowering divided by leaf area per plant at flowering. At crop maturity, the grain yield and biomass (earhead weight + straw weight) was recorded in the remaining middle row of 1.5 mrl and; harvest index was computed. The data was statistically analyzed in split plot design.

3. RESULTS AND DISCUSSION

3.1 Condition of the Treatments and Grain Yield

In the structures which were made to provide different light intensities, light transmitted to ground, remained similar (nearly 50%) in all the treatments suggests that all the treatments had relatively similar canopy while imposing the light treatments at 30 DAS (Table 1). Grain yield is the product of total biomass production and its partitioning to reproductive structures [16]. Grain yield was decreased by 16.4, 34.7, and 55.7 percent respectively with light intensity of 75, 50, and 25% of natural light (Table 2). Grain yield was positively and highly correlated with biomass at harvest (r= 0.993**) as compared to the HI (r = 0.629*; Table 3). Similar significant positive relationship between biomass and grain yield has been reported by several researchers [17,18,19,20,21]. The decreased grain yield was due to relatively a higher decrease in biomass as compared to reduction in HI.

3.2 Biomass, Leaf Area and Assimilation Rates

The biomass production at harvest was decreased by 11.0, 29.1 and 47.2% respectively with light intensity of 75, 50 and 25% of natural light (Table 2). The biomass production at a given stage will be determined by the extent of canopy cover, photosynthetic rate, and dry matter produced at flowering stage. The leaf area showed a significant positive relationship with biomass at harvest (r = 0.755**) as well as grain yield (r = 0.740**). Hence, the decreased leaf area with decreased light intensity resulted in decreased biomass and grain yield in all the genotypes / duration groups. The leaf area was reduced by 13.7, 19.5 and 20.3% respectively with light intensity of 75, 50 and 25% of natural light (Table 4). In respect to this, the contribution of LAI towards grain yield was observed to the extent of 69.3% (19) and; the yield was increased up to 6.5 LAI [21], therefore, leaf area plays an important role in determining the grain yield under low light conditions. Low light reduces the leaf expansion rates and delays the complete expansion of leaf, thus decreases leaf area per plant under shade conditions [22]. In the present study, the leaf area was reduced under low light intensities, which might be due to higher allocation of biomass towards stem elongation than to leaves [23]. Furthermore, low light intensity increases the lower leaf senescence, might lead to reduced current photosynthesis with higher respiratory demands [21], this could be the reason for lower leaf area under low light intensities in the present study.

Other factor which influences the biomass production (earhead + straw weight) is the photosynthetic rate (gravimetrically, the net assimilation rate or DM/LA). The photosynthetic rate and net assimilation rate were highly correlated [24,25]. In finger millet, total photosynthesis is contributed not only by the leaves but also the earhead up to 15 to 20 percent [26], of which glumes contributes to 65.7 to 83.0% carbon fixation of the earhead during the grain filling phase [27]. The DM/LA was significantly and positively related to biomass at flowering (r = 0.585*), biomass at harvest (r = 0.605*) and the grain yield (r = 0.624*; Table 3). Similar positive relationship between DM/LA and biomass and grain yield has been reported [19,24]. Such DM/LA was decreased by 6.9, 11.4 and 26.3% respectively with light intensity of 75, 50 and 25% of natural light (Table 4). Low light decreases the chlorophyll content, affect the PS-II activity and ETC of light reactions [14] and photosynthetic rate with high density planting where low light intensity prevails [21,22], therefore, light limits the photosynthetic rate, biomass, and grain yield in finger millet. Furthermore, the light intensity during summer crop was 1365 uMm^{-2}s^{-1} as against the monsoon season light intensity of 1212 uMm^{-2}s^{-1}, however, the photosynthetic rates in both the seasons remained almost similar [28], indicating that, nearly 1212 uMm^{-2}s^{-1} could be critical lower limit below which photosynthetic rate will be decreased [29].

The biomass production at harvest is also dependent on the biomass produced at the time of flowering, because reserved photo-assimilates in the stem would be remobilized to reproductive parts during grain filling. The relationship between biomass at flowering and harvest was positive and significant (r = 0.888**, Table 3). Such biomass accumulation at flowering was decreased by 18.1, 28.8, and 39.1 percent due to reduced light intensity of 75, 50 and 25% of natural light (Table 4). The biomass at flowering was dependent both on leaf area (r = 0.858**) and net assimilation rate (r = 0.585*). Principally these two physiological parameters are important in determining the yield of finger millet under low light conditions.

The biomass at a given stage is also dependent on the plant height, the plant height was increased with decreased light intensity (increased shading), as plant tends to grow towards light. The increased plant height due to stem elongation may lead to storage of assimilates in stem, that mobilized to earhead hence deceased grain yield under low light stress. The specific leaf weight (SLW) is the ratio of leaf dry weight to its leaf area, was decreased progressively with increased shading. SLW was decreased by 6.7, 11.7 and 18.2% respectively with 75, 50 and 25% light intensity. SLW had positive significant relationship with DM/LA, HI, biomass, and grain yield (Table 5). In general, sun leaves will be smaller and thicker with higher photosynthetic rates as compared to shade leaves [22] and low light lead to decreased spikelet fertility and crop yield [15]. Under low light conditions, SLA will be increased to capture light [30], in other words the reciprocate SLW was decreased under low light conditions (Table 5) leading to reduced photosynthesis, biomass and grain yield under low light conditions.

3.3 Harvest Index (HI)

Harvest index is the partitioning of dry matter into the reproductive parts, the earhead. Harvest index was shown to contribute to gain yield of finger millet to the tune of 41 percent (19). In the present study, the relationship of HI towards grain yield was significantly positive (r = 0.629*) and the HI was decreased by 5.1, 7.0 and 16.4% respectively with light intensity of 75, 50 and 25% of natural light (Table 2) and was dependent on DM/LA (r=0.592*). Interestingly, the HI was also related positively to leaf area although not significant (r= 0.382^{NS}; Table 3), suggesting that, both leaf area and assimilation rate are important under low light conditions to determine the biomass and grain yield of finger millet.

Table 1. Light intensities at canopy level and light transmission to ground level (u mol.m^{-2}.s^{-1}) at 30 DAS in finger millet varieties

	Light intensity treatments at canopy level				
Light intensity	**100%**	**75%**	**50%**	**25%**	**Mean**
Light intensity at canopy level	1212	967	647	398	
Light intensity at ground level	579	483	303	218	
Light transmission (%)	52.2	50.1	53.2	45.2	50.2
Variety	**Light intensity at ground level in the crop (u mol.m^{-2}.s^{-1})**				
GPU-48	653	617	310	243	456
GPU-28	502	435	315	216	367
L-5	581	399	283	196	365
Mean	**579**	**484**	**303**	**218**	**396**
	SEm ±	**CD @ 5%**			
Varieties	1.68	4.85			
Treatments	1.93	5.57			
Interaction	3.35	9.66			
C.V. (%)	4.69				

Table 2. Effect of light intensity treatments on yield, biomass and harvest index in finger millet

Variety	**Light intensity (LI) treatments at canopy level**				
	100%	**75%**	**50%**	**25%**	**Mean**
	(a) Grain yield (g per 1.5 m row length of 15 hills)				
GPU-48	110.0	99.3	73.0	49.7	80.8
GPU-28	119.7	108.3	98.0	54.0	95.0
L-5	184.0	130.7	93.3	75.7	120.9
Mean	**134.9**	**112.8**	**88.1**	**59.8**	**98.9**
% Redn. Over 100 % LI	**-**	16.4	34.7	55.7	
	SEm ±	**CD@5%**			
Varieties	3.76	11.0			
Treatments	4.34	12.7			
Interaction	7.52	22.1			
C.V. (%)	13.2				
	(b) Total dry matter at harvest (g per 1.5 m row length of 15 hills)				
GPU-48	200.0	198.8	149.3	118.1	166.6
GPU-28	226.7	207.3	190.3	120.0	186.0
L-5	330.3	267.7	196.8	162.0	239.2
Mean	**252.3**	**224.6**	**178.8**	**133.3**	**197.3**
% Redn. Over 100 % LI	-	11.0	29.1	47.2	
	SEm ±	**CD@5%**			
Varieties	7.75	22.7			
Treatments	8.94	26.2			
Interaction	NS				
C.V. (%)	13.6				
	(c) Harvest index				
GPU-48	0.504	0.497	0.489	0.415	0.477
GPU-28	0.528	0.522	0.515	0.450	0.504
L-5	0.558	0.489	0.474	0.465	0.497
Mean	**0.530**	**0.503**	**0.493**	**0.443**	**0.492**
% Redn. Over 100 % LI	-	5.1	7.0	16.4	
	SEm ±	**CD@5%**			
Varieties	0.006	0.016			
Treatments	0.007	0.019			
Interaction	0.011	0.033			
C.V. (%)	3.97				

Table 3. Correlation between growth and yield attributes across light intensities and varieties of finger millet

Parameter	LA	TDMF	DM/LA	GY	TDMH	HI
SLW	0.452^{NS}	0.791**	0.863**	0.749**	0.738**	0.583*
Leaf area (LA)		0.858**	0.121^{NS}	0.740**	0.755**	0.382^{NS}
Biomass at flowering (TDMF)			0.585*	0.885**	0.888**	0.643*
DM/LA				0.624*	0.605*	0.592*
Grain yield (GY)					0.993**	0.629*
Biomass at harvest (TDMH)						0.629*

Table 4. Effect of light intensity treatments on leaf area, biomass and DM/LA at flowering in finger millet varieties

Variety	Light intensity (LI) treatments at canopy level				
	100%	**75%**	**50%**	**25%**	**Mean**
	(a) Leaf area (cm^2 per 1.5 m row length of 15 hills)				
GPU-48	3756	3319	3353	3312	3430
GPU-28	5101	4452	3728	3190	4118
L-5	5746	4820	4657	5124	5087
Mean	**4861**	**4197**	**3912**	**3876**	**4212**
% Redn. Over 100 % LI	**-**	13.7	19.5	20.3	
	SEm ±	**CD@5%**			
Varieties	290	850			
Treatments	NS				
Interaction	NS				
C.V. (%)	4.69				
	(b) Total dry matter at flowering (g per 1.5 m row length of 15 hills)				
GPU-48	65.5	57.3	53.6	49.9	56.6
GPU-28	91.4	68.7	56.2	42.1	64.6
L-5	92.9	78.5	68.3	60.1	74.9
Mean	**83.3**	**68.2**	**59.3**	**50.7**	**65.4**
% Redn. Over 100 % LI	-	18.1	28.8	39.1	
	SEm ±	**CD@5%**			
Varieties	4.69	13.8			
Treatments	5.42	15.9			
Interaction	NS				
C.V. (%)	14.8				
	(c) DM/LA, Total dry matter/ Leaf area (mg.cm^{-2})				
GPU-48	17.6	17.3	16.4	13.7	16.2
GPU-28	17.7	15.5	15.1	13.1	15.3
L-5	17.1	16.2	15.1	11.8	15.1
Mean	**17.5**	**16.3**	**15.5**	**12.9**	**15.5**
% Redn. Over 100 % LI	-	6.9	11.4	26.3	
	SEm ±	**CD@5%**			
Varieties	NS				
Treatments	0.74	2.17			
Interaction	NS				
C.V. (%)	4.69				

Table 5. Effect of light intensity treatments on plant height and specific leaf weight in finger millet varieties

Variety	**Light intensity (LI) treatments at canopy level**				
	100%	**75%**	**50%**	**25%**	**Mean**
		(a) Plant height at harvest (cm)			
GPU-48	70.8	76.0	82.3	96.8	80.5
GPU-28	84.3	99.5	101.8	111.8	99.3
L-5	74.3	81.5	96.7	109.8	90.6
Mean	**76.4**	**85.7**	**93.6**	**104.8**	**90.1**
% Redn. Over 100 % LI	**-**	12.2	22.5	37.2	
	SEm ±	**CD@5%**			
Varieties	0.35	1.03			
Treatments	0.40	1.18			
Interaction	0.70	2.05			
C.V. (%)	3.55				
		(b) Specific leaf weight at flowering ($mg\ cm^{-2}$)			
GPU-48	5.12	5.04	4.41	4.24	4.70
GPU-28	5.38	4.72	4.62	4.24	4.74
L-5	5.12	4.81	4.78	4.30	4.75
Mean	**5.21**	**4.86**	**4.60**	**4.26**	**4.73**
% Redn. Over 100 % LI	-	6.70	11.7	18.2	
	SEm ±	**CD@5%**			
Varieties	NS				
Treatments	0.07	0.22			
Interaction	NS				
C.V. (%)	4.67				

4. CONCLUSIONS

The lower limit of critical light intensity for potential finger millet yield could be nearly 1200 $uMm^{-2}s^{-1}$. Early maturing variety had only 1.68 percent reduction in grain yield at 75% light intensity. Hence, identification of short duration varieties with higher grain yield could be a better option for intercropping systems.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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