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EFFECT OF LOW LIGHT INTENSITY ON KEY TRAITS AND GENOTYPES OF HILLY RICE (*Oryza sativa*) GERMPLASM

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Yield

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ABSTRACT

Low light intensity stress is a critical abiotic stress that reduces rice yield and quality. Present study has been carried out with a set of hill rice germplasm under ambient light and low light condition. Results related to principal components analysis (PCA) revealed that grain yield, plant height and pollen viability are the most informative components accounted for 63.95 % variance among the genotypes studied under low light condition. The three main traits contributing to PCA was. IRCTN 91-84, IRCTN 91-94 and RCPL 1-9C were found to be the most tolerant genotype to low light intensity under this study.

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1 Introduction

Rice is the most important cereal crop of the Eastern and North-Eastern (NE) regions of India. About 80 % of the rice area in Eastern & NE India is rain-fed and exposed to a variety of abiotic stresses among which, low light intensity is the most prevalent across the entire region. North East India, being a high rainfall area with the mean annual rainfall of 1577 to 6002 mm, with average rainy days of 110 to 120 days (Jain et al., 2012; Ray et al., 2014) experiences cloudy days regularly. The light intensity is an important environmental factor for growth and development of rice. The low incidence of solar radiation coupled with fluctuating light due to over-cast sky during the wet season is one of the major constraints for realizing the high productivity in eastern and north eastern India (Adhya et al., 2008). The world's best rice yielding nations are those that get most astounding solar radiation. Even in India, higher yields are obtained in the north western regions, mainly because of higher radiation (380-460 cal/cm^2/h) than in the peninsular and north eastern (250-350 cal/cm^2/h) regions (Venkateswarlu & Visperas, 1987). Low light (<1000MJ/m^2/day) affects all stages of rice growth and reduces yield by approximately 35%; it induces high tiller mortality at vegetative stage, reduction in spikelet number at reproductive stage and reduction in dry matter production after flowering which drastically affects grain yield (Murty & Sahu, 1987). Generally, plants grown under low light show increased stem elongation, decreased tillering and exhibit wide and thin leaves. Besides, the ratio of leaf area to plant biomass increases with decreased irradiance (Murchie et al., 2005). Further, Pengelly et al. (2005) reported 21% reduction in leaf thickness under low light. Although some low light tolerant varieties like Ajay and Rajalaksmi are reported, so far there is no specific breeding programme (reported) for developing varieties for low light intensity. Tolerance to low light is genetically controlled, but little is known about the genes attributing to the trait.

Yield under stress is an important criterion and can be used as a selection index in breeding for low light intensity tolerance. The rate of yield or biomass reduction by stress (yield under stress as percent of yield under non-stress) is often used as an estimate of resistance in terms of plant production, in addition to absolute yield under stress (Zhang et al., 2015). Further, Venkateswarlu et al. (1987) suggested that in identifying plants less susceptible to low light stress, evaluation of seedlings does not help, because light stress exerts a serious influence only during the reproductive and ripening phases. Low light intensity has been reported to delay grain filling in rice and reduction in rice yield by 27-37% (Yoshida & Parao, 1976). In addition, the fact that sugar reserve during vegetative stage strongly influence grain filling, the influence of light at early vegetative stage (not seedling) may play a significant role in yield under low light.

Among the eastern Indian states, the states in the north eastern hills experience the cloudiest conditions. Therefore, the hill rice genotypes possibly possess better tolerance to low-light intensity than the rice germplasm from the plains. Keeping this in mind, the present study focuses on a systematic evaluation of the promising hill rice germplasm to identify low light tolerant and susceptible contrasting germplasm. In addition, the study also aims at identifying agronomic and physiological traits highly correlated to low light tolerance.

2 Materials and Methods

The present study was carried out in the farm of Plant Breeding, Division of ICAR Research Complex for NEH Region, Umiam, Meghalaya, India during kharif 2014. The light intensity (in lux units) was measured using a luxmeter (TES 1332A digital Lux meter) from both outside and inside the greenhouse three times in a day on a daily basis and later on this was converted to µmol quanta m^{-2} s^{-1}. Plants were grown in plastic pots (diameter 20cm) containing soil and FYM in the ratio of 3:1. All the pots were well watered and required plant protection measures were taken. The experiment was laid out in a strip-plot design with 3 replicates.

One hundred rice genotypes previously screened in the previous study at ICAR-RC-NEH, from which a set of 38 genotypes were used for this study (Table 1). Control set was grown under natural ambient light condition, while Treatment set was grown under 50% shading as suggested by Venkateswarlu & Visperas (1987).

Table 1 List of the 38 rice genotypes studied

Sl. No.	Genotype	Sl. No.	Genotype
1	Ryllo White	20	Calrose
2	Kuki	21	Local Black
3	IRCTN 91-95	22	Kuban 3
4	Mujudo	23	Hua-110
5	Ryllo Red	24	IR-30-3
6	IRCTN 91-57	25	Tangla
7	Abor-B	26	Megha Rice-1
8	Megha Rice-2	27	IRCTN 91-82
9	IRCTN 91-84	28	Mipun
10	Nami	29	Dullo-8
11	Zielum	30	K-332
12	IRCTN 91-66	31	RCPL 1-2C
13	RCPL 1-9C	32	No. 49
14	RCPL-1-8C	33	Kba Rim
15	IRCTN 91-94	34	Niver
16	Tami Hikari	35	Reshim
17	Eiko	36	Mawlong
18	SR-3925-13-1	37	Khonorullo
19	Abor Red A	38	Nonglwai

Shading was maintained from 30 days after seedling until maturity. In each pot 4 seedlings were transplanted and two such pots for each genotype were taken for control and treatment. Three plants from each pot was randomly sampled and used for data recording.

Total number of tillers present in each plant was counted at physiological maturity. Plant height (cm) was measured at harvest from the base of the plant to the tip of the furthest leaf. Canopy temperature depression (CTD) was measured with an infra red thermometer (TES 1326S). Relative chlorophyll content was estimated at booting, heading, and flowering, using chlorophyll content meter (model make CCM-300) and expressed in mg/m^2. The quantity of grain-bearing panicles of each plant was tallied to know the quantity of successful panicles. Spikelet fertility was calculated using the formula,

Spikelet fertility (%) = (Filled grains per plant/ Total grains per plant) ×100

To calculate pollen viability of each genotype, anthers were mildly crushed in 1% potassium iodide solution and observed under the microscope attached with camera (model make).Viable pollen shook up the stain, while nonviable pollens were not stained. Phenological data for booting and flowering was calculated from the date of sowing. Dry weight was taken after oven drying at 70^{o}C for 72h to a constant weight. One hundred grains from each genotype was counted and weighed to calculate seed weight. Total grains in each plant were weighed to determine grain yield per plant. Harvest index was calculated as:

Harvest index (%) = [(Total grain weight)/ (Total grain weight + Shoot dry weight)] x 100

Data analysis was performed using standard statistical procedures like analysis of variance, Pearson correlations coefficients, PCA etc. LSD values among means were tested at 5% significance level.

Principal Component Analysis (PCA) is one of the important tools available, which used for summarizing and describing the inherent genetic variation in crop genotypes. This technique helps in identification of traits that help in distinguishing selected genotypes based on similarities in one or more traits and classify the genotypes into separate groups (Ravikumar et al., 2015). Principle component analysis-was carried out using EXEL Stat software.

3 Results and Discussion

Data regarding the maximum and minimum light intensity during the kharif season in both treatment (inside greenhouse) and control ambient conditions (outside greenhouse) were recorded. The average monthly light intensity received during the growth period (July-November 2014) for both control and treatment is depicted in Figure 1. An analysis of the light data indicated that the highest average light intensity for control and treatment condition was received during the month of November and September, respectively (Figure 1). It was observed that on an average, morning time (around 9 AM) received the highest light intensity.

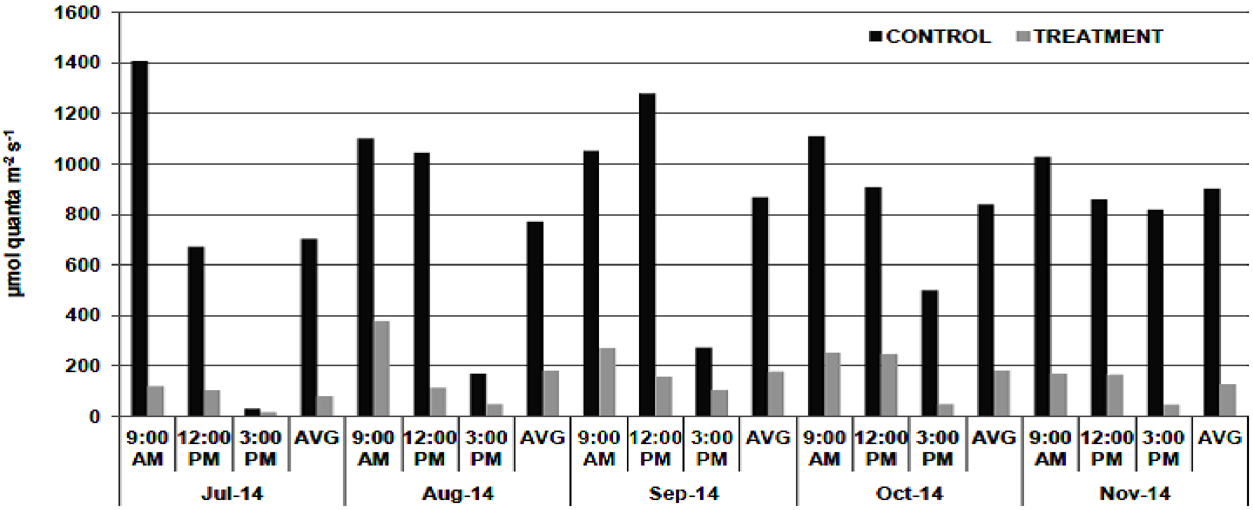


Figure 1 Variation in light intensity (µmol quantam m^{-2} s^{-1} units) during the rice growing period (July-November 2014). Average monthly variation in light intensity under low light and ambient light conditions measured at 9 AM, 12 PM and 3 PM every day

In the present study, with the 38 genotypes during kharif-2014, there was a general increase in plant height under low light condition. There was a general decrease in panicle weight, panicle length, number of effective panicle, spikelet fertility and total grain yield per plant. The 100 grain showed a general decrease in all the genotypes under low light condition and same was the case with harvest index. Grain yield reduction under low light stress was mainly attributed to decreased spikelet fertility and decreased number of grains per panicle. It has been previously suggested that low irradiance treatments in rice significantly diminished grain yield, particularly during the reproductive and ripening phases (Singh, 2005). All the above observations are in confirmative with the previous observations made by Murchie et al. (2005), Liu et al. (2014), Sridevi & Chellamuthu (2015) and Barmudoi & Bharali (2016).

3.1 Analysis of variance and correlation among traits

During kharif-2014, the analysis of variance (Table 2) revealed that there was a presence of considerable variation among the genotypes with respect to all the traits such as panicle weight, biological yield, number of panicles per plant, spikelet fertility, pollen viability, plant height, CTD, seed weight, number of tillers per plant, days to flowering, chlorophyll content and grain yield. Genotypes did not contribute significantly to variation in relative chlorophyll content. Light intensity contributed significantly to variation in all the traits, except harvest index. Similarly, variation due to genotype X light interaction was found to be significant for all the traits, except harvest index, indicating differential response of genotypes to light intensity.

Under low light condition, number of panicles per plant, harvest index, number of tillers per plant and panicle weight had strong positive correlation with grain yield (Table 3). Number of tillers per plant showed significant correlation with number of panicles per plant, biological yield and canopy temperature depression (CTD). Chlorophyll content demonstrated positive correlation with spikelet fertility, seed weight and grain yield. Plant height showed negative correlation with most of the traits mainly grain weight, chlorophyll content, spikelet fertility, canopy temperature depression (CTD) and 100 seed weight. Among them all Number of tillers per plant demonstrated the most elevated level of relationship with Number of panicles per plant. The correlation studies under low light condition suggests that number of effective panicles, number of tillers per plant, panicle weight and harvest index have positive correlation with the grain yield which is confirmative with the findings of Barmudoi & Bharali (2016) in their study. Chlorophyll content showed positive correlation with spikelet fertility and grain yield and this response has also been reported in a previous study (Restrepo & Garcés, 2013).

3.2 Principle component analysis

PCA performed on quantitative traits in this study revealed that the first three most informative components accounted for 58.209 % and 63.952 % variance among the 38 genotypes of hill rice under control and treatment condition, respectively (Table 4). For the first principle component (PC1), Number of panicles per plant (0.44), grain yield (0.43) and biological yield (0.40) were found to be the major contributors under ambient light; whereas grain yield (0.46), Number of panicles per plant (0.43) and Number of tillers per plant (0.39) were the major contributors under low light condition.

Table 2 Analysis of variance of the thirty eight rice genotypes from NEHR India with the traits under study

		PW	BY	EP	SF	PV	PH	CTD	TN	SW	DF	HI	RCC	GY
Source of Variation	**D.f.**	**Mean sum of squares**												
Replication	2	1.17	2.35	20.77	33.42	7.64	327.35	0.77	25.14	0.16	8.11	105319.62	1479.92	50.22
Light	1	25.06*	3367.14**	4272.68**	65032.22**	568.18*	22085.68**	611.85**	5134.75**	21.63*	9227.85**	415644.82	1575.76**	4999.18**
Error(L)	2	0.57	8.81	7.90	123.19	25.10	127.59	4.81	10.08	0.01	8.01	95412.86	226	45.27
Genotype	37	0.69**	42.64*	24.70**	604.53**	456.03**	499.56**	10.97**	25.12**	0.26**	72.86**	16906.89*	1.05	78.62**
GXL	37**	0.37**	80.96**	34.29**	549.53**	305.58**	707.84**	11.32**	36.61**	0.14**	70.44**	8729.43	2637.7**	35.22**
Error(G)	148	0.17	31.53	8.14	240.45	114.90	94.77	5.50	10.89	0.07	3.51	10130.55	2361.65	10.34
TSS	227	0.41	55.63	34.00	632.74	201.84	359.89	9.96	40.09	0.21	66.44	14383.15	997.21	48.16

Abbreviations: * and ** = significant at Pα=0.05 and Pα=0.01, respectively; PW= panicle weight, BY= biological yield, EP= number of effective panicles per plant, SF= spikelet fertility, PV= pollen viability, PH= plant height, CTD= canopy temperature depression, TN= number of tillers per plant, SW= seed weight, DF= days to flowering, HI= harvest index, RCC= relative chlorophyll content and GY= grain yield

Table 3 Pearson correlations coefficients among functional traits under 30% low light conditions

Variables	PW	BY	RCC	EP	SF	PV	PH	CTD	TN	SW	DF	HI	GY
PW	**1**												
BY	0.235	**1**											
RCC	0.339	-0.017	**1**										
EP	0.305	**0.538**	0.138	**1**									
SF	**0.531**	0.083	**0.347**	0.221	**1**								
PV	0.242	0.006	0.011	-0.073	0.155	**1**							
PH	0.225	0.290	-0.200	-0.086	-0.059	**0.354**	**1**						
CTD	0.192	0.235	0.145	**0.457**	0.053	-0.206	**-0.348**	**1**					
TN	0.259	**0.637**	-0.035	**0.896**	0.087	-0.239	0.114	**0.405**	**1**				
SW	-0.232	-0.308	**0.356**	-0.017	-0.046	-0.020	**-0.404**	0.248	-0.179	**1**			
DF	0.020	0.115	-0.159	0.217	0.010	0.079	**0.401**	-0.236	0.308	-0.278	**1**		
HI	**0.563**	-0.076	0.232	**0.392**	0.403	0.185	-0.125	0.124	0.275	-0.079	0.130	**1**	
GY	**0.548**	**0.403**	**0.366**	**0.767**	**0.397**	0.069	-0.160	**0.400**	**0.639**	0.036	0.147	**0.751**	**1**

Correlation coefficients in bold face are significant at 5% level of significance

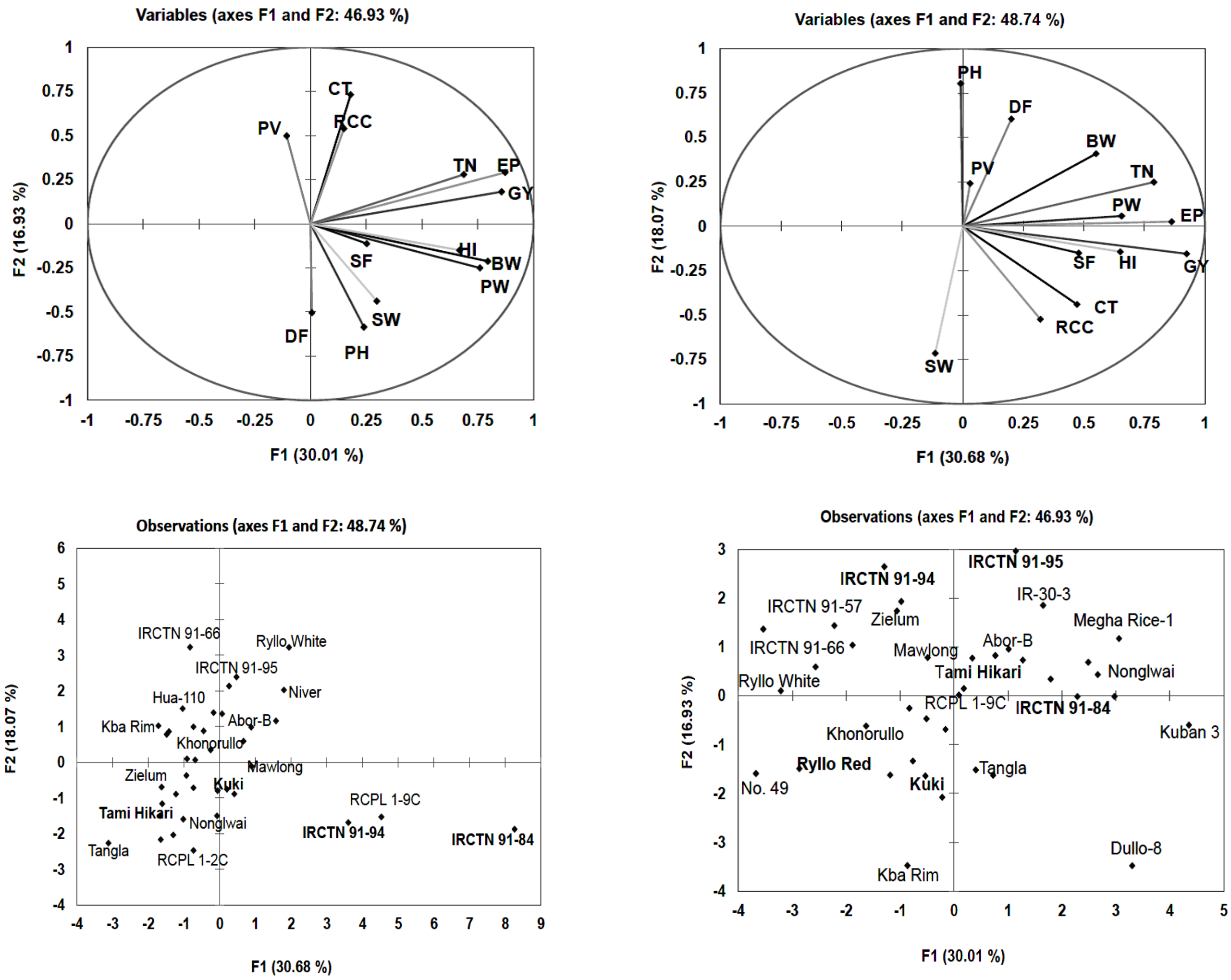
Abbreviations: PW= panicle weight, BY= biological yield, EP= number of effective panicles per plant, SF= spikelet fertility, PV= pollen viability, PH= plant height, CTD= canopy temperature depression, TN= number of tillers per plant, SW= seed weight, DF= days to flowering, HI= harvest index, RCC= relative chlorophyll content and GY= grain yield

Table 4 Principle component analysis (PCA) performed on quantitative traits in this study.

	Ambient light (Control)			**Low light (Treatment)**		
	PC1	PC2	PC3	PC1	PC2	PC3
Eigen value	3.901	2.201	1.466	3.988	2.348	1.977
Variability (%)	30.006	16.927	11.276	30.679	18.065	15.207
Cumulative %	30.006	46.934	58.209	30.679	48.745	63.952
Top 3 traits contributing to PCA	No. of panicles per plant (0.44)	CTD (0.49)	Chlorophyll Content (0.45)	Grain Yield (0.46)	Plant Height (0.52)	Pollen Viability (0.44)
	Grain Yield (0.43)	Pollen Viability (0.33)	Seed Weight (0.43)	No. of panicles per plant (0.43)	Days to Flowering (0.39)	Spikelet Fertility (0.37)
	Biological Yield (0.40)	Chlorophyll Content (0.36)	Spikelet Fertility (0.40)	No. of Tillers per plant (0.39)	Biological Yield (0.26)	Panicle Weight (0.36)

Eigen values and percentage variability explained by the three most informative principal components (PC1, PC2 and PC3) and the top three morphological traits contributing towards them

In the case of PC 2, CTD (0.49) and plant height (0.52) were the major contributors under ambient and low light conditions, respectively. Chlorophyll content (0.45), seed weight (0.43) and spikelet fertility (0.40) were major contributors to PC 3 under ambient condition; whereas pollen viability (0.44), spikelet fertility (0.37) and panicle weight (0.36) were the contributors under low light condition. Previously, principal component analysis indicated that the characters like grain yield per plant, panicle weight, spikelet fertility and biological yield are important characters for distinguishing the tolerant genotypes from susceptible ones. Similar results were found in rice by workers like Rashid et al. (2008), Uga et al. (2003) and Zamira et al. (2003)



CONTROL TREATMENT

Figure 2 Principle component analysis showing the biplot for factor 1 and factor 2 in both control and treatment condition

In this study, PCA indicated that grain yield, Number of panicles per plant, spikelet fertility, plant height and canopy temperature were the major traits in relation to low light intensity. PCA also identified IRCTN-91-84; IRCTN-91-94 and RCPL-1-9C are found as unique genotypes performing better under low light intensity. These genotypes had higher grain yield, higher spikelet fertility and the highest number of effective panicles (Figure 2).

3.3 Performance of genotypes with respect to important traits

In this study low light intensity has a direct effect on number of panicles per plant, and spikelet fertility which finally affects the grain yield. Chlorophyll content also a major trait which response greatly under low light condition.

The results of chlorophyll contents are given in the graph (Figure 3A). In control conditions, Reshim showed the highest relative chlorophyll content (478.5 µmole/m^2) which was followed by Mawlong and IRCTN-91-57; whereas under low light intensity conditions, K-332 showed the highest relative chlorophyll content (461.75 µmole/m^2) followed by Mawlong and IRCTN-91-84, respectively. The lowest relative chlorophyll content was observed in Calrose (330.25 µmole/m^2) and IRCTN-91-86 (373.50 µmole/m^2) under control and treatment conditions, respectively. Previously, it has been suggested that varieties that are tolerant to low light exhibit higher chlorophyll b and lower chlorophyll a/b ratio in their leaves when compared with those that perform poorly in low light (Liu et al., 2014).

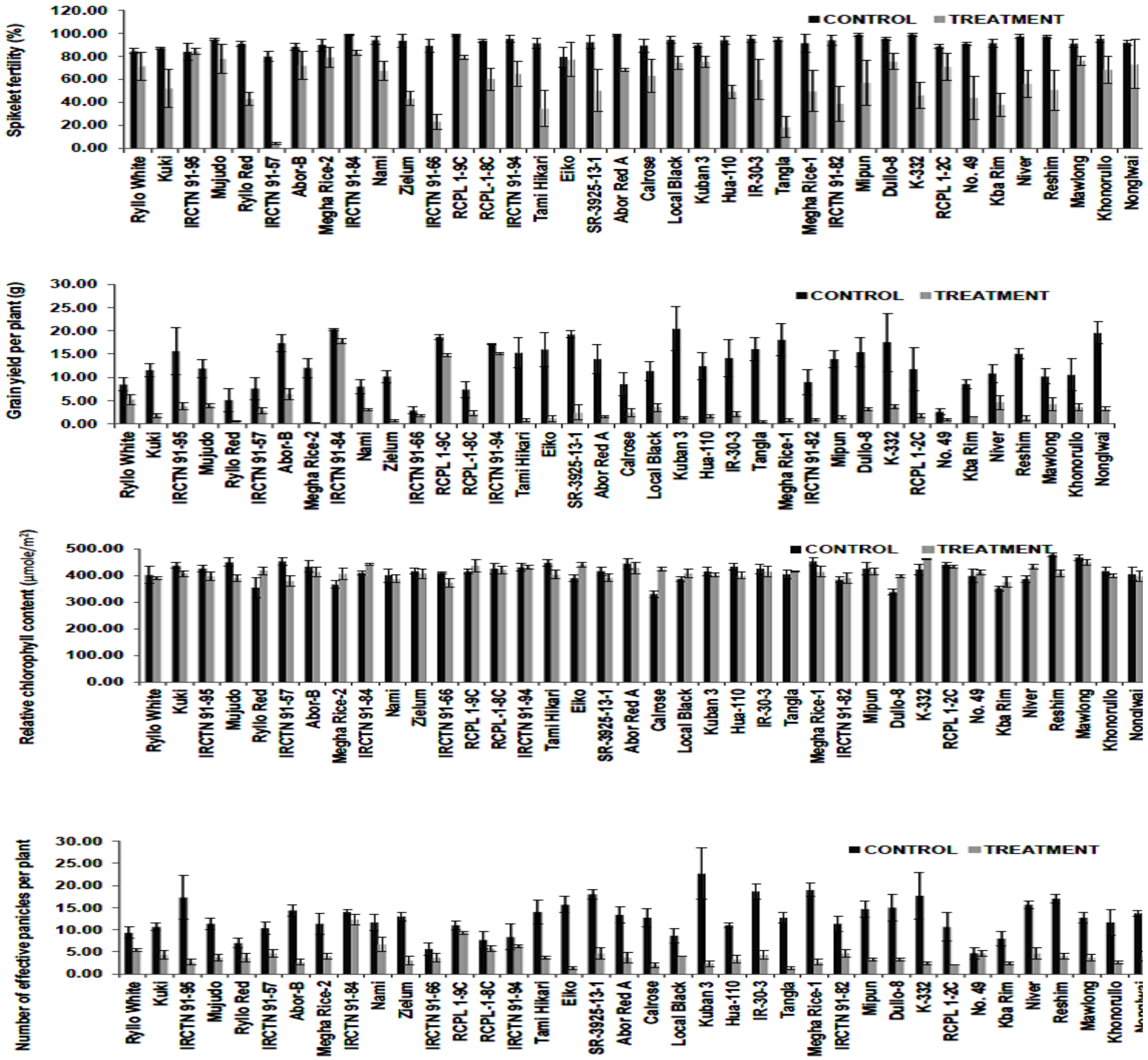


Figure 3 Variation for major trait in a set of different genotypes evaluated under ambient light and low light conditions. Major traits measured were (A) relative chlorophyll content in µmole/m^2, (B) number of panicles per plant (C) spikelet fertility in % and (D) grain yield per plant (in gram).

Under ambient light conditions, Kuban 3 (23) and Megha Rice-1 (19) showed the highest number of effective panicles, whereas Number 49 (5) and IRCTN-91-66 (6) had the least number. In the low light conditions, IRCTN-91-84 (12) and RCPL-1-9C (9) had the highest and Eiko (1), Tangla (1) had the least number of effective panicles (Figure 3B)

Under ambient light conditions, highest spikelet fertility was observed in K-332 (98.87 %), Mipun (98.58 %) and IRCTN-91-84 (98.57 %) whereas Eiko (79.33 %) and IRCTN-91-57 (79.84 %) observed the lowest. Under treatment conditions, IRCTN-91-95 (84.23 %) and IRCTN-91-84 (82.87 %) showed the highest and IRCTN-91-57 (4.13 %) followed by Tangla (18.26 %) showed the lowest spikelet fertility (Figure 3C).

Total grain yield under ambient light was the highest in Kuban 3 (20.43 g) followed by IRCTN-91-84 (20.3 g) and the lowest in Number 49 (2.63 g) followed by IRCTN-91-66 (2.9 g). Whereas, under treatment conditions, the highest total grain yield was found in IRCTN-91-84 (17.80 g) followed by IRCTN-91-94 (15.2 g) and the lowest in Megha Rice-2 (0.30 g) followed by Tangla (0.50 g) (Figure 3D). IRCTN 91-84, IRCTN 91-94 and RCPL 1-9C found to be tolerant genotypes under low light condition. These three genotypes showed lowest reduction in grain yield from ambient light to low light condition (Figure 3D). It has been suggested that solar radiation in tropics is one of the major climatic factors limiting grain yield in rice (Barmudoi & Bharali, 2016).

Pollen viability also found has a good impact on grain yield under low light condition. In this study tolerant genotype IRCTN 91-84 showed less reduction in viable pollen than one of the susceptible genotype Kuki (Figure 4).

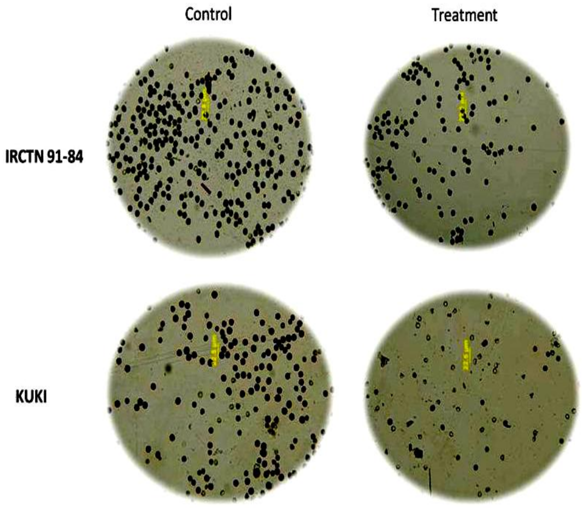


Figure 4 Pollen viability of the genotypes IRCTN 91-84 and Kuki in both control and treatment conditions. Dark spots are viable pollen and while spots are non viable pollen.

Conclusion

The better performing genotypes can be used for further breeding studies, where contrasting genotypes will be used for development of mapping population to identify the chromosomal regions associates with the low light intensity tolerance.

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Conflict of Interest

Authors declare that there is no conflict of interests arising from this study.

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