Plant Archives Vol. 25, No. 2, 2025 pp. 2305-2312 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.329

PHYSIOLOGICAL AND YIELD RESPONSES OF RICE (*ORYZA SATIVA* L.) TO LOW LIGHT STRESS

Veronica N*, T Srinivas and M Girija Rani
Department of Plant Physiology, Regional Agricultural Research Station, Maruteru,
Acharya N. G. Ranga Agricultural University, Andhra Pradesh, India
*Corresponding author E-mail: n.veronica@angrau.ac.in
(Date of Receiving : 17-07-2025; Date of Acceptance : 07-10-2025)

ABSTRACT

Low light stress is an important abiotic constraint affecting rice (*Oryza sativa* L.) growth and productivity, particularly in the areas that experience prolonged cloudy weather during the cropping season. This is mainly a problem in wet season where the light intensities and duration is less. A field experiment was conducted during *kharif* 2024 at Regional Agricultural Research Station, Maruteru using twenty-nine rice genotypes to study the physiological and yield responses in response to reduced light intensity by imposing 50% shading to the plants. Results revealed that low light stress increased the mean days to 50% flowering and days to physiological maturity by 3 days compared to control. Plant height also increased under low lights stress. Significant reduction in yield and yield components was noted among the genotypes. The panicle number decreased by 9%, while grain number per panicle dropped by 19.3% under stress. Mean 1000-grain weight declined from 18.8 g to 16.9 g and grain yield was reduced by 22%, i.e., from 564 g/m² in control to 440 g/m² under stress. However, genotypes such as Swarnaprabha, IET 32176, and Ratnagiri-8 recorded comparatively higher yields and lower yield reductions (<10%), while Pooja, Karjat-3, and IR8 exhibited severe yield losses (>35%). Total dry matter and harvest index reduced under low lights stress and it was lesser in stress-tolerant genotypes. Under low light stress, chlorophyll a decreased, while chlorophyll b and Total chlorophyll content increased. Genotypes such as Ratnagiri-8, IET 32176 and Swarnaprabha retained a higher total chlorophyll level under low light stress. Overall, the promising rice lines with superior physiological efficiency and yield stability identified can serve as potential donors for breeding programs aimed at developing low light–tolerant rice varieties.
***Keywords* :** Rice, biomass, chlorophyll content, low light, yield.

Introduction

Rice (*Oryza sativa* L.) is a staple cereal food for more than half of the global world population. The productivity of rice is highly influenced by genotype and environmental factors, of which light availability plays a pivotal role (Khush, 2013). Light is the primary energy source needed for photosynthesis that is essential for biomass accumulation that leads to assimilate partitioning and ultimately grain yield. Rice is grown over a range of ecosystems but however, in many rice-growing regions, particularly during the monsoon season or the wet season the crop is subjected to a dense cloud cover, leading to lower availability of light that leads to stress causing significantly impaired growth and yield in the plant (Hao *et al*., 2016). It has been reported that rice requires 1500 bright sunshine (BSS) hours for the period from transplanting to maturity (Suvendhu *et al*., 2017). So reduction in the BSS would result in hampering of the crop in terms of economic yield which is of prime importance to the farmers.

Low light has a negative impact on the growth and productivity of the crop. Low light conditions affect multiple physiological processes, like reduction in the growth, delayed phenology, reduction in photosynthetic rate, changes in the chlorophyll content, reduced dry matter accumulation and reduced sink capacity ultimately leading to reduced grain yield as well as quality (Liao *et al*., 2023). Low light conditions reduces spikelet fertility, panicle number, and 1000-grain weight, contributing to 20–50% yield losses depending on growth stage and genotype (Guo *et al*., 2024; Liu *et al*., 2009). Altered antioxidant activity due to oxidative imbalance also is one of the impact the plants suffer under low light (Liu *et al*., 2014).

Keeping in view increasing occurrences of prolonged cloudy periods and the changing climate scenario this abiotic stress is expected to intensify, posing a serious threat to food security. Previous studies on abiotic stresses have highlighted wide genotypic variability in rice, which offers opportunities for breeding stress-resilient varieties. Moreover, in case of low light stress integrating physiological traits such as chlorophyll retention, efficient photosynthetic capacity and yield stability can serve as critical selection indices. Evaluating the physiological and yield responses of rice under low light stress is thus crucial for identification of tolerant genotypes. This study aims to investigate these responses across diverse rice genotypes, with a focus on chlorophyll content, phenology and grain yield and yield components. Identification of such genotypes and incorporating them in breeding programmes targeted for development of low light tolerant genotypes is needed in the future.

Material and Methods

Field study

Plant material: A field experiment was conducted during *Kharif* 2024 at Regional Agricultural Research Station, Maruteru, using twenty-nine rice genotypes. The list of genotypes along with their designations was presented in Table 1. Nursery was maintained for 25 days then the seedlings were transplanted into the main field in two separate sets. One set served as the control, while the other was subjected to low light stress conditions. The experiment was laid out in a split-plot design with three replications, maintaining a spacing of 20 × 15 cm. The recommended fertilizer dose of nitrogen, phosphorus, and potassium (90:60:60 kg ha^{-1}) was applied. All other standard agronomic practices for irrigated transplanted rice were followed throughout the experiment.

Imposition of stress: Low light stress was imposed one month after transplanting by erecting 50% shade net supported by bamboo poles in one set of genotypes. The light intensity during the cropping season was measured three times using Lux meter. The crop was left under low light conditions until maturity.

Experiment details*:* The experimental data pertaining to morpho-phenological, physiological and yield parameters was recorded both under treatment as well as control.

Morpho-phenological parameters: The number of days taken from sowing till 50% of plants flowered in each plot for every genotype was noted as days to 50% flowering and was expressed in days. Similarly, the number of days taken to attain physiological maturity was noted and expressed as days to maturity. Plant height was recorded at flowering stage with a scale and was measured from the base of root shoot junction till the tip of leaf/panicle.

Chlorophyll content: Biochemical estimation of pigment content was done in flag leaf at reproductive stage (1 week after anthesis). Flag leaf was collected and cut into small pieces and 25 mg of leaf sample was weighed and placed in 80% acetone solution as per the methodology described by Porra *et al*., (1989). The absorbance of the chlorophyll solution was measured using a UV-VIS spectrophotometer. Chlorophyll a and chlorophyll b were measured at 663.2 nm and 646.8 nm respectively and the chlorophyll content was expressed in mg g^{-1} fresh weight (mg g^{-1} FW). Chlorophyll a content, chlorophyll b content and the total chlorophyll content was calculated according to Lichtenthaler and Wellburn, (1983).

Harvest parameters*:* Yield and yield attributes such as panicle number /m^2, grain number per panicle, 1000 grain weight, grain yield, total dry matter and harvest index were recorded. At physiological maturity, from a demarcated area of one square meter panicles were collected and number of panicles were counted and expressed as panicle number /m^2. Later they were threshed, cleaned and the weight of grains was recorded and expressed as grain yield in g/m^2. Five panicles were selected at random in every genotype and all the spikelets were separated from the panicle and filled grains were further separated and expressed as grain number per panicle. A sample of 1000 seeds at random were taken from every genotype under both the conditions and weighed in gm. After harvest the shoot was dried and shoot biomass was recorded. The ratio of economic yield to total biological yield x 100 was computed as harvest index and expressed in %.

Statistical analysis: Two-way analysis of variance (ANOVA) was performed using Statistix 8.1 package. Statistical significance of the parameter means was determined by performing Fisher's LSD test to test the statistical significance.

Results and Discussion

Morpho-phenological parameters

The mean days to 50% flowering increased by 3 days under low light stress treatment with compared to control. It increased from 100 to 103 days. The maximum increase was in IET 32124, IET 3212, IET 31220 and CR-6456-1 by 4 days. In other varieties the increase varied from 1-3 days (Table 2). Similarly, the mean days to maturity increased by 3 days. Maximum increase in number of days was seen in IET-31246, CR-6456-1 and CR Dhan 801 (6 days) and IET-32176, IET-33264, Rajendra Sweta, Ratnagiri-8 and in Swarnaprabha the difference was of 1 day only (Table 2). There was an increase in plant height under low light stress. The mean plant height increased by 4 cm. Maximum increase in plant height was recorded in IET 33263 (9 cm) and minimum Swarnaprabha (1 cm) (Table 2).

Grain yield and yield attributes

Low light resulted in reduction of grain yield and yield attributes in Rice. There was a significant reduction in panicle number under low light stress. The mean reduction of all the genotypes was 9.0% under low light stress. Under low light, higher number of panicles number/m^2 was noted in IET 31220 and Swarnaprabha (429). Lowest was noted in Rajendra Sweta (308) and CR Dhan 801 and IET 32176 (341) (Table 3). The mean grain number per panicle dropped from 144 to 116 under low light stress i.e., by 19.3%. Under stress, higher number of grain number per panicle was noted in IET 32176 (179), IR8 (167), IET-3212, IET 32121 and IET 31220 (143). Lowest was in IET 32150, Karjat-3 (74) followed by IET 33262 (76) (Table 3). The mean 1000 grain weight reduced from 18.8 g in control to 16.9 g under low light stress conditions. Highest 1000 grain weight was noted in Pooja (22.1 g), IET 33264 (21.3 g) and IET 32121 (20.6 g) under low light while lowest test weight was noted in IET 32111 (11.3 g) (Table 3).

The mean grain yield reduced from 564 g/m^2 to 440 g/m^2. Maximum grain yield under low light stress was noted in Swarnaprabha (573 g/m^2), IET 32176 (560 g/m^2) and Ratnagiri-8 (548 g/m^2). The grain yield was lowest in IR 8 (258 g/m^2), Karjat-3 (292 g/m^2) and Pooja (330 g/m^2) (Table 4). The reduction percentage of grain yield under low light was below 10% in Ratnagiri-8, IET-32176, Swarnaprabha and IET 32150. It was above 35% in Pooja, Karjat-3 and IR8. The total dry matter at harvest reduced from 773 g/m^2 in control to 677 g/m^2 under low light stress. Highest total dry matter was recorded in IET 32150 (837 g/m^2) followed by Swarnaprabha (823 g/m^2) under stress. Lowest total dry matter was recorded in Karjat-3 (466 g/m^2) and Pooja (536 g/m^2) (Table 4). Harvest index dropped from 42.2% to 39.6%. Lesser reduction in harvest index was noted in IET-32176 (0.9%), IET 32123 (1.5 %), Swarnaprabha and IET 31246 (3.1%). On the other hand, higher reduction in harvest index was noted in Pooja (15.0) followed by Karjat-3 (13.0%) (Table 4).

Chlorophyll content (mg/g FW)

The mean content of chlorophyll a dropped from 2.84 to 2.58 mg/g FW under low light stress. Higher chlorophyll a content under low light stress was noted in Ratnagiri-8 (3.2 mg/g FW) followed by IET 32176 (2.84 mg/g FW) and Swarnaprabha (2.77 mg/g FW). Lowest chlorophyll a content was noted in IET 33262 (2.09 mg/g FW) (Fig 1a).

There was an increase in the mean content of chlorophyll b from 0.95 mg/g FW in control to 1.39 mg/g FW under low light stress. Majority of the genotypes showed an increased chlorophyll b response under low light stress. Ratnagiri-8 (1.72 mg/g FW) followed by IET 32176 (1.53 mg/g FW) and Swarnaprabha (1.49 mg/g FW) retained higher chlorophyll content under low light stress. These genotypes also had an increase in chlorophyll b under low light stress. Lowest chlorophyll b content was recorded in IET 33262 (1.13 mg/g FW) and IET 32146 (1.14 mg/g FW) (Fig 1b).

The mean total chlorophyll of all the tested genotypes increased from 3.78 to 3.97 mg/g FW under low light stress. Higher chlorophyll content was noted in Ratnagiri-8 (4.92 mg/g FW) followed by IET-32176 (4.37 mg/g FW) and Swarnaprabha (4.26 mg/g FW). Lowest was noted in IET-33262 (3.22 mg/g FW) and IET 32146 (3.26 mg/g FW) (Fig 1c).

Low light stress in rice results in delay in days to 50% flowering and maturity, the reason being that as plants under low light need more time to accumulate the thresholds of carbohydrates and hormonal signals for reproductive transition. Recent study by Nirala *et al*. (2024) in early, medium, and late rice genotypes all showed delayed 50% and 100% flowering and maturity under low light, along with increased plant height. Increase in plant height is mainly due to increase in the internodal length and an increased mean plant height was also reported in rice by Veronica and Ramana Rao, (2023). Elongation generally helps the plant to get better light but may become susceptible to lodging.

Low light reduces the rice grain yield by disrupting photosynthetic rate as well as assimilate partitioning that results in reduction of spikelet number, grain-filling and 1000-grain weight. Nirala *et al*. (2014) in his study in rice noted reduction in panicle number and 1000 grain weight. Reduction in grains per panicle and spikelet fertility due to limited assimilate supply from source to sink has also been reported by Liao *et al*. (2023). Impairment in translocation of photosynthates under low light ultimately hampers the sink filling efficiency, thereby lowering grain yield. Liao *et al*. (2023), who demonstrated that shading after heading stage reduced dry matter accumulation, grain filling, and test weight, ultimately leading to poor yield performance. Similarly, ~25–40% yield losses due to low light during reproductive stages, primarily linked to impaired dry matter remobilization and reduced sink capacity was reported by Guo *et al*. (2024).

Ma *et al*. (2023) reported yield loss of 26.1% to 34.11%, which correlated with reductions in dry matter and grain number per panicle in their study on shading after heading stage in rice. Genotypic differences were clearly observed in the present study, with varieties such as Swarnaprabha, IET 32176, and Ratnagiri-8 recorded comparatively higher yields and lower yield reductions (<10%), while Pooja, Karjat-3, and IR8 exhibited severe yield losses (>35%). They also had a better panicle number, higher 1000-grain weight and lesser reduction in harvest index. It implies that these genotypes possess intrinsic mechanisms that enable them to withstand low light conditions.

Under low light stress, chlorophylls play a critical role as they enhance light-harvesting efficiency by adjusting the balance between chlorophyll *a* and *b*, thereby optimizing energy absorption for photosynthesis when light availability is limited (Yamori, 2016). Chlorophyll a content reduction under less light intensity occurs mainly due to suppressed synthesis of chlorophyll a, the primary pigment responsible for capturing light energy and driving photosystem II activity (Lichtenthaler & Buschmann, 2001) thereby limiting PSII activity and carbon assimilation. It was reported that an exposure to 15d of low light stress in rice when imposed from initial heading stage the varieties that were tolerant to low light stress retain higher chlorophyll b (Zhu *et al*., 2008). In the study, the tolerant genotypes also maintained a higher chlorophyll b content. Similarly, an increase of 20–30% in chlorophyll b under low light stress were observed by Hao *et al*. (2016), who attributed this as a trait of shade acclimation, where the plant enhances its light harvesting in the blue spectrum to improve efficiency under weak light intensity conditions. Liao *et al*. (2023) reported that the total chlorophyll increasing by 1.68–29.70% compared with control.

Conclusion

Low light stress adversely affects phenology, yield components and grain productivity in rice, though genotypes vary widely in their response. In the present study, genotypes such as Ratnagiri-8, IET 32176, and Swarnaprabha exhibited superior performance by maintaining higher chlorophyll levels and having higher grain yield with minimal yield reductions under low light that emphasizes on their potential as donors for developing low light–tolerant rice varieties.

Table 1: List of genotypes utilised in the experiment

S.No	Genotype
1	CR Dhan 801
2	CR-6456-1
3	IET-31204
4	IET-31220
5	IET-31237
6	IET-31246
7	IET-32121
8	IET-3212
9	IET-32123
10	IET-32124
11	IET-32130
12	IET-32134
13	IET-32146
14	IET-32150
15	IET-32175
16	IET-32176
17	IET-33261
18	IET-33262
19	IET-33263
20	IET-33264
21	IR 8
22	Karjat-3
23	Pooja
24	Pooja (ZC)
25	Rajendra Sweta
26	Ratnagiri-8
27	IET 32111
28	Swarnaprabha
29	IET 32112

Table 2: Effect of low light stress on morpho-phenological traits in rice genotypes.

Genotype	Days to 50% flowering			Days to maturity			Plant height (cm) (at flowering)		
	C	LLS	Mean	C	LLS	Mean	C	LLS	Mean
CR Dhan 801	96	99	97	127	133	130	149	152	151
CR-6456-1	98	102	100	129	135	132	137	141	139
IET-31204	92	95	93	122	127	124	147	153	150
IET-31220	106	110	108	136	141	139	153	159	156
IET-31237	100	103	102	131	133	132	126	128	127
IET-31246	95	98	97	125	131	128	142	147	144
IET-32121	106	108	107	136	139	137	157	163	160
IET-3212	111	115	113	140	144	142	147	152	149
IET-32123	102	104	103	133	135	134	128	133	131
IET-32124	101	105	103	132	137	135	119	127	123
IET-32130	92	93	93	122	124	123	138	141	140
IET-32134	95	97	96	127	130	128	144	147	146
IET-32146	100	103	101	130	133	131	153	158	156
IET-32150	97	100	99	126	130	128	113	119	116
IET-32175	100	102	101	129	132	130	108	112	110
IET-32176	101	102	101	131	132	132	148	150	149
IET-33261	101	103	102	130	133	131	174	177	176
IET-33262	101	104	103	132	136	134	128	132	130
IET-33263	98	100	99	128	130	129	158	167	162
IET-33264	99	100	100	129	130	130	121	123	122
IR 8	98	100	99	128	131	129	144	148	146
Karjat-3	107	109	108	137	139	138	154	156	155
Pooja	96	98	97	127	129	128	155	159	157
Pooja (ZC)	108	111	110	137	139	138	148	154	151
Rajendra Sweta	109	110	110	139	140	140	139	144	142
Ratnagiri-8	109	110	109	137	138	138	141	148	145
IET 32111	96	98	97	124	129	127	120	124	122
Swarnaprabha	97	98	98	127	128	127	123	124	123
IET 32112	98	99	99	128	130	129	132	136	134
Mean	**100**	**103**		**130**	**133**		**140**	**144**	
LSD (T)	0.19			0.29			0.97		
LSD (V)	0.73			1.12			3.67		
LSD (TxV)	1.04			1.58			5.20		
CV (%)	0.63			0.74			2.27		

Table 3: Impact of low light stress on yield and yield attributes in rice genotypes

Genotype	Panicle number /m^2			Grain number per panicle			1000 grain weight (g)		
	C	LLS	Mean	C	LLS	Mean	C	LLS	Mean
CR Dhan 801	407	341	374	137	111	124	22.1	19.8	21.0
CR-6456-1	418	352	385	146	122	134	15.4	13.8	14.6
IET-31204	418	385	402	136	118	127	18.6	16.3	17.5
IET-31220	451	429	440	175	143	159	22.0	20.4	21.2
IET-31237	451	418	435	169	133	151	18.1	16.1	17.1
IET-31246	418	385	402	128	94	111	20.3	18.8	19.6
IET-32121	462	374	418	170	143	157	20.7	20.6	20.6
IET-3212	418	385	402	179	143	161	18.1	17.0	17.5
IET-32123	418	385	402	155	123	139	17.3	15.1	16.2
IET-32124	429	396	413	163	125	144	19.0	16.3	17.7
IET-32130	418	396	407	114	93	104	22.2	19.0	20.6
IET-32134	418	374	396	109	93	101	21.4	18.7	20.1
IET-32146	440	396	418	165	132	149	22.2	18.5	20.3
IET-32150	451	418	435	97	74	86	19.0	17.1	18.1
IET-32175	440	396	418	114	98	106	19.0	17.2	18.1
IET-32176	418	341	380	226	179	202	16.4	15.5	16.0
IET-33261	407	396	402	155	123	139	19.3	17.9	18.6

IET-33262	429	418	424	97	76	87	15.5	13.9	14.7
IET-33263	429	407	418	131	108	119	17.4	14.2	15.8
IET-33264	429	418	424	144	120	132	22.1	21.3	21.7
IR 8	418	363	391	208	167	187	17.2	15.1	16.2
Karjat-3	440	407	424	99	74	87	20.4	18.1	19.3
Pooja	429	396	413	193	141	167	18.8	15.1	16.9
Pooja (ZC)	451	396	424	135	115	125	23.0	22.1	22.6
Rajendra Sweta	407	308	358	174	137	156	13.6	11.9	12.8
Ratnagiri-8	418	407	413	113	99	106	21.1	20.5	20.8
IET 32111	385	352	369	152	123	137	13.0	11.3	12.1
Swarnaprabha	440	429	435	111	97	104	12.8	12.0	12.4
IET 32112	385	363	374	97	79	88	18.1	16.0	17.0
Mean	**426**	**387**		**145**	**117**		**18.8**	**16.9**	
LSD (T)	9.0			2.55			0.08		
LSD (V)	34.0			9.72			0.08		
LSD (TxV)	48.0			13.7			0.45		
CV (%)	7.26			6.5			1.55		

Table 4: Impact of low light stress on yield and yield attributes in rice genotypes

Genotype	**Grain yield (g/m^2)**			**Total Dry Matter (g/m^2)**			**Harvest Index (%)**		
	C	**LLS**	**Mean**	**C**	**LLS**	**Mean**	**C**	**LLS**	**Mean**
CR Dhan 801	564	441	502	800	684	742	41.3	39.2	40.3
CR-6456-1	531	391	461	688	603	646	43.4	39.3	41.4
IET-31204	608	456	532	810	669	740	42.9	40.4	41.7
IET-31220	555	425	490	773	666	719	41.8	38.9	40.4
IET-31237	619	490	555	828	715	772	42.7	40.7	41.7
IET-31246	582	452	517	807	658	733	42.0	40.7	41.3
IET-32121	526	377	451	733	596	665	41.9	39.4	40.6
IET-3212	592	455	524	817	680	749	42.2	40.1	41.1
IET-32123	550	441	496	782	644	713	41.2	40.6	40.9
IET-32124	563	452	508	772	665	719	42.3	40.4	41.4
IET-32130	537	415	476	722	684	703	42.4	37.9	40.1
IET-32134	523	391	457	695	586	641	42.9	40.1	41.5
IET-32146	564	438	501	817	696	756	40.9	38.6	39.8
IET-32150	560	544	552	803	837	820	40.9	39.3	40.1
IET-32175	561	494	528	704	657	681	44.1	42.2	43.2
IET-32176	603	560	581	809	773	791	42.6	42.2	42.4
IET-33261	543	452	497	754	670	712	41.9	40.2	41.1
IET-33262	568	371	470	766	596	681	42.6	38.4	40.5
IET-33263	550	404	477	754	672	713	42.1	37.6	39.9
IET-33264	585	521	553	748	730	739	43.9	41.8	42.8
IR 8	531	258	394	738	701	719	41.8	39.6	40.7
Karjat-3	564	292	428	720	466	593	43.9	38.2	41.1
Pooja	571	383	477	745	655	700	43.4	36.9	40.1
Pooja (ZC)	527	330	429	781	536	658	40.3	38.2	39.3
Rajendra Sweta	545	460	503	792	711	752	40.8	39.3	40.0
Ratnagiri-8	594	548	571	788	788	788	43.0	41.1	42.0
IET 32111	619	474	546	871	743	807	41.5	39.0	40.3
Swarnaprabha	616	573	595	833	823	828	42.4	41.1	41.8
IET 32112	531	458	495	756	736	746	41.3	38.2	39.8
Mean	**565**	**440**		**773**	**677**		**42.2**	**39.6**	
LSD (T)	21.0			28.0			0.63		
LSD (V)	78.0			105			2.38		
LSD (TxV)	111.0			149			3.37		
CV (%)	13.5			12.6			5.08		

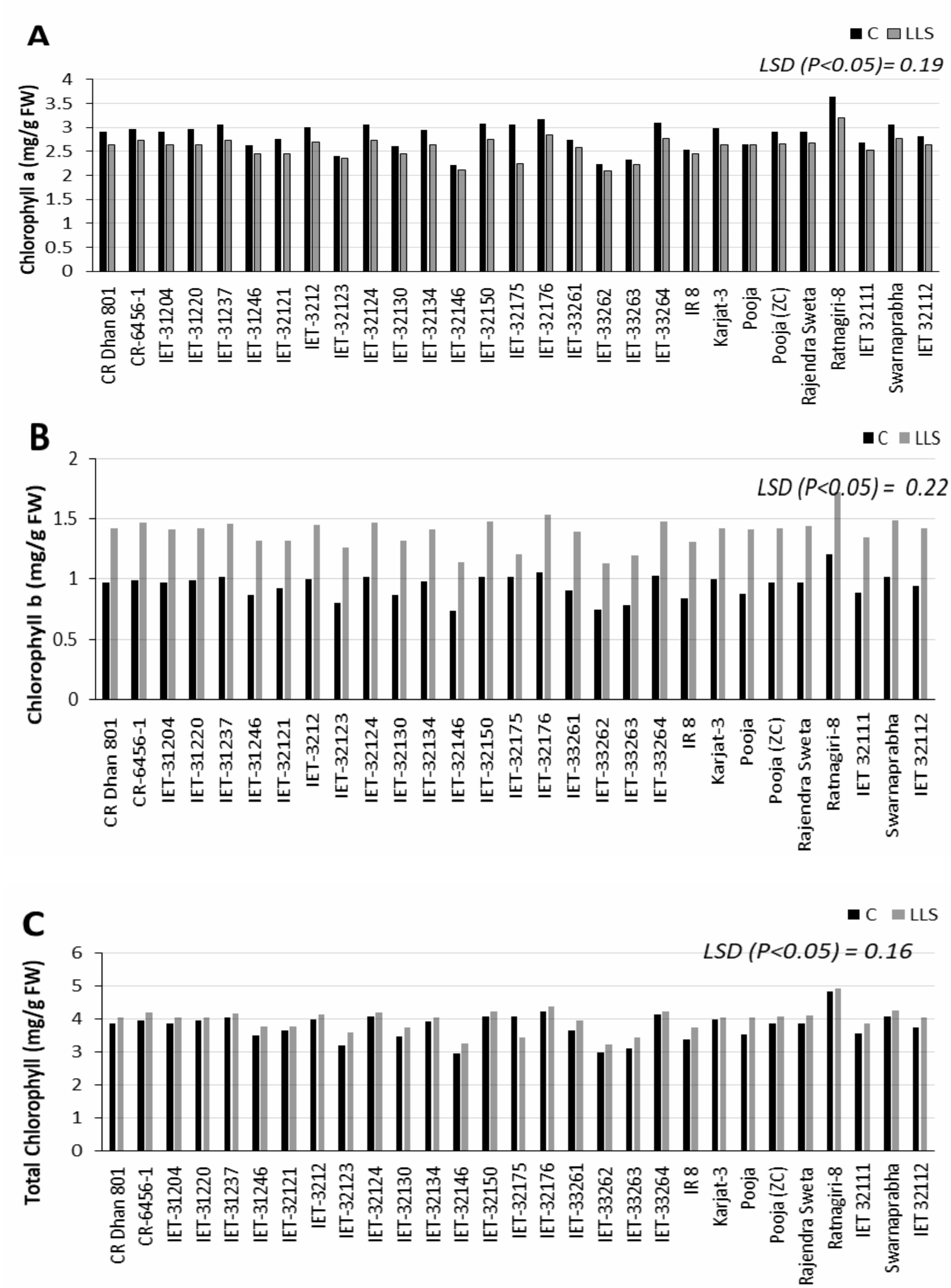

Fig. 1: Impact of low light stress on chlorophyll content in rice genotypes

Acknowledgement: This experiment is a part of AICRIP programme. So ICAR- AICRP for providing material for the experiment is highly acknowledged

Conflict of interest: The authors declare that they have no conflict of interest

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