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PHENOTYPIC PLASTICITY IN TROPICAL IRRIGATED RICE CULTIVARS UNDER LOW LIGHT AND NITROGEN SUPPLEMENTATION

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Introduction

The environment-induced variation in plant phenotype defines phenotypic plasticity (PP), which is the ability of a specific genotype to present multiple phenotypes in response to the environment (Pennacchi et al., 2021). One approach to quantifying the plant's acclimatability in relation to the environment is to estimate it through indices. The multivariate plasticity index (MVPi), proposed by Pennacchi et al. (2021), is an integrative index for analyzing PP in the context of a systemic assessment of phenotypic traits (Garcia et al., 2021). Evaluating the PP is a crucial strategy to understand the mechanisms of adjustment of the functional characteristics of the genotypes in environments with climate change.

Solar radiation deficit in the tropical environment is one of the main climatic factors that interfere with rice yield (Barmudoi and Bharali, 2016). Low light during plant development can cause stress and limit production (Li et al., 2020). The reproductive phase, especially the grain-filling stage, is more impacted by low light in irrigated rice (Santos et al., 2017). Factors such as photosynthetic pigment synthesis and non-structural carbohydrate (soluble carbohydrates and starch) content are influenced by light limitation in the rice-growing environment (Li et al., 2020). In low-light environments, smaller amounts of nitrogen (N) are allocated to panicles compared to those under natural light (Liu et al., 2014). Therefore, a strategy to compensate for the damage caused by light limitation would be to increase N supplementation. Studies report that N supplementation can mitigate the negative effects of low light on the total accumulation of nutrients, number of tillers, grain mass per panicle, and yield (Pan et al., 2016; Wei et al., 2018).

Another way to deal with low light effects is using tolerant genotypes, which show less yield reduction under these conditions (Panda et al., 2019). Markers and genes associated with morphophysiological changes in rice genotypes have been described for low light tolerance (Dutta et al., 2018). Low-light tolerance in different environments is attributed to varieties with higher efficiency in light capturing and using, leaf area, pigments content, osmotic regulation and oxidative protection (Restrepo and Garcés, 2013; Liu et al., 2014).

Thus, a comprehensive understanding of the complex interactions under low light conditions is essential, particularly in the context of climate change. The study tested the hypothesis that increased nitrogen supplementation enhances the phenotypic plasticity and acclimatization of rice cultivars under light-limited environments. The present study aimed to evaluate the multivariate plasticity index for tropical irrigated rice cultivars under N rates in a low light environment.

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Material and Methods

The study was conducted in 2021/2022 at Goianira, GO, Brazil. The experiment evaluated BRS CATIANA and IRGA 424, two major irrigated rice cultivars widely grown in Brazil over the past decade. Days after transplant (DAT) were calculated from 15 days after emergence in trays. Seedling transplantation was carried out in December 2021. The irrigation was applied by flooding, with a fixed water depth of 10 cm. Nitrogen cover fertilization (50 or 180 kg ha^{-1} of N) was split in three stages, according to technical recommendations: at V2 and V3 phases of initial development, and in V6 phase (end of tillering). The N source used was urea. At the beginning of flowering (R4), half of the experimental plots were submitted to shading (70% of natural radiation) until physiological maturation. This 30% shading was achieved by using a black 30% high-density polyethylene (HDPE) (SOLPACK, Brazil).

The flag leaf length (FLL) and flag leaf width (FLW) were obtained from the average value of measurements in ten plants in each plot at 101 DAT. The flag leaf area (FLA) was calculated by the product of the length and width of the flag leaf, using 0.75 as a correction factor. The Falker Chlorophyll Index (FCI) was measured in the plants at the same period using the electronic chlorophyllometer ClorofiLOG® (CFL 1030, Falker). In each plot, three readings of chlorophyll a (CHLA), b (CHLB) and total (CHLT) were performed in the median region of fully expanded flag leaves, to calculate the average value. Values were expressed as dimensionless FCI, proportional to values measured in the laboratory (Falker, 2008).

The soluble carbohydrate content in leaves (CCL) and stems (CCS) was determined by the phenol-sulfuric method proposed by Dubois et al. (1956). For the calculation, a standard curve elaborated with aqueous solutions of D-glucose was used, and the results were expressed in mg of soluble carbohydrates g^{-1} dry matter (DM). The starch in leaves (SCL) and stems (SCS) was extracted from the plant material after exhaustive extraction, according to Amaral et al. (2007). The results were expressed in mg starch g^{-1} DM, based on a glucose standard curve. The sum of soluble carbohydrates and starch represent the non-structural carbohydrate content.

The multivariate plasticity index (MVPi) was determined according to Pennacchi et al. (2021). For this, the analysis of variance canonical (AVC) was applied through the Euclidean distances of the values between the two light conditions (Non-Shaded - NS, and Shaded - S). MVPi was determined for each genotype (BRS CATIANA and IRGA 424) and nitrogen levels (50 and 80 kg ha^{-1} of N). The number of dimensions in the AVC was equal to the number of quantitative variables evaluated in season.

Results and Discussion

Low light significantly increased the width and the flag leaf area, chlorophyll content and leaf carbohydrate content (Table 1). However, low light significantly decreased carbohydrate content in the stem. The increase in nitrogen resulted in a significant increase in most variables, except CCL, SCL and SCS. In general, BRS CATIANA presented significantly higher values for most variables analyzed, except for CCL, in which IRGA 424 presented a higher mean. Leaf area variation is one of the main morphological characteristics that respond to luminosity, which tends to increase under low-light to enhance light interception (Gratani, 2014). Fabre et al. (2016) demonstrated that increasing flag leaf size in the presence of qTSN4, a quantitative trait locus (QTL) reported for high yield, was associated with increased photosynthetic rates, along with lower specific leaf area and higher N content per leaf mass in low light. Photosynthetic pigments can be altered according to variations in luminosity. It was reported in a previous study that chlorophyll content was positively correlated with spikelet fertility and grain yield (Restrepo and Garcés, 2013).

Table 1. Flag leaf area, chlorophyll and non-structural carbohydrate content of irrigated rice cultivars grown under different light conditions and application of nitrogen rates, in 2021/2022, in the experimental unit of the Embrapa Arroz e Feijão, in Goianira, GO, Brazil.

variable	unit	significance	Nitrogen rate ($kg\ ha^{-1}$)		Cultivar		Light conditions	
			50	180	BRS CATIANA	IRGA 424	Non-shaded (NS)	Shaded (S)
FLL	cm	N^{**} C^{**}	24.90 b	27.39 a	27.51 a	24.78 b	25.62	26.66
FLW	mm	N^{**} LC^{***}	11.59 b	12.62 a	11.95	12.25	11.40 b	12.80 a
FLA	cm^2	N^{***} LC^{**}	21.64 b	26.00 a	24.74	22.90	22.00 b	25.65 a
CHLA	-	N^{*} C^{***} LC^{**}	25.00 b	27.33 a	29.74 a	22.59 b	24.62 b	27.70 a
CHLB	-	N^{**} C^{***} LC^{***}	7.23 b	8.78 a	10.31 a	5.71 b	6.96 b	9.05 a
CHLT	-	N^{*} C^{***} LC^{**}	32.24 b	36.11 a	40.05 a	28.30 b	31.60 b	36.76 a
CCL	$mg\ g^{-1}$ DM	C^{**} LC^{***}	19.57	16.72	15.57 b	20.71 a	14.30 b	21.99 a
CCS	$mg\ g^{-1}$ DM	N^{**} C^{***} LC^{***}	14.48 b	20.76 a	22.35 a	12.89 b	22.64 a	12.60 b
SCL	$mg\ g^{-1}$ DM	^{ns}	13.35	13.62	13.49	13.48	13.23	13.74
SCS	$mg\ g^{-1}$ DM	C^{**}	12.28	13.45	14.74 a	10.99 b	13.74	11.98

*, **, *** and ^{ns} correspond to significant at 5%, 1%, 0.1% and not significant, respectively, by the F test for each factor (Nitrogen – N, Cultivar – C, and Light conditions - LC). Averages followed by the different lowercase letter for each factor differ from each other according to Tukey's test ($p \leqslant 0.05$). FLL - flag leaf length, FLW - flag leaf width, FLA - flag leaf area, CHL - chlorophyll a, b and total, CCL - carbohydrate content in leaves, CCS - carbohydrate content in stems, SCL - starch in leaves, and SCS – starch in stems.

Low light is known to suppress the activity of key enzymes involved in starch hydrolysis, such as amylase activity, and sucrose synthesis (Tian, 2005). The lower CCS under low light may be related lower activity enzymatic. On the other hand, higher CCL under low light must be to problems redistribution. Lower CCL may result in reductions in the total number of spikelets and number of fertile spikelets under low light (Dutta et al., 2017). Thus, to maintain higher carbohydrate content in leaves may demonstrate a strategy of tolerance. Higher N supplement showed higher MVPi and presented higher physiological changes, such as alterations in flag leaf area, chlorophyll index and non-structural carbohydrates (Figure 1A). BRS CATIANA showed greater changes under low light in chlorophyll and CCS parameters, while IRGA 424 showed higher changes in flag leaf biometry and CCL (Figure 1B). Greater phenotypic plasticity may represent an adaptive strategy for coping with environmental fluctuations (Gratani, 2014).

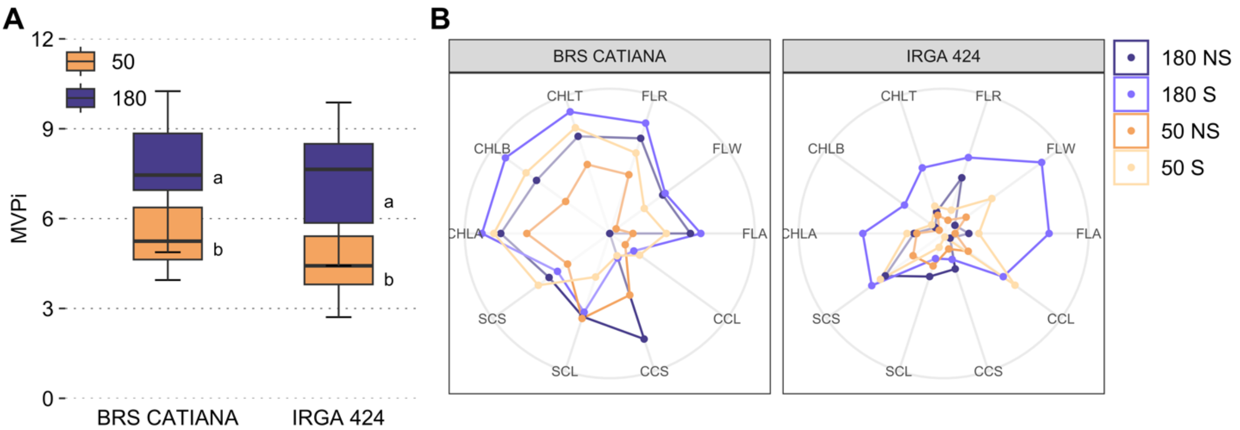

Figure 1. Multivariate plasticity index (MVPi) (A) and radar-type graphs for morphophysiological characters (B) in irrigated rice cultivars (BRS CATIANA and IRGA 424) submitted to light conditions (NS – Non-Shaded and S – Shaded) and nitrogen levels (50 and 180 $kg\ ha^{-1}$), in the 2021/2022, in the experimental unit of the Embrapa Arroz e Feijão, in Goianira, GO, Brazil.

Averages followed by the different lowercase letter for each factor differ from each other according to Tukey's test ($p \leqslant 0.05$). FLL - flag leaf length, FLW - flag leaf width, FLA - flag leaf area, CHL - chlorophyll a, b and total, CCL - carbohydrate content in leaves, CCS - carbohydrate content in stems, SCL - starch in leaves, and SCS – starch in stems.

Conclusions

The flag leaf biometry, chlorophyll and non-structural carbohydrates content are key indicators to assess the acclimatability of irrigated rice cultivars in environments with limited light. The MVPi proved to be a valuable integrative tool to assess the phenotypic adjustments of rice cultivars under abiotic stress. Higher N supplementation increases phenotypic plasticity in tropical irrigated rice under low light.

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