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Article

Relative Competitiveness Between Cultivated and Weedy Rice under Full and Low Light

Competitividade Relativa entre Arroz Cultivado e Arroz Daninho em Ambiente sob Plena Radiação e sob Redução de Luminosidade

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ABSTRACT - Cultivated and weedy rice biotypes exhibit morphophysiological variations under low light, affecting competition between plants. The aim of this study was to assess relative competitiveness between cultivated and weedy rice under full and low light. Three experiments were conducted in a greenhouse, using a completely randomized design with four repetitions. The treatments in the experiment I were arranged in additive series while in the experiments II and III treatments were arranged in replacement series. Experiments II and III were carried out concomitantly to assess coexistence between the rice cultivar and weedy rice. The treatments consisted of different plants proportions: 100:0 (cultivated rice monoculture), 75:25, 50:50, 25:75 and 0:100 (weedy rice monoculture), keeping the total plant population obtained in experiment I (240 plants m^{-2}) constant. Experiment II was conducted with full solar radiation and III under 50% light. The variables analyzed were shoot dry weight and plant height, 35 days after emergence (DAE). Competition among plants was evaluated via graphs and by interpreting competition indices. Concerning shoot dry weight, mutual losses were recorded between competitors, whereas equal competition for resources was observed for plant height. Weedy rice was more competitive than cultivated rice regardless of the light environment assessed, indicating the need for integrated methods to control this weed.

Keywords: intraspecific competition, *Oryza sativa*, low light.

RESUMO - Em condições de baixa luminosidade, biótipos de arroz daninho e arroz cultivado apresentam variação morfofisiológica, tendo implicações na competição entre plantas. O objetivo desse trabalho foi avaliar a competitividade relativa entre arroz cultivado e arroz daninho, em ambiente sob plena radiação e sob redução de luminosidade. Foram conduzidos três experimentos, em ambiente protegido, utilizando delineamento experimental completamente casualizado, com quatro repetições. Os tratamentos do experimento I foram arranjados em série aditiva e nos experimentos II e III em série de substituição. Os experimentos II e III foram conduzidos concomitantemente, avaliando a convivência do cultivar de arroz com o arroz daninho. Os tratamentos foram constituídos por proporções de plantas: 100:0 (monocultivo de arroz cultivado); 75:25; 50:50; 25:75 e 0:100 (monocultivo de arroz daninho), mantendo-se constante a população total de plantas (240 plantas m^{-2}) obtido no experimento I. O experimento II foi conduzido com plena radiação solar e o III sob redução de 50% de luminosidade. As variáveis analisadas foram: matéria seca da parte aérea e estatura de plantas, aos 35 dias após a emergência. A análise da competição entre plantas foi realizada por aplicação de diagramas e interpretações dos índices de competitividade. Para a variável matéria seca da parte aérea ocorreu prejuízo mútuo entre os competidores,

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já para estatura das plantas houve equivalência na competição pelos recursos do meio. Independente do ambiente avaliado, o arroz daninho apresenta habilidade competitiva superior ao arroz cultivado, indicando a necessidade de métodos integrados para o manejo dessa espécie daninha.

Palavras-chave: competição intraespecífica, *Oryza sativa*, baixa luminosidade.

INTRODUCTION

Competition between weeds and cultivated plants is one of the main causes of yield losses in agricultural crops. In this respect, weedy rice (*Oryza sativa* L.) is considered one of the main weeds in irrigated rice crops (Shivrain et al., 2010) and by competing with the crop for minerals, water and light (Zhang et al., 2014), can cause yield losses of up to 90% and compromise grain quality (Dai et al., 2016). Weedy rice belongs to the same taxon (species) of the cultivated rice (*Oryza sativa* L.), characterizing intraspecific competition (Roush et al., 1989).

In irrigated rice, nutrients and sunlight quickly become the most limiting resources (Burgos et al., 2006). Distinct morphophysiological traits such as vigor, high tiller production and height give weedy rice a competitive advantage (Abraham and Jose, 2014). These characteristics are responsible for larger leaf area and higher photosynthetic capacity (Dai et al., 2016), enabling plants to better compete for solar radiation (Streck et al., 2008a).

The availability of global solar radiation is one of the factors that most interferes in the yield potential of rice, exhibiting a linear relation with yield (Steinmetz et al., 2013). Sunlight regulates the physiological and biophysical processes of plants (Yang et al., 2013); it is vital to photosynthesis and acts as an environmental signaler, altering plant metabolism and growth (Jiao et al., 2007) and potentially influencing competition between plants (Liu et al., 2009).

Low light levels can occur in rice-producing areas worldwide due to shading by the canopy (Aumonde et al., 2013), the presence of neighboring plants (Concenço et al., 2008; Schaedler et al., 2009) or cloud cover (Singh, 2000). Another related factor is the El Niño Southern Oscillation (ENSO), a large-scale phenomenon that affects the weather and climate at different locations across the world, including southern Brazil (Streck et al., 2009), the country’s largest rice-producing region (SOSBAI, 2014). one of the consequences One of the consequences of the warm phase anomalies of ENSO is reduced solar radiation due to more frequent rainfall, particularly from November to January (Streck et al., 2008b), critical period in the rice growth cycle.

Studying light quality is a new approach to understand the biology of competition between plants and can be used to develop weed management technologies (Merotto Jr. et al., 2009), replacement series being the most valuable method for evaluating this interaction (Swanton et al., 2015). Research has found no difference in growth between weedy and cultivated rice under low light conditions (Venske et al., 2013). Our hypothesis is that competitive ability between weedy and cultivated rice changes under low light. The aim of this study was to assess relative competitiveness between cultivated and weedy rice in natural (full solar radiation) and low light environments.

MATERIAL AND METHODS

Three experiments were conducted between 2013 and 2014, in a greenhouse located at 29°09’22.4"S and 56°33’11.9"W, using a completely randomized design with four repetitions. The experimental units were 8 L (0.05 m^2 surface) plastic pots filled with sieved soil classified as haplic plinthosol (Embrapa, 2013), with the following chemical composition: pH = 4.8; $CEC_{pH7.0}$ = 15.6 $cmol_c$ dm^{-3}; OM = 1.7%; clay content = 21%; phosphorus (P) = 6.8 mg dm^{-3}; and potassium (K) = 48 mg dm^{-3}.

Experiment I was conducted in additive series. Monocultures of irrigated (IRGA 424) and weedy rice (biotype 32B) were assessed to determine the plant population (m^{-2}) at which shoot dry weight (SDW) becomes independent of the population – reciprocal yield law (Radosevich et al., 2007). The populations analyzed were 2, 4, 8, 16, 32 and 64 plants pot^{-1}, corresponding to 40, 80, 160, 320, 640 and 1,280 plants m^{-2}, respectively. At 35 days after emergence (DAE), the plants were cut at ground level and dried in an oven at 65 °C until constant weight, when SDW was determined (g per plant). Constant SDW was obtained with a population of 240 plants m^{-2} (equivalent to 12 plants pot^{-1}) for the IRGA 424 cultivar and biotype 32B (data not showed).

Experiments II and III were carried out concomitantly, in a replacement series design, to assess the coexistence of the rice cultivar and weed. The treatments consisted of different plants proportion: 100:0 (cultivated rice monoculture), 75:25, 50:50, 25:75 and 0:100 (weedy rice monoculture), keeping the total plant population obtained in experiment I (240 plants m^{-2}) constant. Experiment II was conducted under full solar radiation and experiment III at an average of 50% light reduction, measured using a radiometer (Li-cor, Inc. LI-185B), with a polypropylene screen attached to the experimental units. Daily readings were taken (9 a.m.) of the environmental temperature and the soil underneath the polypropylene screen and at full solar radiation; an average difference of approximately 1.22 and 2.38 °C was observed for the environmental and soil temperatures, respectively. When the plants displayed three leaves, a constant water depth of 3 cm was maintained in the experimental units.

Plants can already detect light quality in the seedling stage, signaling that competition will occur and altering their characteristics (Vidal and Merotto Jr., 2010). As such, SDW and plant height (PH) were determined at 35 DAE, considered enough time to evaluate relative competitiveness. Plant height was measured from ground level to the tip of the leaf blade of the last fully developed leaf (12 plants per repetition); SDW was determined as described in experiment I. Based on these data, graphical analysis was used to assess relative yield (RY = species mixture mean/monoculture mean) and total relative yield (TRY = RYc + RYw), with the respective plant proportions, where RYc = relative yield of cultivated rice and RYw = relative yield of weedy rice.

The graphs were interpreted based on the following: RY = 1 (straight line), when both species are equally capable of interfering with each other; RY < 1 (concave line), when antagonism occurs in the growth of one or both competitors; RY > 1 (convex line), when there is synergism in the growth of one or both competitors. TRY = 1 (straight line), when there is competition for the same resource; TRY > 1 (convex line), when there is no competition; TRY < 1 (concave line), when mutual loss occurs (Cousens, 1991; Radosevich et al., 2007).

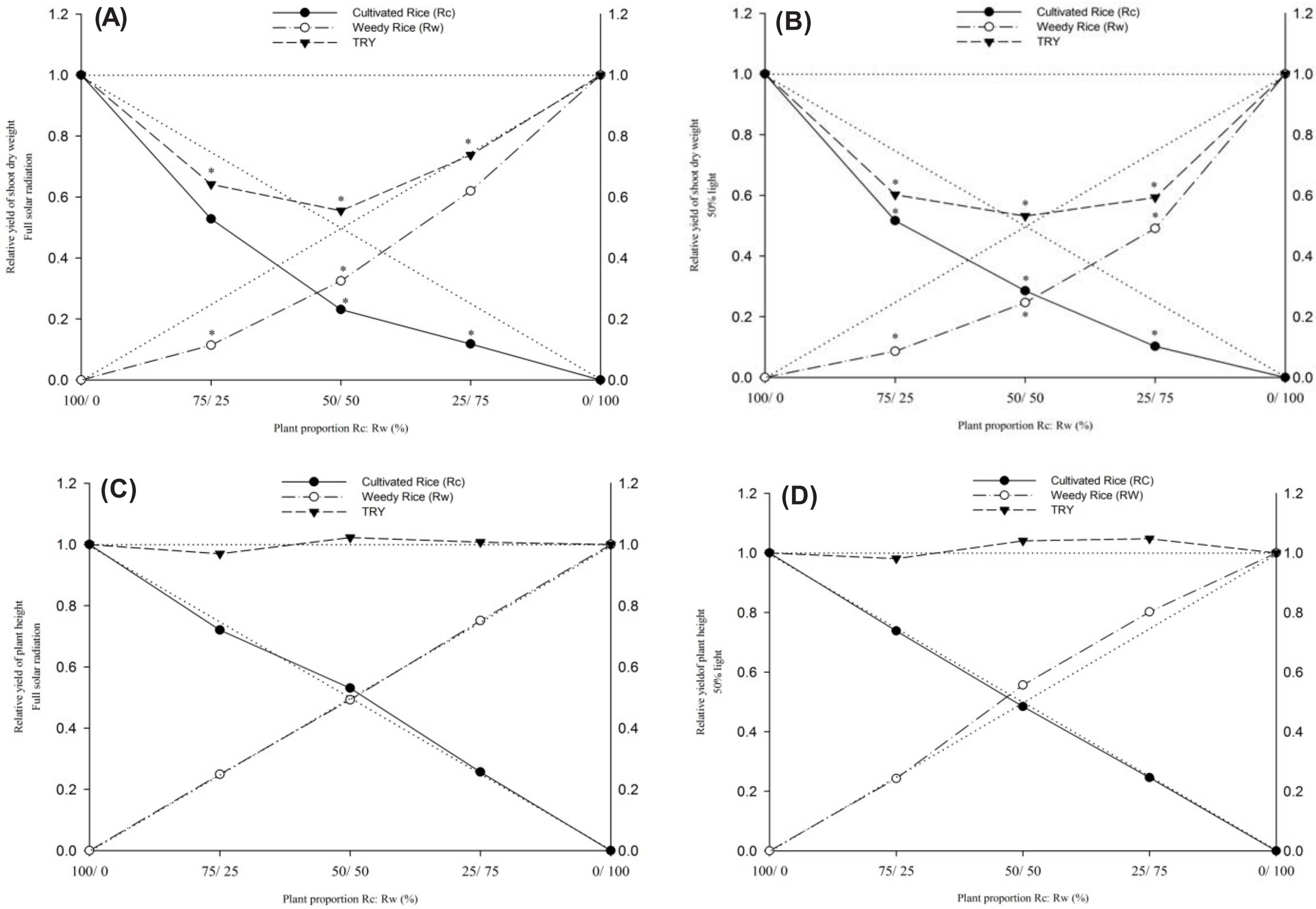
The relative competition intensity index (RCI = RYc/ RYw), relative clustering coefficient (K = RYc/ [1-RYc] or RYw/ [1-RYw]) and competitive ability (C = RYc - RYw) were calculated in line with Cousens and O'neill (1993) using a 50:50 species proportion, and indicating which genotype is the most competitive (Cousens, 1991). The RCI index expresses the relative growth of the rice cultivar (c) in relation to weedy rice (w); K denotes the relative dominance of the cultivar (c) over the weed (d); and C indicates which genotype is the most competitive. Cultivated rice (c) is more competitive than weedy rice (w) when RCI > 1, Kc > Kw and C > 0; and the inverse is true if RCI < 1, Kc < Kw and C < 0 (Hoffman and Buhler, 2002).

In statistical analysis of relative yield, the differences in RY values (RYD) at proportions of 25%, 50% and 75% in relation to the values on the hypothetical straight line of the respective proportion. The t-test was used to analyze the differences in RYD, TRY, RCI, K and C (Roush et al., 1989; Hoffman and Buhler, 2002). The null hypothesis used to test RYD and C was that the means were equal to zero ($H_0 = 0$); for TRY and RCI, that the means were equal to 1($H_0 = 1$); and for K, that the differences between mean Kc and mean Kw were equal to zero ($H_0 = 0$).

The criterion used to differentiate between the RY and TRY curves and competitive ability indices was the presence of differences for at least two plants proportions (Bianchi et al., 2006). The PH and SDW results for each plant proportion, expressed as mean values per plant, were submitted to analysis of variance and treatments means compared to controls using Dunnett's test ($p \leq 0.05$).

RESULTS AND DISCUSSION

Graphic analysis of the replacement experiments (II – full solar radiation and III – 50% light reduction) for shoot dry weight (SDW) showed a significant difference for at least two plant proportions. The data obtained for this variable produced a concave line for relative yield (RY) and total relative yield (TRY) for both the irrigated rice cultivar (IRGA 424) and weedy rice biotype (32B), considering both environments assessed (Figure 1A, B). For plant height (PH), RY and TRY were equal to 1 (straight line) in both environments, with no difference among the plant proportions studied and hypothetical relative yield (Figure 1C, D).



Filled (●) and empty circles (O) represent the RY of cultivated and weedy rice, respectively, and the triangles (▼) indicate TRY. The dotted lines represent hypothetical relative yield, when there is no mutual interference between the cultivar and biotype. * Significant according to the t-test (p≤0.05). 29°09'22.4"S; 56°33'11.9"W, 2013-2014.

Figure 1 - Relative yield (RY) and total relative yield (TRY) for shoot dry weight (SDW) and plant height (PH) under natural light (A and C) and 50% light (B and D) for the irrigated rice cultivar (IRGA 424) and weedy rice biotype (32B).

For SDW in the low light environment, relative yield differences (RYD) were recorded for all competitor proportions; however, under natural light, differences were only observed for competitors at equal or lower proportions (50:50 or 25:75). For PH no differences were found between IRGA 424 and 32B proportions in either of the environments studied (Table 1).

Joint analysis of the RY and TRY graphs concerning to shoot dry weight (SDW) indicated antagonism, that is, mutual losses occurred for both the rice cultivar and weedy rice biotype when in competition, regardless of the environment assessed. The results obtained for plant height (PH) demonstrate that each competitor has the same ability to interfere with the other since they compete for the same available resources in the environment (Swanton et al., 2015). Since they belong to the same species and exploit the same ecological niche, rice genotypes compete for the same resources in time and/or space (Fleck et al., 2008; Rubim et al., 2014).

Table 1 **-** Relative yield differences (RYD) and total relative yield (TRY) for proportions of cultivated rice plants (IRGA 424) associated with weedy rice (biotype 32B) for the variables shoot dry weight (g per plant) and height (cm) under full solar radiation (natural) and 50% light (low light). 29º09'22.4"S; 56º33'11.9"W, 2013-2014

Environment		Plant proportions Rc(1):Rw(2) (%)		
		75:25	50:50	25:75
Shoot Dry Weight (g per plant)				
Natural	TRY	0.64 (± 0.09)*	0.56 (± 0.06)*	0.74 (± 0.08)*
	RYD Cultivated rice	- 0.22 (± 0.09)ns	- 0.27 (± 0.02)*	- 0.13 (± 0.02)*
	RYD Weedy rice	- 0.14 (± 0.01)*	- 0.18 (± 0.04)*	- 0.13 (± 0.08)ns
Low light	TRY	0.60 (± 0.03)*	0.53 (± 0.03)*	0.59 (± 0.02)*
	RYD Cultivated rice	- 0.23 (± 0.03)*	- 0.21 (± 0.03)*	- 0.15 (± 0.02)*
	RYD Weedy rice	- 0.16 (± 0.01)*	- 0.25 (± 0.01)*	- 0.26 (± 0.02)*
Height (cm)				
Natural	TRY	0.97 (± 0.02)ns	1.02 (± 0.04)ns	1.01 (± 0.01)ns
	RYD Cultivated rice	- 0.03 (± 0.02)ns	0.03 (± 0.05)ns	0.01 (± 0.00)ns
	RYD Weedy rice	- 0.00 (± 0.01)ns	- 0.01 (± 0.01)ns	0.00 (± 0.01)ns
Low light	TRY	0.98 (± 0.05)ns	1.04 (± 0.04)ns	1.05 (± 0.04)ns
	RYD Cultivated rice	- 0.01 (± 0.02)ns	- 0.02 (± 0.02)ns	- 0.00 (± 0.01)ns
	RYD Weedy rice	- 0.01 (± 0.03)ns	0.06 (± 0.02)ns	0.05 (± 0.03)ns

(1) Cultivated rice; (2) Weedy rice; ns not significant; * significant according to the t-test (p≤0.05). Amounts in parentheses represent standard errors of the means.

One competitor may use the available environmental resources more efficiently than the other; in this respect, the competition indices for SDW under natural light indicate that weedy rice was superior to cultivated rice, exhibiting higher relative competition intensity (RCI) and competitive ability (C) coefficients. For PH under low light, weedy rice obtained a higher RCI and relative dominance (K) when compared to cultivated rice (Table 2). These indices indicate greater competitive ability for weedy compared relation to cultivated rice, regardless of the environment assessed.

Absolute data for SDW and HT, expressed as means per plant, corroborated the results obtained for RYD and TRY. They also indicated, under natural light, 13.2 and 38.6% higher SDW and PH, respectively, for the weedy rice monoculture in comparison to the cultivated rice. Under low light, these values were 13.6 and 29.4% (Table 3), that is, regardless of the light environments assessed, weedy rice shows distinct morphological traits that provide a competitive advantage over cultivated rice (Abraham and Jose, 2014).

Table 2 **-** Competition indices between the rice cultivar (IRGA 424) and weedy rice (biotype 32B), expressed by the relative competition intensity (RCI), relative clustering coefficient (K; Kc = cultivated rice, Kw = weedy rice) and competitive ability (C), calculated at a 50:50 plant proportion, under full solar radiation (natural) and 50% light (low light). 29º09'22.4"S; 56º33'11.9"W, 2013-2014

Environment	RCI	Kc	Kw	C
Shoot Dry Weight				
Full solar radiation	0.72 (± 0.50)*	0.30 (± 0.03)ns	0.49 (± 0.09)ns	- 0.09 (± 0.03)*
Low light	1.18 (± 0.16)ns	0.41 (±0.05)ns	0.33 (± 0.02)ns	0.04 (± 0.03)ns
Height				
Full solar radiation	1.08 (± 0.09)ns	1.23 (± 0.30)ns	0.97 (± 0.08)ns	0.04 (± 0.05)*
Low light	0.87 (± 0.03)*	0.95 (± 0.08)*	1.27 (± 0.10)*	- 0.07 (± 0.02)*

ns Not significant; * significant according to the t-test (p=0.05). Amounts in parentheses represent standard errors of the means.

Table 3 **-** Shoot dry weight (SDW) and height (HT) of the rice cultivar (IRGA 424) and weedy rice biotype (32B) in a replacement series experiment at 35 days after emergence (DAE). 29º09'22.4"S; 56º33'11.9"W, 2013-2014

Environment		Plant proportion (%)					
		100:0 (Ct)	75:25	50:50	25:75	0:100 (Ct)	CV (%)
		Shoot Dry Weight (g per plant)					
Full solar radiation	Cultivated rice	3.36	2.36^{ns}	1.55*	1.58*	-	29.85
	Weedy rice	-	1.77*	2.51*	3.20^{ns}	3.87	20.44
Low light	Cultivated rice	2.67	1.84*	1.52*	1.09*	-	15.21
	Weedy rice	-	1.07*	1.52*	2.02*	3.09	9.92
		Height (cm)					
Full solar radiation	Cultivated rice	25.01	24.03^{ns}	26.03^{ns}	25.65^{ns}	-	10.79
	Weedy rice	-	40.56^{ns}	40.07^{ns}	40.78^{ns}	40.71	3.71
Low light	Cultivated rice	33.69	33.16^{ns}	32.62^{ns}	33.09^{ns}	-	6.78
	Weedy rice	-	46.37^{ns}	55.16^{ns}	53.07^{ns}	47.75	19.54

* Mean differs from the control (Ct) according to Dunnett's test ($p<0.05$). ^{ns} not significant in relation to the control (Ct). CV = coefficient of variation.

Due to its greater vigor, height and larger number of tillers, weedy rice has better competitive ability than cultivated rice in a natural environment (Burgos et al., 2006). However, under low light, plants invest a greater proportion of photoassimilates in increasing leaf area in order to optimize light capture (Gobbi et al., 2011). Changes in height due to light quality allow the formation of a canopy (Concenço et al., 2008; Schaedler, 2009), which may result in lower biomass production.

In cereal grains such as rice, low light causes etiolation and a decline in the number of tillers, directly reducing dry matter (Vidal and Merotto Jr., 2010). Plants are capable of acclimation, whereby they adjust to environmental changes and maintain adequate levels of performance. Under low light, cell components are adjusted to improve light absorption efficiency (Gomes and Juneau, 2017). Its high concentrations of chlorophyll *a* and *b* suggest that weedy rice generally has higher photosynthetic capacity than cultivated rice (Dai et al., 2016), thus justifying its greater competitive ability under restricted light.

Additionally, weedy rice populations exhibit different morphological and phenological characteristics (Shivrain et al., 2010), making it difficult to establish a competition pattern. Rubim et al. (2014) assessed competition between the Puitá INTA CL rice cultivar and weedy rice biotypes and found equal competitive ability between the plants. Conversely, findings more frequently indicate superior competitive ability in weedy when compared to cultivated rice (Fleck et al., 2008; Dai et al., 2014), corroborating the results obtained here. Competitive advantage by one species denotes a greater capacity to assimilate the resources of the ecological niche, resulting in superior growth and development and greater losses for the competitor (Agostinetto et al., 2013).

Regardless of the environment assessed (full solar radiation or low light), weedy rice showed greater competitive ability than cultivated rice. This rejects the hypothesis that competitive ability between weedy and cultivated rice changes under restricted solar radiation. Crop management strategies such as shading weedy rice with cultivated rice and using rice cultivars with superior vigor may be insufficient to control this weed, requiring other integrated methods to control the species in irrigated rice crops. However, field studies are needed to confirm this hypothesis.

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