EFFECTIVENESS OF FUNGICIDES FOR RICE BLAST CONTROL IN LOWLAND RICE CROPPED IN BRAZIL †

[EFECTIVIDAD DE FUNGICIDAS PARA EL CONTROL DEL TIZÓN DEL ARROZ CULTIVADO EN TIERRAS BAJAS DE BRASIL]

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SUMMARY

Rice cultivation is fundamental to Brazil's economy, which is the largest grain-producing country outside the Asian continent. However, several factors harm sustainable rice production, including diseases incidence. The blast is the major rice disease, and annually, losses caused by this disease would be sufficient to feed millions of people. Due to the complexity in rice blast management, fungicide application has been most used by rice growers, however, despite the high number of registered fungicides, is questioned the real efficiency in field conditions. This work aimed to analyze the effectiveness of fungicides in rice blast control and grain yield maintenance in irrigated rice. Experiments were carried out in a randomized block design, with four replications, in 2015/2016 and 2016/2017 crop seasons, at the Rio Grande do Sul Rice Experiment Station located in Cachoeirinha city, RS, Brazil. We tested the efficiency of nine fungicides registered in Brazil with different target sites for rice blast control. The analyzed variables were the Area Under the Disease Progress Curve (AUDPC) in leaves; neck blast incidence; panicle blast severity and grain yield. In general, only the tricyclazole and trifloxystrobin + tebuconazole fungicides were effective in rice blast control with direct reflection on grain yield.
Key words: *Pyricularia oryzae*; *Oryza sativa* L.; sustainability; disease management.

RESUMEN

El cultivo de arroz es fundamental para la economía de Brasil, que es el país productor de granos más grande fuera del continente asiático. Sin embargo, varios factores dañan la producción sostenible de arroz, incluida la incidencia de enfermedades. El tizón del arroz es la principal enfermedad de este cultivo, y anualmente, las pérdidas causadas por esta enfermedad serían suficientes para alimentar a millones de personas. Debido a la complejidad en el manejo de la tizón del arroz, a la aplicación de fungicidas ha sido más utilizada por los productores de arroz, sin embargo, a pesar del alto número de fungicidas registrados en Brasil, se cuestiona la real eficiencia en condiciones de campo. Este trabajo tuvo como objetivo analizar la efectividad de los fungicidas en el control del tizón del arroz y el mantenimiento del rendimiento de grano en arroz bajo riego. Los experimentos se realizaron bajo un diseño de bloques al azar, con cuatro repeticiones, en los ciclos 2015/2016 y 2016/2017, en Rio Grande do Sul, Brasil. Se evaluó la eficacia de nueve fungicidas registrados en Brasil con diferentes sitios especificos para el control del tizón . Las variables analizadas fueron el Área bajo la curva del progreso de la enfermedad (AUDPC) en hojas; incidencia del tizón en elcuello; severidad del tizón en la panícula y rendimiento de grano. En general, solo los fungicidas triciclazol y trifloxistrobina + tebuconazol fueron efectivos en el control del tizón del arroz reflejándose directamente en el rendimiento de grano.
Palabras clave: *Pyricularia oryzae*; *Oryza sativa* L; sostenibilidad; manejo de enfermedad.

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food of more than three billion people around the world (Espe *et al*., 2016). Brazil is the most significant producer country outside the Asian continent, with an annual production of approximately 12 Mt of grains (USDA, 2017). The State of Rio Grande do Sul (RS) in Brazil is the most important national producer, with more than 70% of grain production, where they have grown annually around 1.1 million hectares (CONAB, 2017). Rice yields quadrupled since the beginning of cultivation in

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RS in 1906 (1.8 $t.ha^{-1}$) to the last five years (7.5 $t.ha^{-1}$) (CONAB, 2017).

Due to the projection of increase in the world population, it is necessary to invest in research and technology transfer to reduce the gap between the irrigated rice yield observed in research stations and average yield observed in the field (Espe *et al*., 2016; Ribas *et al*., 2016). Among the main factors that cause loss of productivity of rice in Brazil, we highlight the rice blast (*Magnaporthe oryzae* Couch; anamorph *Pyricularia oryzae* Cavara).

Rice blast is the most critical disease affecting rice cultivation around the world and can cause 100% losses in productivity if adequate management measures are not adopted (Prabhu *et al*., 2009). Currently, it is estimated that the rice blast causes declines of 30% in world rice production, and only those losses would be enough to feed more than 60 million people (Nalley *et al*., 2016).

The integrated rice blast disease management recommended in Brazil involve cultural methods and chemical control. The most important of which is: sowing at the suggested date, balanced nitrogen fertilization, irrigation uniformity, incorporation of cultural remains of rice into the soil, weed management, use resistant varieties and fungicides application (Pak *et al*., 2016; Pooja and Katoch, 2014; Soares *et al*., 2014; Prabhu *et al.*, 2009).

Use of resistant varieties to plant diseases management is an adequate way for the sustainable production of any crop (Mundt, 2014). However, rice blast resistant-varieties have not been presenting stable resistance over the years, being this resistance overcome in three to five years after its release (Prabhu *et al.*, 2009). This loss of resistance is mainly because of the high pathogen genetic variability (Prabhu *et al*., 2009; Zhou *et al*., 2007; Prabhu and Filippi, 2006), occurring selection of new virulent races that overcome the resistance. Therefore, fungicides application in rice blast management is essential, and this practice is preferred by growers of irrigated rice in Brazil and the world (Chen *et al*., 2015; Pooja and Katoch, 2014).

Currently, there are a large number of fungicides registered for blast control in Brazil (AGROFIT, 2017). However, many of them are not efficient for this disease in the field. This situation has been caused the applications of fungicide in an irrational way, increasing the rice production cost, harming the environment and putting food safety at risk through the chemical residues in grains.

Also, studies published in scientific journals evaluating fungicides efficiency in blast control under irrigated rice conditions in Brazil are scarce or conducted and published years ago, not reflecting in the pathogen populations currently present in the environment. Therefore, the purpose of this paper is to fill this gap in information about which fungicides control rice blast in Brazil, assisting technicians and growers in the management of this disease.

This work aimed to analyze the fungicides effectiveness in rice blast control and grain yield maintenance in irrigated rice.

MATERIALS AND METHODS

Experiments were carried out in a randomized block design, with four replications, in the 2015/2016 and 2016/2017 crop seasons, at the Rio Grande do Sul Rice Experiment Station (IRGA) located in the city of Cachoeirinha, RS, Brazil. The experimental area is located at 29º57'02 "S 51º05'02 "W and with seven meters of elevation above sea level. The edaphoclimatic characteristics of the area are favorable for the natural occurrence of rice blast.

The experimental units were composed of plots with dimensions of 5.0 m x 1.53 m, totaling an equivalent area to 7.65 m^2. The treatments consisted of fungicides used for the management of the disease, as described in Table 1. In the 2015/2016 crop season, the fungicide picoxystrobin + cyproconazole was replaced by thiophanate-methyl + mancozeb. Spraying of all other fungicides was similar in all crop season (Table 1).

Guri Inta CL variety was planted at 100 $kg.ha^{-1}$ seeds density, with a population of 400 $plants.m^2$. Sowing occurred on November 17, 2015, and November 19, 2016. These sowing dates were performed at the end of the recommended period to favor rice blast occurrence.

The soil fertilization was carried out during sowing in the amount of 400 $kg.ha^{-1}$ with formulation 04-18-08, according to soil analysis. Covering fertilization was 120 $kg.ha^{-1}$ of nitrogen in urea form, divided twice, once during the V3 development stage and once in the R0 development stage (Counce *et al*., 2000). All other crop management followed the bulletin with the technical recommendations by researchers to cultivation irrigated rice in the south of Brazil (SOSBAI, 2016).

Table 1. Fungicides evaluated for the control of rice blast in irrigated rice in the 2015/2016 and 2016/2017 crop season.

Common Name	Chemical Group	Dosage (kg or L/ha)	Target Site and Code (FRAC)	FRAC Code	Season	
					2015/2016	2016/2017
Control	-	-	-		X	X
Tetraconazole	Triazole	0.5	G1	3	X	X
Azoxystrobin	Strobilurin	0.4	C3	11	X	X
Tricyclazole	Benzothiazole	0.3	I1	16.1	X	X
Trifloxystrobin + Tebuconazole	Strobilurin + Triazole	0.75	G1 + C3	3 + 11	X	X
Epoxiconazole + Kresoxim-Methyl	Triazole + Estrobilurin	0.75	G1 + C3	3 + 11	X	X
Tebuconazole	Triazole	0.75	G1	3	X	X
Kasugamycin	Antibiotic	1.5	D3	24	X	X
Picoxystrobin + Cyproconazole	Strobilurin + Triazole	0.4	G1 + C3	3 + 11	X	
Thiophanate-methyl + Mancozeb	Benzimidazole + Dithiocarbamate	2.5	M + B1	1+ M03		X

Two fungicides sprays in 2015/2016 season were performed. The first occurred at the end of the R2 stage and, the second 15 days after the first. For the 2016/2017 season, we performed three fungicides sprays. The first spray was in V8 vegetative stage when began the first symptoms of rice blast in leaves, and the other spray in same stages applied in previous season, that is, the final stage of R2 and 15 days after. The fungicide applications was carried out with a precision costal pulverizer, pressurized to CO^2 with a constant pressure of 40 PSI, with a spray volume of 200 liters per hectare.

During the 2015/2016 crop season, we evaluated the neck blast incidence, panicle blast severity, and grain yield. We collected randomly 15 panicles within the plot at 20 days before harvest for incidence and severity evaluation. The neck blast incidence was quantified counting number of plants showing disease symptoms, and for panicle blast severity we used the scale proposed by Silva-Lobo *et al*. (2012). Grain yield was determined by harvesting 5 m^2 of the plot and then expressed in $kg.ha^{-1}$, with grain moisture adjusted to 13%.

During the 2016/2017 crop season, in addition to all variables evaluated in the 2015/2016 season, we assessed the leaf blast, beginning with the appearance of disease first symptoms in leaves, and in a seven-day interval using a proposed scale by IRRI (2013). With leaf blast data, we calculated the Area Under the Disease Progress Curve (AUDPC) using the formula proposed by Campbell and Madden (1990).

All data was subjected to ANOVA and mean of variables that demonstrated significance by F-test ($p<0.05$) were compared by using Duncan test at 5% probability of error. SAS program version 9.0 (SAS, 2000) was used.

RESULTS

Crop Season 2015/2016

There was statistical significance for all tested variables (Table 2). The neck blast incidence showed that only tricyclazole, trifloxystrobin + tebuconazole and picoxystrobin + cyproconazole fungicides control the disease around 58%, differing from the control (Table 2). As for the panicle blast incidence, the fungicide tetraconazole did not affect the disease severity, being equal to the control, whose severity was superior to 65% (Table 2). On the other hand, the fungicides kasugamycin, tebuconazole, and epoxiconazole + kresoxim-methyl had an intermediate effect in disease severity control, being in an average 17% more effectivecompared to control. Finally, the fungicides tricyclazole, trifloxystrobin + tebuconazole, picoxystrobin + cyproconazole and azoxystrobin showed the best control of panicle blast severity with severity values around 30% (Table 2).

Rice blast reduced the grain yield since the average yield in control was only 1,899 kg/ha (Table 2), not differing from treatments with tetraconazole, epoxiconazole + kresoxim-methyl, and tebuconazole. The fungicides azoxystrobin, kasugamycin, and picoxystrobin + cyproconazole showed no difference among them and were superior to control. On the other hand, the treatments that provided the highest grain yield were by applying the fungicides trifloxystrobin + tebuconazole and tricyclazole, showing on average 310% higher grain yield than control without fungicide application (Table 2).

The ANOVA evidenced the absence of significance for AUDPC variable, whereas for other variables there was significance by F-test (Table 3). The panicle blast incidence was reduced only by tricyclazole and trifloxystrobin + tebuconazole, being tricyclazole superior to all the other fungicides, showing half of the disease incidence in relation to control (Table 3). In comparison to 2015/2016 crop season, the panicle blast incidence was higher, and the disease was observed in all analyzed panicles in control without fungicide application (Table 3). On the other hand, the absence of significance for AUDPC indicates that even though the rice blast had occurred on the leaf, it did not show significant progress (Table 3).

For rice blast severity in the panicle, we observed a similar response with disease incidence, whose treatments tricyclazole and trifloxystrobin + tebuconazole showed on average 20% lower disease severity compared to control (Table 3). Also, the fungicides kasugamycin and azoxystrobin showed lower panicle blast severity compared to control, but superior about the best treatments tricyclazole and trifloxystrobin + tebuconazole (Table 3).

Crop Season 2016/2017

As in the 2015/2016 crop season, grain yield was profoundly affected by rice blast in 2016/2017 season. We observed that the fungicides trifloxystrobin + tebuconazole and tricyclazole were on average 228% higher than control in grain yield, not different from each other (Table 3). Also, azoxystrobin and kasugamycin were superior to control but lower than the trifloxystrobin + tebuconazole and tricyclazole treatments (Table 3).

Table 2. Neck blast incidence, panicle blast severity and grain yield with fungicides application in 2015/2016.

Fungicides	Incidence (%)	Severity (%)	Grain yield (kg/ha)
Tetraconazole	96.67 A[1]	67.17 A	1514.10 C
Control	98.33 A	66.58 A	1899.17 C
Epoxiconazole + Kresoxim-Methyl	96.67 A	49.33 B	2529.88 C
Tebuconazole	91.67 A	50.42 B	2541.75 C
Azoxystrobin	78.33 A	29.92 C	3068.52 B
Kasugamycin	86.67 A	49.09 B	3484.99 B
Picoxystrobin + Cyproconazole	66.67 B	31.65 C	3770.66 B
Trifloxystrobin + Tebuconazole	58.34 B	33.58 C	5516.22 A
Tricyclazole	50.00 B	27.83 C	6251.58 A

[1]Means in same columns followed by the same letter do not differ significantly ($p \leq 0.05$) according to Duncan's test.

Table 3. The Area Under the Disease Progress Curve (AUDPC) in leaves, neck blast incidence, panicle blast severity and grain yield with fungicides application in 2016/2017.

Fungicides	AUDPC	Incidence (%)	Severity (%)	Grain yield (kg/ha)
Tetraconazole	137.62NS[1]	100.00 A[2]	59.08 A	3928.80 C
Tebuconazole	128.88	100.00 A	51.75 A	4231.80 C
Control	131.12	100.00 A	50.66 A	4183.24 C
Epoxiconazole + Kresoxim-Methyl	135.25	100.00 A	48.75 A	3916.55 C
Thiophanate-methyl + Mancozeb	136.50	95.00 A	40.33 A	4903.86 C
Kasugamycin	134.75	90.00 A	31.67 B	6060.72 B
Azoxystrobin	128.62	94.99 A	30.33 B	6094.23 B
Trifloxystrobin + Tebuconazole	132.63	73.33 B	16.17 C	9135.95 A
Tricyclazole	129.13	50.00 C	14.42 C	9903.79 A

[1] Not significant ($p>0.05$) according to F-test.[2] Means in the same columns followed by the same letter do not differ significantly ($p \leq 0.05$) according to Duncan's test.

DISCUSSION

Rice blast is the major irrigated rice disease (Nalley *et al*., 2016; Chen *et al*., 2015; Kunova *et al*., 2012; Prabhu *et al*., 2009). This disease can cause productivity losses of up to 100% (Filippi and Barata, 2014; Kunova *et al*., 2014; Prabhu *et al.*, 2009). Mainly when it attacks the neck or panicles of rice, which directly affects the filling of grains. Chemical control with fungicides has been the most used by rice growers in the state of Rio Grande do Sul in Brazil. Since most of the available vaieties are susceptible to rice blast (Ogoshi, 2015), the use of fungicides, in this case, is vital for blast management in order to achieve high grain yield (Chen *et al.*, 2015; Kunova *et al.*, 2014; Prabhu and Filippi, 2006).

Currently, there are 49 fungicides registered in the Ministry of Agriculture, Livestock and Food Supply (MAPA) for rice blast control in Brazil (AGROFIT, 2017), is recommended for seed treatment and aerial spraying. These fungicides are composed of a single active ingredient or by mixtures of two or more active ingredients, which have eight different target sites following classification by FRAC (2017).

Despite the high number of registered fungicides available for rice blast control in Brazil (49 fungicides for seed treatment and aerial spraying), we observed that many of them are not effectivet, especially for the neck and panicle blast control. This situation directly affects grain yield and can cause severe economic losses to rice growers. Given this, the knowledge of the actual effectiveness of fungicides currently available in the market is essential for success in the management of rice blast in lowlandconditions.

In the present work, we tested several fungicides for blast control in irrigated rice during two crop seasons; we chose these fungicides according to different modes of action, representing fungicides registered in MAPA for aerial application. Among the nine fungicides tested, only the tricyclazole fungicides and the trifloxystrobin + tebuconazole mixture were efficient in panicle blast control, reflecting directly on high grain yield (Tables 2 and 3).

The fungicides azoxystrobin and picoxystrobin + cyproconazole showed a reduction in panicle blast severity. However, we did not observe the same result in grain yield. Chen *et al*. (2015) analyzed the effect of azoxystrobin and kresoxim-methyl fungicides for blast control in irrigated rice in China and found that both fungicides had disease control superior to 73% of efficiency and resulted in high grain yield, these results are in contrast of our results. Others reports showed that fungicide azoxystrobin is efficient in the rice blast control with direct reflection on grain yield in countries such as Italy, Taiwan, and the United States (Chen *et al.*, 2015; Kunova *et al*., 2014; Kunova *et al.*, 2012; Jin *et al*., 2009; Fang *et al*., 2009).

These positive results of the azoxystrobin fungicide in blast control in lowland rice are divergent to that found in our study, possibly due to the difference in the *M. oryzae* populations in Brazil compared to other countries. This inference may be related to the low sensitivity of several isolates of the pathogen to fungicide azoxystrobin. Since for *M. oryzae* population, which infects wheat in Brazil, strains of this fungus resistant to azoxystrobin have already been found (Castroagudín *et al.*, 2015; Oliveira *et al*., 2015). However, this hypothesis still needs to be confirmed for rice in Brazil.

In general, the fungicide that promoted the best response for rice blast control in our work was tricyclazole. This fungicide is the standard for control this disease in Brazil and several other countries and, your application alone or in combination with other fungicides, has shown satisfactory results in rice blast control (Chen *et al*., 2015; Kunova *et al.*, 2014; Ganesh *et al*., 2012; Kunova *et al*., 2012; Prabhu *et al*., 2002). Tricyclazole was superior to the fungicide tebuconazole in the panicle blast control and avoided a yield loss in irrigated rice in Brazil (Prabhu *et al*., 2002).

Magar *et al*. (2015) analyzed the effectiveness of several fungicides in rice blast control in irrigated rice. They showed that the fungicide tricyclazol + hexaconazole were the most effective for control of leaf and neck blast exceeding 79%, being reflected directly in high yields. Tricyclazole was the most efficient in the rice blast control in irrigated rice in India, in addition to reducing the disease severity, the fungicide application also increased the tillering number per plant, panicle length, number of grains per panicle and, grain yield (Pandey, 2016).

The fungicide trifloxystrobin + tebuconazole showed, in our present work, the same disease control effectiveness in comparison to tricyclazole. Our results revealed that trifloxystrobin + tebuconazole is an alternative option for rice blast management in Brazil, mainly for active ingredient rotation and, consequently, preventing a possible fungus resistance to fungicides.

Pramesh *et al*. (2016) analyzed the effectiveness of trifloxystrobin + tebuconazole in rice blast and sheath blight control in irrigated rice and verified that this fungicide was most effective in control of both diseases in India. Silva-Lobo (2004) evaluated the effectiveness of fungicides in blast control in upland rice in Brazil and found that fungicide trifloxystrobin

+ tebuconazole showed a lower severity of panicle blast, similar to tricyclazole.

In our work, tricyclazole and trifloxystrobin + tebuconazole were the most effective in rice blast control with direct reflection on high grain yield. Therefore, we highlight the importance thet of technicians and rice growers correctly choose the fungicide for sustainable management of blast in lowland rice cultivation in Brazil.

CONCLUSIONS

Tricyclazole and trifloxystrobin + tebuconazole were the most effective in rice blast control with direct reflection on high grain yield.

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