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Implications on the management of the weedy rice (Oryza spp.): a silent enemy

Implicaciones en manejo del arroz maleza (Oryza spp.): un enemigo silencioso

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ABSTRACT. Weedy rice (Oryza spp.), a specific weed of cultivated rice, is one of the most damaging and important weeds in rice production systems worldwide. Its high genetic similarity to commercial rice makes its control challenging. This review examines the implications of weedy rice management, focusing on the evolution and spread of herbicide resistance. The introduction of imidazolinone-resistant rice (Group 2) (Clearfield® technology) initially offered effective control. However, over-reliance on this technology has led to the evolution of resistant weedy rice biotypes through gene flow and selection pressure, as documented in numerous countries. In response, the Provisia™ rice system, resistant to the ACCase-inhibiting herbicide quizalofop (Group 1), has been introduced as an alternative for controlling weedy rice and other weeds, primarily from the Poaceae family. This work emphasizes the sustainable management of this weed as a set of strategies that combine these technologies with crop rotation, diverse modes of action, and the reduction of the soil seed bank to decrease the evolution of herbicide resistance and ensure viability in rice production.

KEYWORDS: gene flow, herbicide, imidazolinone, resistance.

RESUMEN. El arroz maleza (Oryza spp.), una maleza conspecífica del arroz cultivado, una de las más dañinas e importantes en los sistemas de producción de arroz a nivel mundial. Su alta similitud genética con el arroz comercial hace que su control sea desafiante. Esta revisión examina las implicaciones del manejo del arroz maleza, centrándose en la evolución y propagación de la resistencia a herbicidas. La introducción del arroz resistente a imidazolinonas (Grupo 2) (tecnología Clearfield®) inicialmente ofreció un control eficaz. Sin embargo, la dependencia excesiva de esta única herramienta ha llevado a la evolución de biotipos de arroz maleza resistente mediante flujo génico y presión de selección, como se ha documentado en numerosos países. En respuesta, el sistema de arroz Provisia™, resistente al herbicida inhibidor de ACCasa, quizalofop (Grupo 1), ha sido introducido como alternativa al control del arroz maleza y otras malezas de la familia Poaceae principalmente. Este trabajo enfatiza el manejo sostenible de esta maleza como un conjunto de estrategias que combinen estas tecnologías con rotación de cultivos, diversos modos de acción y la disminución del banco de semillas para ralentizar la evolución de resistencia y asegurar la viabilidad en la producción arrocera.

PALABRAS CLAVE: flujo génico, herbicida, imidazolinonas, resistencia.

INTRODUCTION

Rice is one of the most important crops in the world and is widely cultivated in tropical countries (Chirinda et al., 2018). It is considered in several regions as a highly priority crop for food security, and even governments promote its production. These regions include, but are not limited to, India, China, the southern United States, Southern America, and Central America (Muthayya et al., 2014). However, its production is being limited by different pests, where weeds are one of the most important due to their potential to cause high yield losses (Oerke, 2006). Weeds are the main constraint due to their ability to quickly establish, adapt, and compete for essential resources, including water, nutrients, light, and space, ultimately reducing yield (Moreno-Serrano et al., 2024).

Nonetheless, weedy rice is one of the most important weeds in almost all rice production regions. Its presence in rice production systems results in significant yield losses and a reduction in commercial grain quality due to contamination (Kaloumenos et al., 2013). Yield losses from weedy rice infestation can vary from 5 to 100 % in the worst-case scenario (Sudianto et al., 2013). Its importance in rice production systems is because of the genetic similarity with cultivated rice (*Oryza sativa*), which makes it highly difficult to control in commercial rice systems.

MATERIALS AND METHODS

The review was conducted through an intensive search of existing literature, from which key aspects regarding herbicide resistance and the management of weedy rice biotypes, as well as their impacts on agriculture, were extracted. The methodology for selecting information involved exploration, screening, critical analysis, and interpretation of relevant literature.

RESULTS AND DISCUSSION

Weedy rice and cultivated rice are currently classified as the same species, Oryza sativa, and share a high degree of genetic similarity. This makes weedy rice difficult to distinguish at early growth stages and complicates its control using selective herbicides in rice production (Kaloumenos et al., 2013). In early 2000, rice production systems were revolutionized by the introduction of imidazolinone-resistant rice (Clearfield® rice) (Sudianto et al., 2013). Clearfield® rice was developed in the USA by the Louisiana State University (LSU) through the induction of chemical mutagenesis, which led to a mutation in the acetolactate synthase (ALS), also called acetohydroxyacid synthase (AHAS) (Avila et al., 2005; Shivrain et al., 2009). ALS enzyme is responsible for the biosynthesis of branched-chain amino acids (valine, leucine, and isoleucine) in plants. Without these amino acids, plants can grow and eventually die because of their inability to synthesize proteins that are essential for cell division (Dayan, 2019).

Therefore, the mutation in the ALS gene in Clearfield® rice led to resistance to imazethapyr (Group 2), a potent ALS inhibitor used to control a wide spectrum of problematic weeds such as (Echinochloa curs-galli (L.), Digitaria spp, Cyperus iria, Cyperus rotundus, and others), without compromising the normal growth or productivity of the Clearfield® rice (Bzour et al., 2018).

Additionally, Clearfield® technology continues to be used in rice production systems because its soil and foliar activity provide extended, season-long weed control (de Avila et al., 2021). It is a safe product because it does not contain any microbial transgene, hence it is not considered a genetically modified crop. In addition, it is harmless to animals since the ALS biosynthetic pathway is only present in plants and some bacteria (Zhou et al., 2007). Even though Clearfield® technology offers important benefits, reliance on this system as the primary strategy for weed control has promoted the evolution of imidazolinone-resistant weedy rice biotypes in many rice-growing regions (Table 1).

Table 1

Summarizes documented cases of weedy rice resistance to imidazolinone herbicides (Group 2) across several rice-growing countries. No elucidated (NE), Target Site-Resistance (TSR).

Country	Herbicide	Group	Chemical Family	Resistance Mechanism	Specie	Source
Argentina	Imazapic Imazapyr Imazethapyr	2	Imidazolinones	NE	*O. sativa var. sylvatica*	Presotto et al., (2024)
Brazil	Imazethapyr Imazapic	2	Imidazolinones	NE	*O. sativa var. sylvatica*	Menezes et al., (2009)
Colombia	Imazamox Imazapyr	2	Imidazolinones	NE	*O. sativa var. sylvatica*	Velásquez et al., (2020)
Greece	Imazamox Imazethapyr	2	Imidazolinones	TSR	*O. sativa var. sylvatica*	Kaloumenos et al., (2013)
Italy	Imazamox	2	Imidazolinones	TSR	*O. sativa var. sylvatica*	Scarabel et al., (2012)
Malaysia	Imazapic Imazapyr	2	Imidazolinones	NE	*O. sativa var. sylvatica*	Dilipkumar et al., (2018)
Turkey	Imazamox	2	Imidazolinones	TSR	*O. sativa var. Sylvatica*	Unan et al., (2024)
United States	Imazethapyr	2	Imidazolinones	TSR	*O. sativa var. sylvatica*	Rajguru et al., (2005) Shivrain et al., (2006) Sales et al., (2008) Kuk et al., (2008)
Costa Rica	Imazapyr Imazapic	2	Imidazolinones	NE	*O. sativa* var. *sylvatica*	Heap, (2025)

This resistance has been attributed mainly to gene flow from Clearfield® cultivars, resulting in an exponential increase in the weedy rice seedbank (Merotto et al., 2016; Chiapinotto et al., 2024). This situation led to the implementation of new strategies for weed control that are mainly oriented to reduce the size of the soil seedbank to delay the evolution of multiple herbicide resistance, as well as crop rotation including soybeans (Glycine max), corn (Zea mays), and others (Beckie & Harker, 2017).

However, a new alternative was released a few years ago by BASF (ProvisiaTM) as an alternative to reduce imidazolinone resistance weedy and grassy biotypes. ProvisiaTM rice technology was developed by the induction of a mutation in the Acetyl CoA carboxylase (ACCase gene), which confers a high resistance level to the Aryloxphenoxypropionate herbicide Quizalofop-ethyl (quizalofop) (Camacho et al., 2019). Due to the graminicide activity of all ACCase inhibitor herbicides, ProvisiaTM could be used as a transitional technology to delay multiple herbicide resistance. On the other hand, recommendations should be considered, such as efficient doses, crop rotation (rice-soybean-corn) or others, the use of different herbicide modes of action, and potentially reducing seedbank strategies (false seedbed).

In addition, the use of herbicides with different modes of action can also be a challenge due to the antagonism between quizalofop and other herbicides; therefore, some studies can be conducted to determine the efficacy of herbicide mixtures without compromising the weed control (Barbieri et al., 2022). Another consideration to avoid the same situation as Clearfield® is the recurrent use of this technology as a unique weed control tool, because in rice systems, hybridization can occur even if it is less than 1% where physical and biological factors play an important role. It occurs because rice has hermaphrodite flowers, but the pollen grains appear at anthesis and can be transferred by the wind to weedy rice plants (Jiang et al., 2012).

CONCLUSION

Weedy rice remains a significant and constant threat due to its close genetic proximity to cultivated rice. Clearfield® technology represented a significant advance in its control, but its intensive use has, in many cases, accelerated the selection of resistant rice biotypes, thereby compromising its long-term effectiveness. The recent emergence of Provisia™ technology offers a valuable alternative for weedy rice control, providing a tool for managing populations that have evolved resistance to imidazolinones (Group 2). However, the history of Clearfield® serves as a cautionary tale: no single technology is a permanent solution.

Sustainable weedy rice management depends on the implementation of Integrated Weed Management (IWM) strategies. These should include rotating chemical technologies such as those mentioned above, using herbicides with different target sites, crop rotation with other species that facilitate the identification and management of weedy rice biotypes, and cultural practices aimed at reducing the soil seed bank. Future research should be focused on the correct identification of resistant biotypes to disrupt ecological dynamics and act in time to decrease the emergence of other resistant biotypes, thus protecting the productivity and sustainability of rice systems.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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