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Evaluation of quizalofop tank-mixtures for quizalofop-resistant rice

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ABSTRACT

Effective grass weed control in rice is becoming more difficult due to herbicide resistance. To combat weed resistance a new non-GMO resistant rice is under development. Quizalofop, an acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicide, can be applied over-the-top of quizalofop-resistant rice for selective grass control. Due to the absence of broadleaf weed control from this herbicide, other herbicides will be needed to achieve control of a diverse weed spectrum. Antagonism often occurs when mixing ACCase-inhibiting herbicides with other herbicides; thus, two experiments were conducted to evaluate quizalofop in tank-mixes with common rice herbicides having either grass or broadleaf activity. Both greenhouse experiments were a two-factor factorial where factor-A was quizalofop rate and factor-B was tank-mix partner. The first experiment contained tank-mix partners for grass control with some treatments having activity on broadleaf species as well. The second experiment contained tank-mix partners that when applied alone are not effective in controlling grass weeds. The first experiment included labeled rates of clomazone, pendimethalin, thiobencarb, quinclorac, propanil, imazethapyr, bispyribac, penoxsulam, cyhalofop, and fenoxaprop in tank-mixes with quizalofop at 0 or 80 g ai ha^{-1} on common grass weeds found in rice production. The second experiment included labeled rates of triclopyr, acifluorefen, carfentrazone, salfufenacil, halosulfuron, halosulfuron + thifensulfuron, bentazon, or 2,4-D amine in tank-mixes with quizalofop at 0, 80, or 160 g ai ha^{-1}. Tank-mix interactions for percent control or biomass reduction were evaluated using Colby's method. Overall, quizalofop alone provided effective control of all grass species evaluated (> 90%) in both experiments, except for ACCase-resistant Amazon sprangletop. When quizalofop was tank-mixed with other herbicides, antagonism was observed for various combinations on multiple grass weeds. The acetolactate synthase (ALS)-inhibiting herbicides consistently antagonized quizalofop in terms of grass weed control and biomass reduction. Likewise, the addition of propanil to quizalofop antagonized the graminicide based on multiple grass species evaluated. Similarly, the auxinic herbicides antagonized quizalofop, with 2,4-D being the most consistently antagonistic tank-mix partner, resulting in reduced control of all grass weeds evaluated compared to quizalofop alone. Overall, the results indicate caution should be taken before tank-mixing quizalofop with other rice herbicides, and ultimately, separate applications may be needed when a diverse spectrum of grasses, broadleaves, and/or sedges are present in a rice field.

1. Introduction

The increase in occurrence of herbicide resistant barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.), sprangletop (*Leptochloa ssp.*), and weedy rice (*Oryza sativa L.*) has been well documented (Burgos et al., 2008; Norsworthy et al., 2013; Tehranchian et al., 2016). With this increase in herbicide-resistant weeds, achieving efficacy controlling weeds in rice production systems is becoming more difficult. To help combat this issue, a new herbicide resistant rice type is being developed to control troublesome grass weeds. Provisia™ rice (BASF Corporation, Research Triangle Park, NC), which is resistant to quizalofop, is set to be commercialized in 2018 (personal communication, John Schultz, BASF Corporation). Quizalofop-resistant rice was developed through traditional breeding methods, specifically by developing SNP-based markers which were properly tagged for quizalofop resistance (Camacho Montero, 2017). Inheritance studies explained that this resistance was due to a single dominant gene.

Quizalofop, an acetyl coenzyme A carboxylase (ACCase)-inhibiting

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herbicide, has been used for control of annual and perennial grass weeds (Shaner, 2014). Applications of quizalofop effectively control barnyardgrass and red rice (Noldin et al., 1998), which are two of the most problematic weeds in Arkansas rice production (Norsworthy et al., 2013).

Quizalofop is a member of the aryloxyphenoxy propionate family of ACCase-inhibiting herbicides. Like other ACCase-inhibiting herbicides, quizalofop has no activity on broadleaf weed species (Shaner, 2014). This lack of activity in broadleaf species is due to having the accD gene, which causes the presence of the herbicide-tolerant prokaryote form of ACCase, compared to grass species which have the herbicide-sensitive eukaryote form of ACCase (Konishi and Sasaki, 1994). With no broadleaf control, producers growing quizalofop-resistant rice will need to rely on other herbicides to control a diverse weed spectrum. Commonly, herbicides are tank-mixed because applying two or more herbicides as a mixture often increases spectrum of control as well as saves time and money over sequential applications (Hatzios and Penner, 1985). Moreover, due to increased cost efficiency, tank-mixes can contain multiple herbicides, insecticides, fungicides, and fertilizers. For proper management of herbicide-resistant weed species growers are currently including residual herbicides along with postemergence herbicides to overlap residual activity (Willingham et al., 2008; Norsworthy et al., 2012). Adding residual herbicides is especially important for quizalofop due to the low residual activity of the herbicide (Lancaster et al., 2018).

Although tank-mixing of herbicides is a common practice, efficacy of the herbicides mixed together can often be affected. When this type of interaction occurs, the results may be synergistic, additive, or antagonistic (Colby, 1967). In respect for grass weed control, antagonism of efficacy is more common than synergism (Damalas, 2004). Antagonism of grass weed control between many ACCase-inhibiting herbicides and broadleaf herbicides have well documented (Brommer et al., 2000; Scherder et al., 2005; Kammler et al., 2008). Overall, ACCase-inhibiting herbicides are antagonized by many different herbicides from multiple mechanisms of action. Zhang et al. (2005) reported antagonism of the rice graminicide fenoxaprop on barnyardgrass control from tank-mixes with bensulfuron (ALS-inhibitor), carfentrazone (PPO-inhibitor), and halosulfuron (ALS-inhibitor), all being common herbicides used in rice production. Likewise, broadleaf signalgrass (*Urochloa platyphylla (Munro ex C. Wright) R.D. Webster*) control from fenoxaprop was antagonized by tank-mixes with triclopyr (synthetic auxin) and halosulfuron (Buehring et al., 2006). Antagonism between tank-mixes of halosulfuron, triclopyr (synthetic auxin), and propanil (PSII-inhibitor) with the rice graminicide cyhalofop has also been reported (Scherder et al., 2005).

Quizalofop has been antagonized by tank-mixes with many different herbicides. Minton et al. (1989a,b) reported quizalofop to be antagonized in tank-mixes with chlorimuron (ALS-inhibitor), imazaquin (ALS-inhibitor), and lactofen (PPO-inhibitor) for barnyardgrass control and imazaquin for red rice control. Similarly, tank-mixes with auxinic herbicides such as 2,4-D amine and dicamba can antagonize quizalofop (Blackshaw et al., 2006; Underwood et al., 2016). Interactions among tank-mixes often are rate specific, with the antagonistic effects overcome with increased graminicide rate (Hatzios and Penner, 1985).

Current label restrictions for quizalofop use in broadleaf crops limit single applications to 92.5 g ai ha^{-1} (Anonymous, 2003), with most quizalofop antagonism research evaluating rates ranging from 9 to 70 g ai ha^{-1} (Minton et al., 1989a,b; Culpepper et al., 1999; Blackshaw et al., 2006; Underwood et al., 2016). In quizalofop-resistant rice, the herbicide can be applied at 100–138 g ha^{-1}, a higher use rate than in broadleaf crops (Anonymous, 2017). Enabling these higher use rates in quizalofop-resistant rice may overcome the potential for antagonism that has been observed at lower use rates.

Early results have proven quizalofop to be highly efficacious for grass weeds when used in the quizalofop-resistant rice system (Hale et al., 2016; Lancaster et al., 2016). However, due to quizalofop historically only being labeled in broadleaf crops, there is no research on the potential interactions with common rice herbicides. Determining the compatibility of quizalofop with herbicides used in rice is important to developing appropriate application recommendations for quizalofop-resistant rice. Thus, multiple experiments were conducted to determine the tank-mix interactions between quizalofop and rice herbicides having either broadleaf or grass activity.

2. Materials and methods

Two greenhouse experiments were conducted in the fall of 2015 and the spring of 2016 to determine the tank-mix interactions of quizalofop with rice herbicides on grass weeds found in rice production systems. One experiment evaluated tank-mix interactions of quizalofop with rice herbicides having grass activity, while the other experiment evaluated quizalofop with broadleaf rice herbicides that have little or no efficacy on grasses.

2.1. Quizalofop tank-mix interactions with herbicides having grass activity

The experiment was conducted as a two-factor factorial (2 × 11, totaling 22 treatments), randomized complete block design (RCBD), with factor-A being rate of quizalofop and factor-B being tank-mix partner. The experiments consisted of 4 replications and was conducted twice, with experimental runs considered a random effect. Quizalofop (Targa™ herbicide, Gowan Company, Yuma, AZ) was applied at either 0 or 80 g ai ha^{-1} alone or in tank-mixture with herbicides listed in Table 1. All treatments containing quizalofop, imazethapyr, or penoxsulam contained crop oil concentrate (COC) (Agri-Dex, Helena

Table 1
Tank-mix partners with grass activity applied alone and with quizalofop at 80 g ai ha^{-1}.

Herbicide treatments[ab]	Rate	Trade name	Manufacturer	Address
	g ai ha^{-1}			
Clomazone	313	Command 3E	FMC Corporation	Philadelphia, PA
Pendimethalin	1060	Prowl H_2O	BASF Corporation	Research Triangle Park, NC
Thiobencarb	3360	Bolero	Valent USA Corporation	Longwood, FL
Quinclorac	283[b]	Facet L	BASF Corporation	Research Triangle Park, NC
Propanil	2240	Riceshot	RiceCo	Memphis, TN
Imazethapyr	70	Newpath	BASF Corporation	Research Triangle Park, NC
Bispyribac	28	Regiment	Valent USA Corporation	Longwood, FL
Penoxsulam	35	Grasp SC	Dow AgroSciences	Indianapolis, IN
Cyhalofop	313	Clincher	Dow AgroSciences	Indianapolis, IN
Fenoxaprop	122	Ricestar HT	Bayer CropScience	Research Triangle Park, NC

[a] Any treatments containing quizalofop, imazethapyr, or penoxsulam contained crop oil concentrate at 1% v v-1. Any treatments containing bispyribac contained 2.5% v v^{-1} nonionic surfactant.
[b] Quinclorac expressed as g ae ha^{-1}.