Herbicide-resistance in *Echinochloa oryzoides* and *E. phyllopogon* in California Rice Fields

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Early watergrass (*Echinochloa oryzoides*) and late watergrass (*E. phyllopogon)* have become the most serious weeds in California *rice* since continuous flooding was used to suppress barnyardgrass *(E. crus-galli)*. Continuous use of a limited number of available graminicides and an increasing number of control failures led to the investigation of herbicide resistance in early watergrass and late watergrass. Greenhouse dose-response studies with POST applications of molinate (Ordram), thiobencarb (Bolero), fenoxaprop-ethyl (Whip), and bispyribac-sodium (Regiment) estimating GR_{50} (herbicide dose to inhibit growth by 50%) values suggested resistance to all herbicides in two late watergrass accessions, and to Ordram and Bolero in one early watergrass accession, when compared to susceptible late watergrass and early watergrass control accessions, respectively. No resistance was detected in dose-response studies with propanil. Minimum and maximum ratios (R/S) of the GR_{50} values of resistant to susceptible late watergrass plants (in two experiments involving two resistant accessions) were 7.8 and > 13.3 for Bolero, 2.2 and 4.3 for Ordram, 16.5 and 428.7 for Whip, and 2.0 and 12.0 for Regiment. Minimum and maximum early watergrass R/S ratios (average of two experiments) were 21.9 and 4.6 for Bolero and Ordram, respectively. Thus, early and late watergrass populations may have developed cross and/or multiple resistance. Cross-resistance occurs when a given weed biotype is resistant to different herbicides through a common mechanism, and usually refers to herbicides that share a common mechanism of action. Multiple resistance involves different herbicides and more than one resistance mechanism; this is usually the case of resistance to chemically unrelated herbicides with different mechanisms of action on the weed. A resistant late watergrass (one accession tested) and the susceptible control were killed by POST applications of glyphosate, glufosinate, and clomazone, and by a PRE application of pendimethalin. Thus, the repeated herbicide use patterns resulting from the restricted availability of grass herbicides, and the prevailing practice of continuous rice culture have led to the selection of early watergrass and late watergrass biotypes, with the capacity to survive treatment by different herbicides. Therefore, it is important that the control of these grasses be diversified by the full use of preventive, mechanical, and cultural practices aimed at eliminating the survival, seed production, and dispersal of plants that escape herbicide treatment. Herbicides will continue to be the key resource for weed control in rice, and the importance of avoiding the repeated use of herbicides with the same mode of action cannot be overemphasized. Alternating or mixing herbicides with different modes of action that are equally effective on the target weed should help delay the buildup of resistance. Decisions on alternative herbicides can become more difficult when resistance has already developed to more than one herbicide. In such cases non-chemical means of weed control, such as water management, must be optimized. Some of the fields with resistant watergrass appear in relative proximity, suggesting that dispersal of resistant seed may occur. It is important to prevent transporting resistant seed across fields with agricultural implements, particularly when equipment is shared among growers. It is advisable that the areas infested with herbicide resistant watergrass be harvested last, and the equipment cleaned before proceeding to a new location. Good weed control along irrigation canals is also very important. The possibility of having no tolerance for the presence of watergrass in certified rice seed should be explored. The availability of new herbicides, especially with different modes of action than the existing ones, will be essential to avoid the repeated use of the same chemicals, and thus to delay the buildup of herbicide resistance. Knowledge of herbicide modes of actions and patterns of herbicide resistance, through scouting and testing, will provide a rational basis for herbicide use. Propanil is an amide herbicide that inhibits electron transport at photosystem II, and can also inhibit RNA and protein synthesis, and affect plasmalemma function. Bolero and Ordram are thiocarbamate herbicides that affect lipid (very long-chain fatty acids) biosynthesis. Whip is an aryloxyphenoxy-propionate that inhibits Acetyl CoA carboxylase, and bispyribac is an ALS inhibitor like bensulfuron. Regiment is a new herbicide for which registration in rice is being pursued.

Useful references

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