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A DISSERTATION FOR THE DEGREE OF MASTER OF SCIENCE

Baseline Sensitivity of *Echinochloa* spp. to Triafamone using Multi-Hole Tray assay

AUGUST, 2020

MAJOR IN CROP SCIENCE AND BIOTECHNOLOGY
DEPARTMENT OF PLANT SCIENCE
THE GRADUATE SCHOOL OF SEOUL NATIONAL UNIVERSITY

BY

JANG HO BOO

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UNDER THE DIRECTION OF PROF. DO-SOON KIM
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF SEOUL NATIONAL UNIVERSITY

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APPROVED AS A QUALIFIED DISSERTATION OF
JANG HO BOO
FOR THE DEGREE OF MASTER OF SCIENCE
BY THE COMMITTEE MEMBERS

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ABSTRACT

Baseline sensitivity of *Echinochloa* spp. to Triafamone using Multi-Hole Tray assay

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Herbicide resistance in *Echinochloa* species has been a serious problem in paddy weed management using herbicide. Understanding the baseline sensitivity of an important weed to a new herbicide becomes essential in herbicide development as the baseline sensitivity provides the potential risk of herbicide resistance development in the weed. Therefore, this study was conducted to estimate the baseline sensitivity of *Echinochloa* species, *E. oryzicola* and *E. crus-galli*, to a new acetolactate synthase (ALS) inhibitor triafamone. For this study, a multi-hole tray assay was designed to assess herbicide dose-responses of multiple accessions in a limited space at a time. Pre-germinated seeds of *E. crus-galli* and *E. oryzicola* accessions collected in Gyeonggi and Gangwon provinces in 2016

were planted in the multi-hole tray placed in the triangular plastic tray and grown under semi-flooded condition in the greenhouse. At the 4 leaf stage, the triangular plastic tray containing the multi-hole tray was fully flooded and triafamone was applied to the flooded tray at a range of doses, 0, 3.125, 6.25, 12.5, 25, 50, 100 g a.i. ha^{-1}. Non-linear regression analysis by fitting fresh weight measured at 30 days after treatment (DAT) to the log-logistic model estimated GR_{50} values, the dose requiring 50% fresh weight reduction of *Echinochloa* and the baseline sensitivity index (BSI) was calculated by dividing the greatest GR_{50} value by the smallest GR_{50} value for each *Echinochloa* species. For *E. oryzicola*, the GR_{50} values ranged from 3.09 g to 95.06 g a.i. ha^{-1} with the mean of 11.34 and the median of 5.19 g a.i. ha^{-1}, resulting in the BSI of 30.76. For *E. crus-galli*, the GR_{50} values ranged from 1.89 g to 31.39 g a.i. ha^{-1} with the mean of 7.24 and the median of 5.87 g a.i. ha^{-1}, resulting in the BSI of 16.61. Our findings thus suggest that triafamone has a high potential risk of herbicide resistance development in *Echinochloa* species, with a greater potential risk of herbicide resistance development in *E. oryzicola* than *E. crus-galli*. This may be due to the long-term use of other ALS inhibitors for *Echinochloa* control in paddy rice fields of Korea for over 30 years. Therefore, the integrated use of triafamone with other herbicides with different modes of action is highly recommended to maintain its sustainable use in paddy field condition. To maintain the sustainability of

triafamone, it is necessary to use triafamone in mixture or in rotation with other herbicides with different modes of action.

Keywords: baseline sensitivity, *Echinochloa* spp., multi-hole tray assay, triafamone

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1. INTRODUCTION

Ehinochloa species is one of the major weeds in paddy fields and one of the most troublesome weeds due to its high competitiveness (Moon et al., 2010) as well as dominance in paddy fields. It is essential to control *Echinochloa* species for securing rice yield, so chemical herbicides have played a key role in *Echinochloa* species management. However, the continuous use of herbicides, particularly those with the same mode of action such as acetyl CoA carboxylase (ACCase) and acetolactate synthase (ALS) inhibitors, has resulted in herbicide resistance development in *Echinochloa* species. Since 2007, when the first herbicide resistant *Echinochloa* species was reported in the Seosan reclaimed paddy field (Im et al., 2009), *Echinochloa* species has become a primary target weed for a new herbicide development in Korea. Many new herbicides with a particular activity against *Echinochloa* species have been developed including triafamone, which claims that it can control herbicide resistant *Echinochloa* species.

Triafamone is a new ALS inhibitor belonging to a sulfonanilide herbicide discovered and developed by Bayer CropScience AG, Germany (Rosinger et al., 2012). It can control not only *Echinochloa* species but also many other broadleaf and sedge weeds with relatively wide application window ranging from preemergence to late post-emergence timings, up to the 4 leaf stage of *Echinochloa* species. The first commercial registration in Korea was made in 2012 and has been applied to the flooded paddy field for post-emergence weed control. Although it is claimed that triafamone can control existing herbicide resistant *Echinochloa* species including ALS inhibitor resistant *Echinochloa* species because triafamone belongs to a different chemistry from the other ALS inhibitors belonging to sulfonylurea and triazolopyrimidine, flucetosulfuron and penoxsulam, respectively. However, no study has been conducted to test against existing ALS inhibitor resistant *Echinochloa* species. ALS inhibitors have extensively been used in Korean paddy fields since the first introduction of ALS inhibitor bensulfuron-methyl in 1987. Therefore, it is likely that natural variation in sensitivity of *Echinochloa* species to triafamone might be changed due to the other ALS inhibitors used previously. It is necessary to evaluate natural variation in the sensitivity to triafamone at early stage of its introduction because the baseline sensitivity provides us with information of potential herbicide resistance development.

When a new herbicide is newly introduced to control a particular weed, there is a natural variation in the sensitivity of the weed to the new herbicide. The larger the variation, the greater the potential risk of resistance development to the herbicide is. Natural variation defines that each accession in the same species has different innate genetic variation, indicating the range of innate resistance/sensitivity among populations (Robertson et al., 1995). Based on the natural variation of herbicide sensitivity, we can estimate baseline sensitivity, which provides information related to field dose recommendation and potential risk of herbicide resistance development (Beckie et al., 2000; Paterson et al., 2002; Tang et al., 2011). However, baseline sensitivity study requires dose-response study with a large number of weed accessions, so costs a lot due to the requirement of large space, long period of time and many efforts. A new test method for the baseline sensitivity study is needed to save space, time, labor and cost.

Therefore, this study was conducted to develop a new test method for the baseline sensitivity test with *Echinochloa* species, and to evaluate baseline sensitivity of two *Echinochloa* species, *E. oryzicola* and *E. crus-galli*, to triafamone in order to estimate the potential risk of triafamone resistance development in *Echinochloa* species.

2. LITERATURE REVIEW

2.1. Herbicide resistant weeds in paddy fields

Herbicide resistant weeds have been a serious problem in agricultural land worldwide, and was only recently been reported. Up to now, 514 cases of herbicide resistant weeds have been reported globally against 167 different herbicides of more than 20 sites of action (Heap, 2020). Furthermore, 92 crops were affected by herbicide resistant weeds (Fartyal et al., 2018). Development of herbicide resistance in paddy fields is a big challenge for rice production, particularly in Asian countries. In Japan, the first herbicide resistant weed was reported in *Monochoria korsakowii* in 1997 (Itoh et al., 1999), and then resistant *Monochoria vaginalis* and *Lindernia michrantha* were reported (Kohara et al., 1999; Yoshida et al., 1999). In Korea, the first herbicide resistance was reported in *Monochoria korsakowii* in Seosan paddy fields in 1998 (Park et al., 1999), and other resistant weeds were subsequently reported in *Monochoria vaginalis*, *Lindernia dubia*, *Rotala indica*, *Cyperus difformis* L. and *Scirpus juncoides* (Park et al., 2001). Up to now, 15 herbicide resistant weed species have been reported in Korean paddy fields; *Monochoria korsakowii*, *Monochoria vaginalis*, *Lindernia dubia*, *Schoenoplectus juncoides*, *Cyperus difformis*, *Saqittaria pyqmaea*, *Schoenoplectus fluviatilis*, *Echinochloa oryzicola*, *Eleocharis* *acicularis*, *Blyxa aubertii*, *Echinochloa crus-galli*, *Sagittaria trifolia*, *Ludwigia prostrata*, *Leptochloa chinensis* and *Conyza canadensis* (Park et al., 1999; Kwon et al., 2000; Park et al., 2001; Kuk et al., 2002; Im et al., 2003; Im et al., 2005; Park et al., 2006; Im et al., 2009; Park et al., 2010; Park et al., 2011; Park et al., 2013; Aung et al., 2018).

Echinochloa is one of the most troublesome weeds among herbicide resistant species, especially in Asia where rice is a major crop. The competition between *Echinochloa* species and rice significantly affects the yield loss (Ni et al., 1996). Emergence of herbicide resistant *Echinochloa* species reduces rice product yield due to its high competitiveness as well as efficiency of weed control (Ni et al., 1996). Many studies have been made to control resistant *Echinochloa* species in Asia. For instance, in 1991, resistant *Echinochloa* species was first reported in Guangdong Province, China (Huang, 1993). In Japan, cyhalofop-butyl (ACCase inhibitor) resistant *Echinochloa crus-galli* var. *formosensis* was first reported in Okayama Province. (Iwakami et al., 2015). In case of Korea, among 50 *Echinochloa* species (Michael., 1983), *E. crus-galli* and *E. oryzicola* are most dominant species distributed in Korea (Lee et al., 2013). Herbicide resistant *Echinochloa* species was first reported in Seosan paddy field (Im et al., 2009), and furthermore multiple herbicide resistance was reported in *Echinochloa* spp. afterwards (Kim, 2016; Song et al., 2017). However, single or multiple herbicide resistant in Korea is limited to ALS and ACCase-inhibitors (Won et al., 2014). Resistant *Echinochloa* species was also confirmed using chlorophyll fluorescence (Zhang et al., 2016 and 2017). Herbicide resistant *Echinochloa* species in Korea are known to have metabolism-based resistance (Kim, 2016; Song et al., 2017). As a part of efforts to control herbicide resistant weeds, new herbicides with different chemical structures and biological profiles have also been introduced, including ALS inhibitors such as triafamone (Rosinger et al., 2012), HPPD inhibitors such as tefuryltrione (Song et al., 2016), and auxinic herbicides such as florpyrauxifen-benzyl (Duy et al., 2018).

Resistant weeds are caused by the continuous use of herbicides with the same mode of action (Holt et al., 1993). In the 1980s, SU (sulfonylurea) herbicides were registered and distributed in Korea. Initially, herbicides mixture of SU and butachlor to control weeds in early stage have been widely used (Park et al., 2002). Due to such wide uses combined with the increased cultivation area of rice, *Echinochloa* species that are resistant to one-shot-treatment herbicide that mixed SU herbicide with molinate or mefenacet increased in early 1990s. Furthermore, selection pressure of SU herbicide (Primiani et al., 1990; Prather et al., 2000) made herbicide resistant *Echinochloa* species to spread across most of the provinces in Korea (Lee et al., 2017). Once a weed develops a resistance for a specific herbicide, it is common that the weed is not controlled by other herbicides with the same mode of action (Holt et al., 1993). Thus, a detailed analysis on development of herbicide resistance is needed.

2.2. Baseline sensitivity study

Baseline sensitivity can provide herbicide resistance criteria of dose-response of a new herbicide (Espeby et al., 2011), thus it can give an index of herbicide resistance potential under continuous use of herbicide in weed population (Tang et al., 2011). Baseline sensitivity studies have been widely used in the medical field and other types of pesticides (Lautt et al., 1998; Tang et al., 2011; Wise et al., 2008; Wong et al., 2010; Yuan et al., 2006). For instance, baseline sensitivity study can provide recommend dose of insecticide of pesticide to prevent insect (Cahill et al., 1996; Lautt et al., 1998; Wise et al., 2008; Wong et al., 2010) and determine standard dose of germicide to pathogen and epidemic disease (Tang et al., 2011; Yuan et al., 2006). Various herbicides with different modes of action have been used to control resistant *Ehinochloa* species; for example, PS II, ACCase, and ALS inhibitor. (Baltazar et al., 1994; Im et al., 2009; Won et al., 2014). However, there is an increasing concern that herbicide resistant weeds may develop for those new herbicides because metabolism-based herbicide resistance often shows resistance to other herbicides with different chemical structures and modes of action (Hatzios., 2004; Yu et al., 2014). Basic information such as recommended dose and application timing is needed to predict danger of resistant occurrence to newly registered herbicide. A detailed study is needed for an accurate prediction and efficient controlling, and baseline sensitivity test is a good method for gaining basic information needed for application of newly registered herbicide (Paterson et al., 2002; EPPO, 2003). The baseline sensitivity study can be used to set recommended dose, to predict the risk of herbicide resistance before new herbicides are registered, to prepare for the future list of continuous use of the new herbicides based on baseline information (Beckie et al., 2000), and can be a way to set an effective weed management (Paterson et al., 2002; Vidotto et al., 2007). Species also will have different responses to external stimulation such as temperature, moisture, salinity, wind, soil condition, fungicide, and insect (Mehta, 2018), because each plant species has different innate tolerance due to the natural variation (Robertson et al., 1995), which means that natural resistant varieties may exist. Therefore, it is necessary to investigate natural variation in herbicide sensitivity in every single weed species as the variation in sensitivity to a new herbicide can imply potentials for herbicide resistance development at high selection pressure (Warwick et al., 1991).

The main objective of baseline sensitivity study is to evaluate natural variation in herbicide sensitivity of species poulation in a target area (Espeby et al., 2011;

Kanetis et al., 2008; Lim, 2013). A few baseline sensitivity studies were conducted for several herbicides in last two decades. Baseline sensitivity of *Papaver rhoeas* collected from three European countries, Italy, France, Spain, and UK was investigated for florasulam and revealed that P. rhoeas accession from Spain had greater sensitivity variation (Paterson et al., 2002). The baseline sensitivity of 3 *Echinochloa* species was also investigated for 6 herbicides revealing that *Echinochloa* species had a high sensitivity variation even in the same species and *E. crus-galli* was more sensitive to most of the herbicides (Vidotto et al., 2007). Penoxsulam on *Alisma plantago-aquatica* L., *Cyperus difformis*, and *Schoenoplectus mucronatus* was recently investigated to estimate the baseline sensitivity in these paddy weeds (Loddo et al., 2018). Even old herbicides were also investigated to evaluate their baseline sensitivity in a specific weed. Glyphosate and dalapon on *Lolium rigidum* and *Bromus diandrus* in Spain (Barroso et al., 2010), various herbicides on Illinois waterhemp (Patzoldt et al., 2002), and dicamba on waterhemp in Nebraska (Crespo et al., 2016) were investigated. In Korea, baseline sensitivity study for *E. crus-galli* was also conducted for herbicides inhibiting very long chain fatty acid synthase (VLCFAs) to estimate potential risk of resistance development to VLCFAs inhibitors (Lim, 2013). Nowadays, baseline sensitivity study becomes essential for a new herbicide to estimate the potential risk of herbicide resistance development

3. MATERIALS AND METHODS

3.1 Collection of *Ehinochloa* species

Seeds of *E. crus-galli* and *E. oryzicola* accessions were collected from paddy fields located in Gyeonggi and Gangwon provinces, Korea in 2016. Among collected accessions, 40 and 81 accessions of *E. crus-galli* and *E. oryzicola*, respectively, were selected for the study (Figure 1, Table A1 and Table A2).

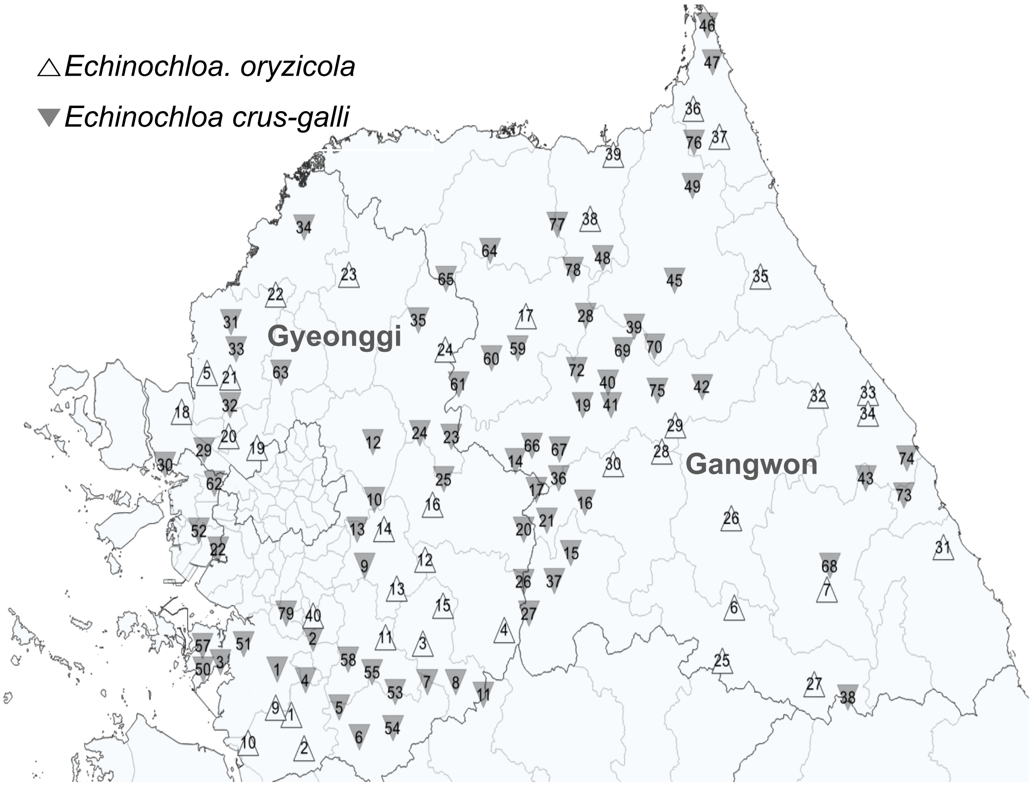


Figure 1. Collection sites of *E. crus-galli* and *E. oryzicola* accessions.

3.2. Plant preparation

Experiment was conducted in the greenhouse located at the Experimental Farm Station of Seoul National University, Suwon, Korea. *Echinochloa* spp. seeds were germinated in the growth chamber under a 14-hour photoperiod and 30/25℃ day/night temperature for 72 hours, and the pre-germinated seeds were planted into the multi-hole tray (3.5 cm x 3.5 cm x 4.5 cm)filled with paddy soil (Figure 3). Each accession was planted in each hole of the multi-hole tray and *Echinochloa* plants were grown under semi-flooded condition until the 3 leaf stage. Afterwards, the plants were maintained under flooded condition until the 4^{th} leaf stage when triafamone was treated.

3.3. Baseline sensitivity study by the multi-hole tray assay

To evaluate the baseline sensitivity of *Echinochloa* species to triafamone (Figure 2), whole plant dose-response study with *Echinochloa* accessions collected from different locations is required. For the whole plant dose-response study, the multi-hole tray assay was conducted as described in Figure 3 as this assay is designed for direct herbicide application to the flooded paddy field. At the 4 leaf stage of *Echinochloa* species, triafamone (4.9% SC, Bayer CropScience AG, Korea) was directly applied to the flooded multi-hole tray, which was submerged into the triangular plastic tray fully filled with water, at a range of doses from 3.125 g to 100 g a.i. ha^{-1} and untreated control was included. The trays were then arranged in the greenhouse in a randomized block design with 3 replications. At 30 days after treatment (DAT), visual efficacy and shoot fresh weight were measured.

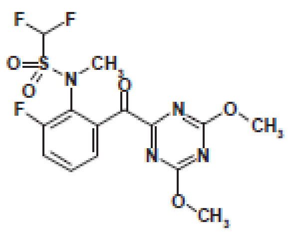
Common name	Triafamone
Chemical name (IUPAC)	2'-[(4,6-dimethoxy-1,3,5-triazin-2-yl)carbonyl]-1,1,6'-trifluoro-N-methylmethanesulfonanilide
Structural formula	

Figure 2. Chemical name and structure of triafamone.

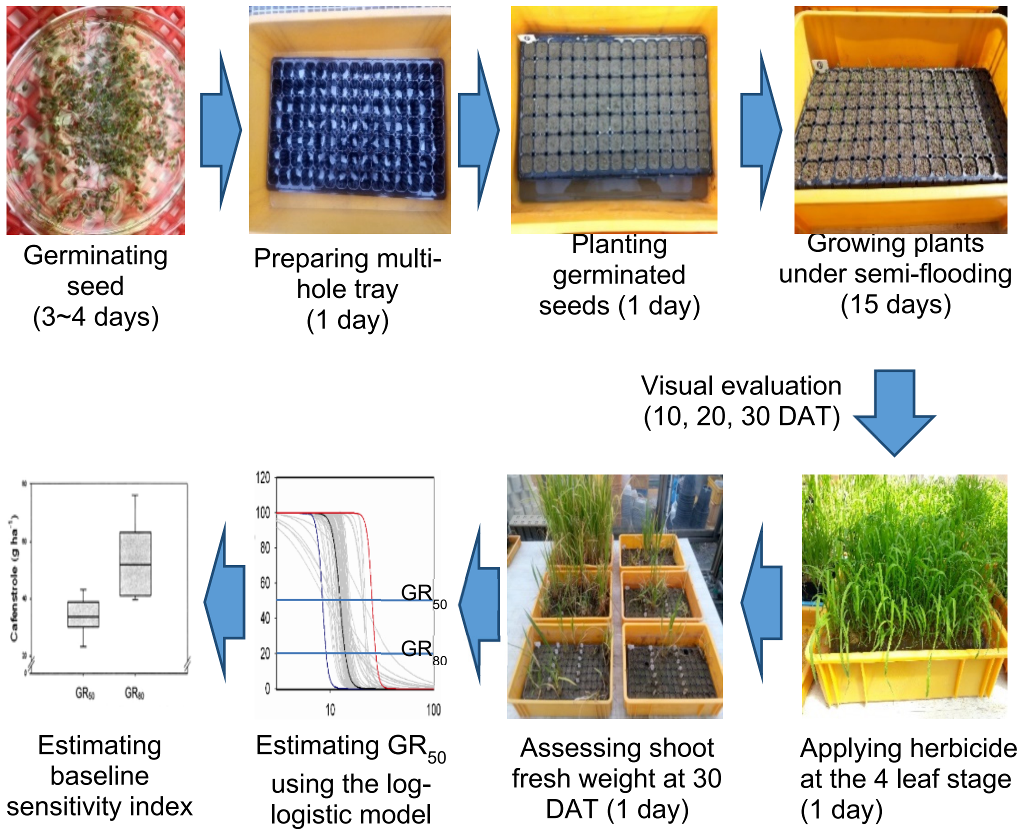


Figure 3. Procedure of baseline sensitivity study using multi-hole tray assay.

3.4. Statistical analysis

All the data were subjected to analysis of variance (ANOVA). Non-linear regression analysis was conducted to fit both the visual efficacy and fresh weight measured at 30 DAT to the log-logistic model, a standard dose-response curve (Streibig, 1980), as follows,

$$Y = \frac{100}{1 + \left(\frac{D}{GR_{50}}\right)^{B}} \qquad [1]$$

Where, Y is the response, D is herbicide dose, B is the slope of the curve, and the GR_{50} refers to a triafamone dose that causes 50% growth inhibition as compared to untreated control. The aboveground fresh weight was expressed as percentages based on untreated controls before the statistical analysis.

To evaluated the baseline sensitivity, baseline sensitivity index was calculated by dividing the greatest GR_{50} value ($GR_{50\ max}$) by the smallest GR_{50} value ($GR_{50\ min}$) as follows,

$$BSI = \frac{GR_{50,Max}}{GR_{50,Min}} \qquad [2]$$

All the statistical analyses were conducted using Prism 7.04 (GraphPad Softwares, USA).

4. RESULTS

4.1. Dose-response of *E. oryzicola* in responding to triafamone

The baseline sensitivity study was conducted using the multi-hole tray assay with *E. oryzicola* accessions and the non-linear regression analysis revealed a typical dose-responses of *E. oryzicola* to triafamone (Figure 4). Iksan accession tested as a resistant reference showed the GR_{50} value of 20.1 g a.i. ha^{-1}, while Suwon accession tested as a sensitive reference showed the GR_{50} value of 3.1 g a.i. ha^{-1} (Figure 5). Therefore, the difference between GR_{50} values of Iksan and Suwon was 6.5 times, demonstrating that the multi-hole tray assay is a useful assay tool for dose-response study and discrimination between resistant and sensitive accessions. As presented in Table A1, 30 accessions (75%) showed GR_{50} value less than 10 g a.i ha^{-1}, suggesting that they are sensitive to triafamone. 7 accessions (17.5%) showed GR_{50} values between 10 g to 20 g a.i ha^{-1}, suggesting that they are moderately sensitive to triafamone. Interestingly, 3 accessions (7.5%) showed GR_{50} value greater than 40 g a.i ha^{-1}. As the recommended dose of triafamone is 50 g a.i. ha^{-1}, these accessions cannot be effectively controlled by triafamone, suggesting that they are already insensitive or resistant to triafamone. The most insensitive or resistant accession was from Paju-1 with the GR_{50} of 95.1 g a.i. ha^{-1}, followed by Yeongwol-2, Gimpo and

Iksan reference with GR_{50} values of 65.1, 39.9, 20.1 g a.i. ha^{-1}, respectively (Table A1).

As presented in Figures 4 and 5, Goseong-1 accession from Gangwon province showed the greatest sensitivity with the smallest GR_{50} of 3.1 g a.i. ha^{-1}, while Paju-1 accession from Gyeonggi province showed the greatest GR_{50} of 95.1 g a.i. ha^{-1} (Table A1), resulting in 30.8 times difference between them. The mean value of GR_{50} was 11.3 g a.i. ha^{-1}, and the median value of GR_{50} was 5.2 g a.i. ha^{-1} (Figure 6). Distribution of *E. oryzicola* accessions by GR_{50} values showed that the graph was right-skewed due to some of accessions with a significantly high GR_{50} value greater than 10 g a.i. ha^{-1} as compared with the median and mean GR_{50} values.

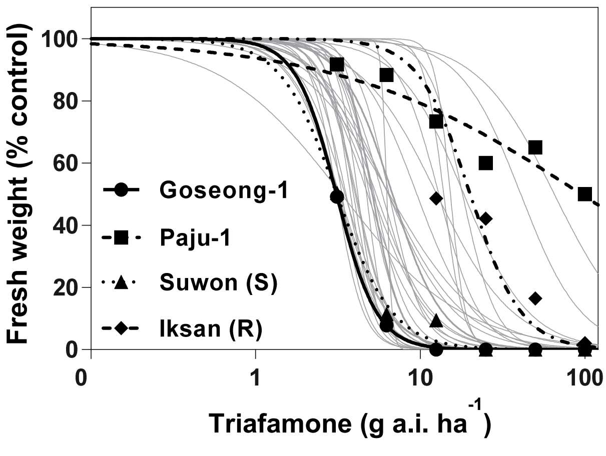


Figure 4. Dose-response curves in fresh weight (% control) of *E. oryzicola* accessions measured at 30 days after triafamone treatment.

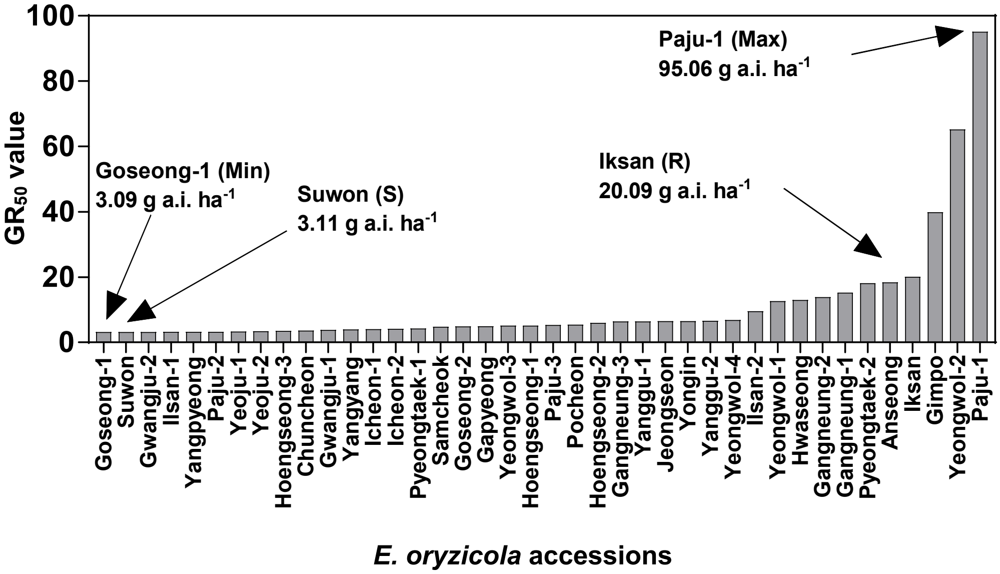


Figure 5. Distribution of GR_{50} values in fresh weight of *E. oryzicola* accessions in responding to triafamone.

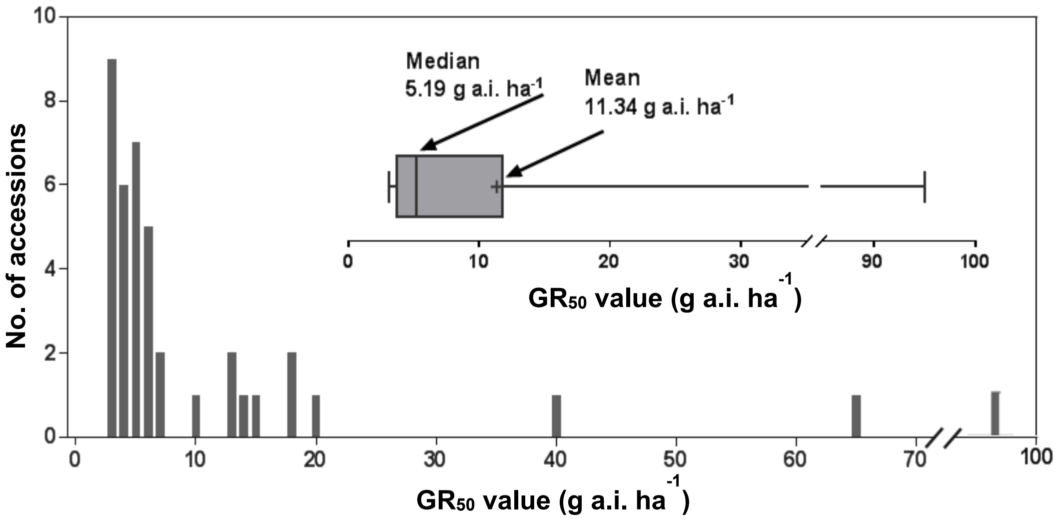


Figure 6. Frequency distribution of *E. oryzicola* accessions by GR_{50} values in fresh weight in responding to triafamone.

4.2. Dose-response of *E. crus-galli* in responding to triafamone

The baseline sensitivity study was conducted using the multi-hole tray assay with *E. crus-galli* accessions and the non-linear regression analysis revealed a typical dose-responses of *E. crus-galli* to triafamone (Figure 7). Seosan accession tested as a resistant reference showed the GR_{50} value of 21.7 g a.i. ha^{-1}, while Suwon accession tested as a sensitive reference showed the GR_{50} value of 6.1 g a.i. ha^{-1} (Figure 8). The difference between GR_{50} values of Seosan and Suwon was 3.5 times, demonstrating that the multi-hole tray assay is a useful assay tool for dose-response study and distinguishing between resistant and sensitive accessions. As presented in Table A2, 72 accessions (89%) showed GR_{50} value less than 10 g a.i. ha^{-1}, suggesting that they are sensitive to triafamone. 6 accessions (7%) showed GR_{50} values between 10 g to 20 g a.i. ha^{-1}, suggesting that they are moderately sensitive to triafamone. 3 accessions (3%) showed GR_{50} values between 20 to 30 g a.i. ha^{-1}, suggesting that they are moderately insensitive to triafamone. The most insensitive or resistant accession was from Wonju-1 with the GR_{50} of 31.4 g a.i. ha^{-1}, followed by Seosan reference, Yongin-1 and Pocheon-2 with GR_{50} values of 21.7, 20.9, 19.8 g a.i. ha^{-1}, respectively (Table A2).

As presented in Figures 7 and 8, Pocheon-3 accession from Gyeonggi province showed the greatest sensitivity with the smallest GR_{50} of 1.9 g a.i. ha^{-1}, while Wonju-1 accession from Gangwon province showed the greatest GR_{50} of 31.4 g a.i. ha^{-1} (Table A1), resulting in 16.6 times difference between them. The mean value of GR_{50} was 7.2 g a.i. ha^{-1}, and the median value of GR_{50} was 5.9 g a.i. ha^{-1} (Figure 9). Distribution of *E. crus-galli* accessions by GR_{50} values also showed that the graph was right-skewed due to some of accessions with a significantly high GR_{50} value greater than 10 g a.i. ha^{-1} as compared with the median and mean GR_{50} values, but the skewedness was less than the case of *E. oryzicola* (Figure 6 and 9).

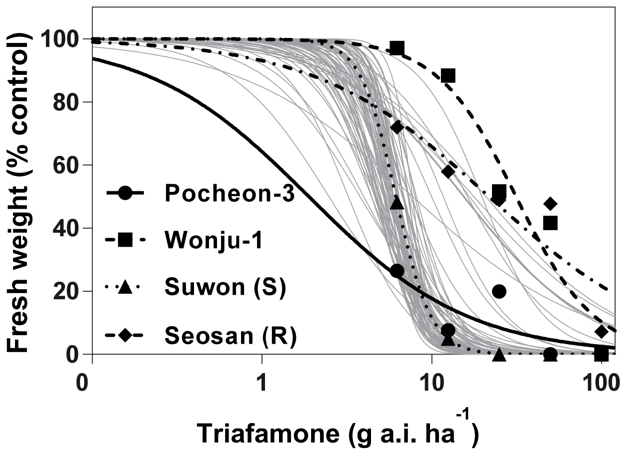


Figure 7. Dose-response curves in fresh weight (% control) of *E. crus-galli* accessions measured at 30 days after triafamone treatment.

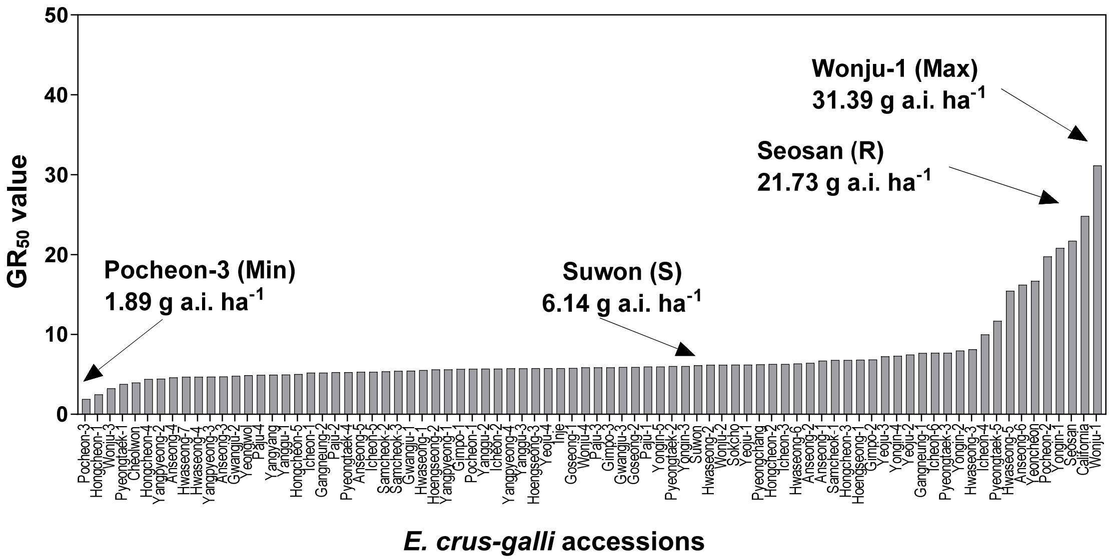


Figure 8. Distribution of GR_{50} values in fresh weight of *E. crus-galli* accessions in responding to triafamone.

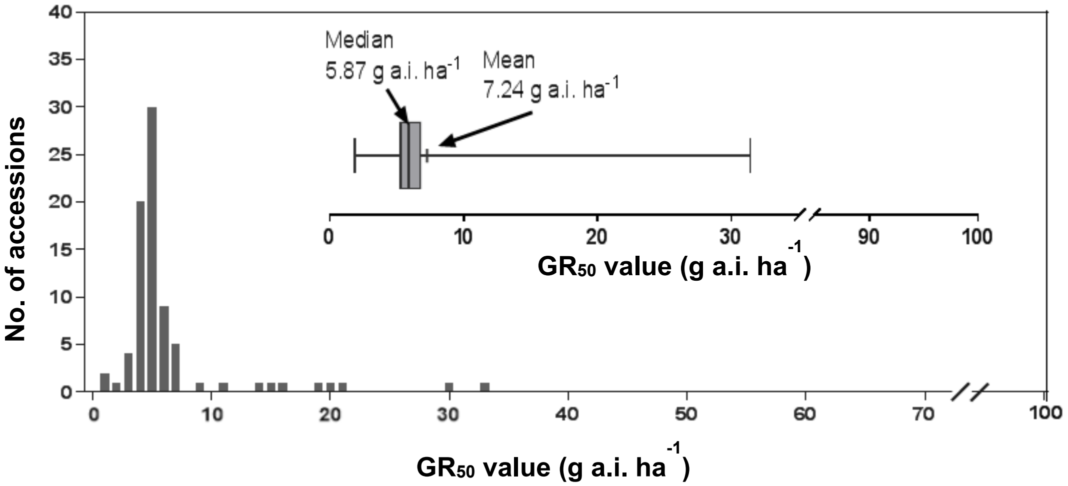
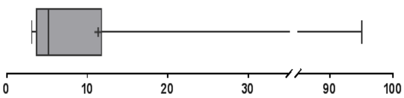
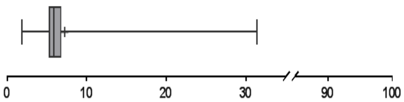


Figure 9. Frequency distribution of *E. crus-galli* accessions by GR_{50} values in fresh weight in responding to triafamone.

4.3. Baseline sensitivity index of triafamone against *Echinochloa* species

Baseline sensitivity indices (BSI) of triafamone to *E. oryzicola* and *E. crus-galli* were calculated by dividing the greatest GR_{50} value by the smallest GR_{50} value (Table 1). The range of GR_{50} values of *E. oryzicola* was wider than those of *E. crus-galli*. In the case of *E. oryzicola*, the GR_{50} values ranged from 1.89 to 31.39 g a.i. ha^{-1}, resulting in 30.76 times difference, so the baseline sensitivity index (BSI) was 30.76. In the case of *E. crus-galli,* the GR_{50} values ranged from 3.09 to 95.06 g a.i. ha^{-1}, resulting in 16.61 times difference, so the baseline sensitivity index (BSI) was 16.61. Overall, the baseline sensitivities of both *Echinochloa* species are greater than 10, suggesting that they have high potential of resistance development or have already developed resistant to triafamone. Interestingly, the greater BSI of *E. oryzicola* than that of *E. crus-galli* indicates that *E. oryzicola* has greater natural variation in sensitivity to triafamone, and thus suggests that *E. oryzicola* has greater risk of future resistance development to triafamone and its resistance development is farther advanced than *E. crus-galli*.

Table 1. The range of GR_{50} values and baseline sensitivity index of *E. oryzicola* and *E. crus-galli*.

Species	*Echinochloa oryzicola*	*Echinochloa crus-galli*
Greatest GR_{50} (A)	95.06 g a.i. ha^{-1}	31.39 g a.i. ha^{-1}
Smallest GR_{50} (B)	3.09 g a.i. ha^{-1}	1.89 g a.i. ha^{-1}
GR_{50} range		
Baseline sensitivity index (A/B)	30.76	16.61

5. DISCUSSION

5.1 Comparison of baseline sensitivity between *Echinochloa* species

Most of GR_{50} values the *E. oryzicola* were located between 3 and 10 g a.i. ha^{-1}, and those of *E. crus-galli* were located between 1 to 10 g a.i. ha^{-1}, revealing that triafamone controlled most of *Echinochloa* species in Gyeonggi and Gangwon provinces effectively. However, that of 3 accessions of *E. oryzicola* and no accession of *E. crus-galli* was located above 40 g a.i. ha^{-1}, indicating that the sensitivity range of the *E. oryzicola* may be higher than that of *E. crus-galli*. The sensitivity range also could be estimated from the difference between mean and median value. The mean and median GR_{50} value of *E. oryzicola* was 11.3 and 5.2 g a.i. ha^{-1}, and those of *E. crus-galli* was 7.2 g a.i. ha^{-1} and 5.9 g a.i. ha^{-1}. This shows that the baseline sensitivity of the *E. oryzicola* is greater than that of *E. crus-galli*, and the population shift was caused by the selection pressure of *E. oryzicola* due to continuous application of herbicide and the innate natural variation of *E. oryzicola* which is higher than *E. crus-galli* (Robertson et al., 1995; Paterson et al., 2002; Espeby et al., 2011).

The BSI of both 2 *Echinochlo*a species shows high value, because some accessions of *Echinochloa* species had high GR_{50} value. The right-skewness indicated herbicide use in Korea inflicted the selection pressure and affected the population shift of *E. oryzicola* and *E. crus-galli* (Vidotto et al., 2007). The reason why BSI of *Echinochloa* species is high was because the mode of action of triafamone is ALS inhibitor. An *E. crus-galli* which is resistant to penoxsulam, an another ALS inhibitor, was reported in Seosan, Chungnam province (Im et al.,2009). Furthermore, cross-resistance to ALS inhibitor of different chemical classes, azimsulfuron (sulfonylurea), penoxsulam (triazolopyrimidine sulfonanilide) and bispyribac-sodium (pyrimidinyl thio benzoate), was reported in *Echinochloa* species (Song et al., 2017). Although triafamone has different chemical class in comparison to existing ALS inhibitor, their common functions are inhibiting acetolactate synthesis, thus resistant to triafamone could occur by a long time usage because of the selection pressure of *Echinochloa* species. As BSI value proves, some accessions of *Echinochloa* species are already progressing selection pressure. Therefore, measures will be needed to control the development of resistant *Echinochloa* species to triafamone.

5.2. Sustainable use of triafamone for *Echinochloa* management

Our study determined that triafamone can control most of the *Echinochloa* species and revealed that *Echinochloa* species tested in this study hade a high baseline sensitivity index (BSI), 30.8 for *E. oryzicola* and 16.6 for *E. crus-galli*. Two (2) *E. oryzicola* accessions, Paju-1 and Yeongwol-2, showed GR_{50} value greater than the recommended dose of triafamone, suggesting that they would not be controlled by the herbicide due to their high insensitivity or resistance. The high BSI values of both *Echinochloa* species indicate that triafamone has a high potential risk of resistance development in both *Echinochloa* species in Gyeonggi and Gangwon provinces of Korea. The high BSI values of *E. oryzicola* and *E. crus-galli* may be related to the history of herbicide use in Korean paddy fields, particularly acetolactate synthase (ALS) inhibitor. Korea has a long history of ALS inhibitor uses, particularly sulfonylurea herbicides from 1987. The existing herbicide resistance in *Echinochloa* species reported are ACCase and ALS inhibitor resistance but their resistance mechanism is related to CP450s-mediated metabolism (Song et al., 2017). Therefore, although triafamone belongs to different chemical class with ALS inhibiting activity, it can also be metabolized by the CP450s, leading to high insensitivity to triafamone. It is clear that the potential risk of resistance development against triafamone would be higher if triafamone is continuously used without rotation or mixing with other herbicides with different modes of action. A longer strategic approach is required for a proper use of triafamone to avoid or minimize resistance development in *Echinochloa* species, not only in Korea but also in other countries where triafamone is registered for *Echinochloa* control in rice.

Herbicides with a particular mode of action have intensively been used in Korea, particularly sulfonylurea (SU) herbicide since the registration of bensulfuron-methyl in 1987. It took 10 years to develop SU resistant weeds with the first SU resistance found in *Monochoria korsakowii* (Park et al., 1999). Due to the continuous use of SU herbicides, resistant weeds to SU herbicides occurred and became widespread (Primiani et al., 1990; Prather et al., 2000). Another 10 years required to develop ACCase and ALS inhibitors resistant *Echinochloa* species since ACCase and ALS inhibitors with a particular activity against *Echinochloa* species were intensively used in early 2000s. It is now necessary not to solely rely on a single herbicide with a particular mode of action but to apply herbicides in rotation or mixture with other herbicides with different modes of action. SU herbicides in mixture with butachlor, molinate or mefenacet have been recommended to control SU resistant weeds (Park et al., 2002). Furthermore, integrated weed management (IWM) including not only chemical herbicide but also physical, biological and cultural methods (Kohli et al., 2006; and Lamichhine et al., 2016) is needed for an effective management of existing herbicide resistant weeds and prevention of potential development of resistant to triafamone in the near future. The use triafamone in mixture or in rotation with other herbicides with different modes of action is needed to maintain the sustainability of triafamone.

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APPENDIX

Table A1. Summary of dose-response study *E. oryzicola* accessions tested for the baseline sensitivity to triafamone

Accession	Collected area		Accession code	GPS information		Statistics data		R^2
No.	Province	City/County		Latitude	Longitude	GR_{50} (SE)	B (SE)	
1	Gyeonggi	Pyeongtaek-1	SNU-E-12.023	37˚03´47.6″	127˚00´01.3″	4.18 (0.36)	6.69 (1.81)	0.94
2	Gyeonggi	Anseong	SNU-E-12.029	36˚59´28.4″	127˚12´37.0″	18.39 (4.18)	2.19 (0.98)	0.69
3	Gyeonggi	Icheon-1	SNU-E-12.049	37˚13´01.0″	127˚25´52.8″	4.02 (1.18)	4.15 (2.73)	0.99
4	Gyeonggi	Yeoju-1	SNU-E-12.057	37˚14´41.6″	127˚41´52.4″	3.32 (1.31)	1.18 (0.42)	0.93
5	Gyeonggi	Paju-1	SNU-E-12.104	37˚48´09.2″	126˚43´22.1″	95.06 (16.95)	0.59 (0.07)	0.89
6	Gangwon	Yeongwol-1	SNU-E-12.166	37˚27´10.8″	128˚27´02.1″	12.59 (1.21)	1.86 (0.30)	0.94
7	Gangwon	Jeongseon	SNU-E-12.175	37˚35´80.4″	128˚77´54.4″	6.46 (0.46)	4.27 (1.67)	0.92
8	Reference	Iksan	SNU-E-06.015	35°55'46.1"	126°54'31.5"	20.09 (6.61)	2.78 (2.21)	0.53

9	Gyeonggi	Hwaseong	SNU-E-12.016	37°04′40.3″	126°56′59.2″	12.96 (3.39)	3.49 (3.29)	0.51
10	Gyeonggi	Pyeongtaek-2	SNU-E-12.018	37°00′09.9″	126°51′36.8″	18.06 (3.15)	4.23 (2.10)	0.76
11	Gyeonggi	Yongin	SNU-E-12.047	37°13′48.6″	127°18′32.9″	6.48 (1.19)	1.59 (0.50)	0.81
12	Gyeonggi	Yeoju-2	SNU-E-12.064	37°23′50.2″	127°26′19.0″	3.34 (0.15)	5.66 (2.64)	0.95
13	Gyeonggi	Gwangju-1	SNU-E-12.070	37°25′05.7″	127°14′48.8″	3.77 (0.15)	6.19 (1.18)	0.98
14	Gyeonggi	Gwangju-2	SNU-E-12.072	37°27′55.5″	127°18′19.3″	3.11 (0.11)	5.31 (2.92)	0.96
15	Gyeonggi	Icheon-2	SNU-E-12.078	37°17′56.1″	127°29′47.4″	4.09 (0.38)	4.17 (1.18)	0.88
16	Gyeonggi	Yangpyeong	SNU-E-12.082	37°31′02.4″	127°27′52.7″	3.19 (0.25)	3.44 (1.25)	0.91
17	Gangwon	Chuncheon	SNU-E-12.092	37°55′28.7″	127°46′28.2″	3.54 (0.23)	4.13 (1.24)	0.92
18	Gyeonggi	Gimpo	SNU-E-12.096	37°43′03.6″	126°38′27.3″	39.85 (9.52)	2.13 (1.00)	0.67
19	Gangwon	Ilsan-1	SNU-E-12.100	37°38′24.6″	126°48′15.1″	3.17 (0.20)	2.88 (0.64)	0.96
20	Gangwon	Ilsan-2	SNU-E-12.101	37°39′56.1″	126°47′43.1″	9.53 (0.64)	2.45 (0.39)	0.98
21	Gyeonggi	Paju-2	SNU-E-12.105	37°47′34.8″	126°47′57.0″	3.23 (0.29)	2.90 (0.91)	0.91

22	Gyeonggi	Paju-3	SNU-E-12.109	37°58′24.7″	126°56′56.6″	5.24 (0.65)	4.12 (1.70)	0.85
23	Gyeonggi	Pocheon	SNU-E-12.132	38°00′59.1″	127°11′29.6″	5.40 (0.50)	2.53 (0.60)	0.92
24	Gyeonggi	Gapyeong	SNU-E-12.144	37°51′07.8″	127°30′33.4″	4.91 (0.34)	4.50 (1.01)	0.94
25	Gangwon	Yeongwol-2	SNU-E-12.163	37°27′19.3″	128°24′30.9″	65.13 (16.87)	1.85 (0.91)	0.37
26	Gangwon	Yeongwol-3	SNU-E-12.164	37°28′82.6″	128°26′43.0″	5.12 (1.16)	4.95 (4.35)	0.59
27	Gangwon	Yeongwol-4	SNU-E-12.170	37°23′02.8″	128°42′33.9″	6.77 (1.10)	2.83 (1.48)	0.77
28	Gangwon	Hoengseong-1	SNU-E-12.190	37°37′36.6″	128°13′05.8″	5.13 (1.15)	2.51 (1.48)	0.85
29	Gangwon	Hoengseong-2	SNU-E-12.191	37°40′87.0″	128°15′50.1″	5.89 (0.22)	3.34 (0.58)	0.99
30	Gangwon	Hoengseong-3	SNU-E-12.198	37°56′65.4″	128°13′32.4″	3.49 (0.55)	3.12 (0.81)	0.99
31	Gangwon	Samcheok	SNU-E-12.211	37°41′22.1″	129°08′73.9″	4.72 (0.59)	7.61 (3.11)	0.92
32	Gangwon	Gangneung-1	SNU-E-12.219	37°72′26.7″	128°96′91.9″	15.22 (7.36)	9.23 (22.22)	0.91
33	Gangwon	Gangneung-2	SNU-E-12.220	37°73′44.0″	128°91′82.8″	13.87 (4.82)	7.25 (22.82)	0.72
34	Gangwon	Gangneung-3	SNU-E-12.225	37°82′00.0″	128°84′54.9″	6.38 (1.25)	2.11 (0.96)	0.81

35	Gangwon	Yangyang	SNU-E-12.237	38°13′68.5″	128°59′76.3″	3.93 (0.34)	5.51 (1.75)	0.91
36	Gangwon	Goseong-1	SNU-E-12.239	38°27′64.2″	128°54′06.5″	3.09 (0.15)	3.54 (0.85)	0.97
37	Gangwon	Goseong-2	SNU-E-12.245	38°48′79.6″	128°42′79.4″	4.79 (0.39)	2.74 (0.56)	0.93
38	Gangwon	Yanggu-1	SNU-E-12.252	38°07′96.6″	127°99′23.4″	6.40 (0.62)	1.88 (0.33)	0.95
39	Gangwon	Yanggu-2	SNU-E-12.255	38°16′78.3″	128°04′08.5″	6.51 (1.58)	2.56 (1.49)	0.45
40	Reference	Suwon	SNU-E-01.004	37°16'09.4"	126°59'23.6"	3.11 (0.29)	2.56 (0.71)	0.93

Table A2. Collected and Statistics data of *E. crus-galli* accessions tested for the baseline sensitivity to triafamone

Accession No.	Collected area		Accession code	GPS information		Statistics data		R^2
	Province	City/County		Latitude	Longitude	GR_{50} (SE)	B (SE)	
1	Gyeonggi	Hwaseong-1	SNU-E-13.009	37°09′36.8″	126°73′16.5″	5.53 (0.47)	3.39 (1.30)	0.95
2	Gyeonggi	Hwaseong-2	SNU-E-13.011	37°13′68.5″	126°69′76.3″	6.18 (0.21)	5.19 (2.50)	0.97
3	Gyeonggi	Hwaseong-3	SNU-E-13.014	37°27′64.2″	126°74′06.5″	8.12 (0.65)	3.55 (0.84)	0.92
4	Gyeonggi	Pyeongtaek-1	SNU-E-13.020	37°08′12.9″	127°02′87.0″	3.78 (0.75)	1.55 (0.38)	0.97
5	Gyeonggi	Pyeongtaek-2	SNU-E-13.024	37°08′40.1″	127°09′26.5″	6.01 (0.46)	2.61 (0.61)	0.96
6	Gyeonggi	Pyeongtaek-3	SNU-E-13.026	37°00′49.1″	127°13′19.5″	7.70 (2.71)	0.84 (0.29)	0.76
7	Gyeonggi	Anseong-1	SNU-E-13.030	37°07′58.2″	127°22′39.7″	6.71 (0.22)	2.82 (0.30)	0.99
8	Gyeonggi	Anseong-2	SNU-E-13.036	37°07′51.6″	127°32′19.0″	6.41 (0.11)	6.08 (2.00)	0.99
9	Gyeonggi	Yongin-1	SNU-E-13.041	37°23′03.6″	127°14′27.3″	20.83 (5.09)	1.10 (0.34)	0.7
10	Gyeonggi	Yongin-2	SNU-E-13.042	37°31′41.5″	127°16′23.1″	7.96 (1.07)	4.40 (1.93)	0.78

11	Gyeonggi	Anseong-3	SNU-E-13.043	37°06′16.5″	127°37′45.0″	4.72 (0.35)	2.98 (0.62)	0.99
12	Gyeonggi	Yongin-3	SNU-E-13.045	37°39′06.8″	127°16′11.5″	7.29 (0.49)	3.40 (0.79)	0.94
13	Gyeonggi	Yongin-4	SNU-E-13.046	37°27′50.3″	127°12′59.3″	7.28 (0.33)	6.00 (1.56)	0.98
14	Gyeonggi	Icheon-1	SNU-E-13.050	37°30′32.5″	127°44′15.0″	5.19 (0.44)	2.94 (0.82)	0.97
15	Gyeonggi	Icheon-2	SNU-E-13.053	37°28′32.4″	127°45′05.7″	5.71 (0.21)	4.39 (1.22)	0.99
16	Gyeonggi	Yeoju-1	SNU-E-13.055	37°31′02.4″	127°57′52.7″	6.20 (0.10)	5.86 (2.09)	0.99
17	Gyeonggi	Yeoju-2	SNU-E-13.058	37°32′47.2″	127°50′20.6″	7.45 (0.52)	2.19 (0.36)	0.96
18	Gyeonggi	Yeoju-3	SNU-E-13.059	37°29′15.6″	127°51′59.1″	7.25 (0.57)	6.26 (2.94)	0.94
19	Gyeonggi	Yeoju-4	SNU-E-13.061	37°43′44.0″	127°57′38.9″	5.76 (0.63)	2.17 (0.56)	0.95
20	Gyeonggi	Icheon-3	SNU-E-13.062	37°27′41.5″	127°45′49.2″	6.29 (0.12)	6.37 (3.56)	0.98
21	Gyeonggi	Icheon-4	SNU-E-13.065	37°28′48.0″	127°50′24.3″	9.99 (1.29)	2.11 (0.57)	0.87
22	Gyeonggi	Yongin-5	SNU-E-13.068	37°25′14.1″	126°45′38.8″	5.97 (0.17)	6.50 (3.59)	0.99
23	Gyeonggi	Gwangju-1	SNU-E-13.069	37°39′45.3″	127°31′38.7″	5.43 (0.54)	2.66 (0.80)	0.95

24	Gyeonggi	Gwangju-2	SNU-E-13.071	37°40′19.6″	127°29′25.6″	4.80 (0.34)	4.18 (1.07)	0.99
25	Gyeonggi	Gwangju-3	SNU-E-13.072	37°37′14.8″	127°30′03.9″	5.88 (0.64)	5.26 (6.88)	0.87
26	Gyeonggi	Icheon-5	SNU-E-13.076	37°20′93.8″	127°45′39.8″	5.31 (0.13)	4.43 (0.60)	0.99
27	Gyeonggi	Icheon-6	SNU-E-13.077	37°16′43.3″	127°46′73.8″	7.69 (0.89)	7.19 (3.76)	0.93
28	Gyeonggi	Yangpyeong-1	SNU-E-13.082	37°50′20.4″	127°58′22.3″	5.60 (0.26)	4.94 (1.84)	0.99
29	Gyeonggi	Gimpo-1	SNU-E-13.094	37°65′05.9″	126°63′78.1″	5.66 (0.57)	5.56 (5.30)	0.96
30	Gyeonggi	Gimpo-2	SNU-E-13.098	37°66′11.1″	126°65′09.5″	6.85 (0.17)	3.67 (0.39)	0.99
31	Gyeonggi	Paju-1	SNU-E-13.104	37°84′44.8″	126°78′09.5″	5.96 (0.09)	4.34 (0.55)	0.99
32	Gyeonggi	Paju-2	SNU-E-13.107	37°83′90.8″	126°77′85.1″	5.25 (0.34)	5.07 (1.83)	0.99
33	Gyeonggi	Paju-3	SNU-E-13.108	37°88′16.6″	126°79′12.3″	5.87 (0.47)	4.04 (2.22)	0.92
34	Gyeonggi	Yeoncheon	SNU-E-13.113	38°07′05.3″	127°02′34.4″	16.68 (2.90)	1.26 (0.30)	0.83
35	Gyeonggi	Pocheon-2	SNU-E-13.119	37°94′99.1″	127°25′11.6″	19.75 (3.46)	2.33 (0.84)	0.77
36	Gangwon	Wonju-1	SNU-E-13.125	37°34′16.8″	127°92′44.8″	31.39 (6.06)	1.87 (0.62)	0.74

37	Gangwon	Wonju-2	SNU-E-13.129	37°33′94.3″	127°91′41.7″	6.19 (0.19)	5.46 (2.79)	0.97
38	Gangwon	Pyeongchang	SNU-E-13.135	37°65′09.9″	128°49′03.9″	6.24 (0.18)	6.36 (5.58)	0.96
39	Gangwon	Hoengseong-1	SNU-E-13.147	37°53′77.2″	128°07′55.3″	6.81 (0 .24)	4.72 (1.11)	0.97
40	Gangwon	Hongcheon-1	SNU-E-13.148	37°76′68.9″	128°02′36.9″	2.48 (1.88)	1.48 (0.97)	0.92
41	Gangwon	Hongcheon-2	SNU-E-13.150	37°73′44.0″	128°03′15.6″	6.29 (0.18)	3.73 (0.58)	0.99
42	Gangwon	Hongcheon-3	SNU-E-13.154	37°75′94.1″	128°18′12.4″	6.79 (0.31)	3.75 (0.79)	0.97
43	Gangwon	Samcheok-1	SNU-E-13.156	37°33′64.0″	129°18′18.1″	6.79 (0.27)	5.53 (1.91)	0.97
44	Gangwon	Gangneung-1	SNU-E-13.161	37°70′81.4″	128°88′14.1″	7.66 (0.42)	3.21 (0.53)	0.96
45	Gangwon	Yangyang	SNU-E-13.174	37°99′47.4″	128°66′04.1″	4.94 (0.64)	2.84 (1.08)	0.96
46	Gangwon	Goseong-1	SNU-E-13.181	38°32′88.3″	128°40′11.4″	5.78 (0.46)	3.58 (1.51)	0.94
47	Gangwon	Goseong-2	SNU-E-13.182	38°31′99.7″	128°41′03.9″	5.89 (0.24)	5.35 (2.75)	0.98
48	Gangwon	Yanggu-1	SNU-E-13.189	38°18′89.6″	128°01′91.0″	4.95 (0.70)	2.32 (0.76)	0.95
49	Gangwon	Inje	SNU-E-13.194	38°11′96.5″	128°19′91.1″	5.77 (0.27)	3.28 (0.68)	0.98

50	Gyeonggi	Hwaseong-4	SNU-E-13.010	37°09′69.4″	126°72′44.1″	4.68 (0.40)	3.68 (1.01)	0.99
51	Gyeonggi	Hwaseong-5	SNU-E-13.012	37°12′97.7″	126°70′74.4″	15.44 (3.06)	1.17 (0.27)	0.85
52	Gyeonggi	Hwaseong-6	SNU-E-13.016	37°27′66.3″	126°71′93.0″	6.33 (0.29)	4.13 (1.32)	0.96
53	Gyeonggi	Pyeongtaek-4	SNU-E-13.021	37°06′67.1″	127°20′25.3″	5.25 (0.59)	5.28 (3.34)	0.99
54	Gyeonggi	Pyeongtaek-5	SNU-E-13.022	37°01′59.3″	127°19′53.4″	11.68 (0.59)	2.30 (0.26)	0.98
55	Gyeonggi	Anseong-4	SNU-E-13.029	37°09′15.3″	127°15′53.5″	4.60 (0.56)	2.87 (0.90)	0.98
56	Gyeonggi	Anseong-5	SNU-E-13.037	37°06′65.7″	127°33′30.5″	5.30 (0.65)	2.34 (0.72)	0.94
57	Gyeonggi	Hwaseong-7	SNU-E-13.039	37°12′82.3″	126°70′42.3″	4.67 (1.20)	2.05 (1.00)	0.89
58	Gyeonggi	Anseong-6	SNU-E-13.044	37°10′53.1″	127°11′15.3″	16.22 (3.34)	1.70 (0.57)	0.74
59	Gyeonggi	Yangpyeong-2	SNU-E-13.080	37°51′11.2″	127°44′93.5″	4.43 (0.43)	2.86 (0.67)	0.99
60	Gyeonggi	Yangpyeong-3	SNU-E-13.084	37°49′54.2″	127°39′40.3″	4.71 (0.54)	2.50 (0.68)	0.99
61	Gyeonggi	Yangpyeong-4	SNU-E-13.085	37°46′66.9″	127°33′06.0″	5.74 (0.26)	3.92 (1.10)	0.99
62	Gyeonggi	Gimpo-3	SNU-E-13.095	37°67′45.0″	126°44′93.1″	5.87 (0.15)	4.41 (0.93)	0.99

63	Gyeonggi	Paju-4	SNU-E-13.102	37°83′14.7″	126°61′99.3″	4.92 (0.58)	3.73 (1.62)	0.98
64	Gangwon	Cheolwon	SNU-E-13.114	38°25′95.0″	127°39′27.1″	3.97 (1.14)	1.76 (0.71)	0.93
65	Gyeonggi	Pocheon-3	SNU-E-13.117	38°00′17.4″	127°30′75.2″	1.89 (1.38)	0.92 (0.39)	0.93
66	Gangwon	Wonju-3	SNU-E-13.122	37°38′34.2″	127°84′66.1″	3.23 (0.63)	2.34 (0.62)	0.99
67	Gangwon	Wonju-4	SNU-E-13.124	37°37′99.9″	127°86′92.2″	5.87 (0.28)	5.16 (2.85)	0.97
68	Gangwon	Yeongwol	SNU-E-13.131	37°22′15.8″	128°45′94.2″	4.88 (0.82)	3.63 (2.15)	0.96
69	Gangwon	Hoengseong-2	SNU-E-13.139	37°50′76.7″	128°00′67.4″	5.59 (0.19)	3.49 (0.57)	0.99
70	Gangwon	Hoengseong-3	SNU-E-13.142	37°51′11.3″	128°09′54.2″	5.75 (0.45)	2.89 (0.80)	0.96
71	Gangwon	Hongcheon-4	SNU-E-13.151	37°71′63.9″	127°89′12.3″	4.41 (0.59)	2.35 (0.64)	0.98
72	Gangwon	Hongcheon-5	SNU-E-13.153	37°78′17.6″	127°96′31.2″	5.01 (0.70)	3.85 (2.14)	0.97
73	Gangwon	Samcheok-2	SNU-E-13.155	37°36′16.3″	129°17′84.3″	5.36 (0.49)	3.98 (1.88)	0.97
74	Gangwon	Samcheok-3	SNU-E-13.158	37°35′99.9″	129°11′26.3″	5.42 (0.56)	2.67 (0.83)	0.95
75	Gangwon	Gangneung-2	SNU-E-13.164	37°75′61.3″	128°02′22.3″	5.20 (0.27)	4.93 (1.33)	0.99

76	Gangwon	Sokcho	SNU-E-13.177	38˚22´38.2″	128˚20´13.9″	6.20 (0.06)	6.76 (2.57)	0.99
77	Gangwon	Yanggu-2	SNU-E-13.190	38˚19´16.1″	127˚93´53.2″	5.70 (0.21)	3.42 (0.59)	0.99
78	Gangwon	Yanggu-3	SNU-E-13.193	38˚20´20.3″	127˚92´94.2″	5.74 (1.06)	7.13 (15.42)	0.97
79	Suwon	Suwon	SNU-E-01.005	37°26'92.02"	126°99'02.35"	6.14 (0.21)	4.16 (1.06)	0.98
80	Seosan-5	Seosan	SNU-E-05.312	36°37'15.4"	126°25'12.1"	21.73 (6.61)	0.84 (0.29)	0.64
81	California	California	SNU-E-11.077	39°34'38.4"N	121°51'11.9"W	17.7 (4.27)	1.05 (0.31)	0.73

ABSTRACT IN KOREAN

다공포트 방법을 이용한 피에 대한 triafamone의 baseline sensitivity

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논에서의 피는 매우 중요한 잡초이며 최근 증가하는 제초제 저항성 피는 전 세계적으로 심각한 문제로 대두되었다. 잠재적인 제초제 저항성 발생 위험 정보를 제공하기 위하여 신규 제초제에 대한 baseline sensitivity 연구는 매우 필수 적이며 이를 통한 저항성 발생 예측은 신규 제초제의 사용전략 수립에 필수적이다. 따라서, 본 연구는 신규 ALS 저해제인 triafamone에 대한 국내 수집 피의 baseline sensitivity를 평가하기 위해 다공포트법을 이용하여 수행되었다. 2016년 경기도와 강원도에서 수집 한 강피 41종과 물피 81종을 다공포트에 이식한 후 반담수상태로 4엽기까지 재배한 후 triafamone을 무처리 포함 총 7가지 농도(0, 3.125, 6.25, 12.5, 25, 50, 100 g a.i. ha $^{-1}$)로 처리한

후 30 일차에 달관약효와 생체중을 조사하였다. Log-logistic model을 이용 비선형회귀분석을 통해 50% 피 방제 약량인 GR_{50} 값을 계산한 후 최대값과 최소값을 비교하여 baseline sensitivity index (BSI)를 구하였다. 강피의 GR_{50} 값의 범위는 최소 3.1 g a.i. ha^{-1}에서 최대 95.1 g a.i. ha^{-1}이었으며, 평균값과 중앙값은 각각 11.34와 5.19 g a.i. ha^{-1}, BSI는 30.76이었다. 물피의 GR_{50} 값의 범위는 최소 1.89 g a.i. ha^{-1}에서 최대 95.06 g a.i. ha^{-1}이었으며, 평균값과 중앙값은 각각 7.24와 5.87 g a.i. ha^{-1}, BSI는 16.61이었다. 따라서 강피와 물피 모두 높은 BSI값을 갖고 있어 저항성 발생 위험도가 높으며 강피가 물피보다 저항성 발생 위험도가 높음을 확인할 수 있었다. 또한 비록 triafamone은 새로운 화학구조를 갖고 있는 ALS 저해제이나 이미 저항성이 진행된 것으로 추정되며 이는 논에서 피의 방제를 위해 다른 ALS 저해제를 장기간 사용했기 때문일 것으로 판단된다. 따라서 피 방제를 위해 지속적으로 triafamone을 사용하기 위해서는 다양한 작용 기작을 가진 다른 제초제와의 혼합 또는 교차 사용이 필요하다.

핵심어: baseline sensitivity, 피, 다공포트, triafamone, baseline sensitivity index

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