Factors destabilizing the control of *Monochoria vaginalis* by rice bran: its conflicting powers influence both suppression and promotion of germination in paddy soil

Takuhito Nozoe\(^a\), Shigenori Miura\(^b\), Junko Tazawa\(^a\), Akira Uchino\(^b\) and Yasuhiro Usui\(^d\)

\(^a\)Department of Regional Strategy, Hokkaido Agricultural Research Center (HARC), National Agricultural and Food Research Organization (NARO), Sapporo, Japan; \(^b\)Division of Crop Production Systems, Central Region Agricultural Research Center (CARC), NARO, Tsukuba, Japan; \(^c\)Division of Plant Disease Management, CARC, NARO, Tsukuba, Japan; \(^d\)Division of Farming System Research, HARC, NARO, Memuro, Japan

**ABSTRACT**

Organic paddy rice (*Oryza sativa* L.) cultivation can be negatively impacted because of the weeds growth like *Monochoria vaginalis*. Although the rice bran application is useful in combating weed, its performance is not consistent. In this study, laboratory experiments were conducted to elucidate the effects of rice bran on the suppression and promotion of germination of *M. vaginalis*. Suppression experiments involved incubating mixtures of flooded soil and rice bran. This was followed by a germination experiment in the collected soil solutions. A negative and significant correlation was observed between germination and the electric conductivity (EC) of the solution. None of the seeds germinated when the EC of the Gray Lowland soil was over 130 mS m\(^{-1}\). Conversely, the seeds in the Andosols’ solution germinated even when EC was over 130 mS m\(^{-1}\). Thus, the solutions of the Andosols had different mechanisms of suppression than the Gray Lowland soils. To understand the promotion of germination, air-dried soil was prepared after the flooded incubation of rice bran and soil mixture, simulating a long-term application of rice bran. Germination was analyzed in a filtrate of the mixture of air-dried soil and distilled water. The addition of rice bran significantly promoted germination. There was a negative and significant correlation between germination and dissolved oxygen (DO) suggesting that hardly decomposable components like antioxidants in rice bran decreased O\(_2\) and stimulated germination because the seeds of *M. vaginalis* require very little O\(_2\) for germination.

**KEYWORDS**

*Monochoria vaginalis*; organic rice farming; paddy soil; rice bran; electric conductivity; dissolved oxygen

**CONTACT** Takuhito Nozoe  nozoe@affrc.go.jp

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1. Introduction

The transplanting cultivation of paddy rice (*Oryza sativa* L.) under organic farming conditions requires intensive weed control to maintain crop production. Particularly, the heartshape false pickerelweed (*Monochoria vaginalis*) (Burm. f.) Kunth is the most common and noxious weed species affecting *O. sativa* L. production (Nakai & Toritsuka, 2009) (Figure 1). Although several farmers apply rice bran on the surface of paddy fields to suppress the growth of this weed, its mechanism has not been fully elucidated yet, although multiple factors are believed to be associated with its control efficacy. For instance, it was reported that the growth suppression was attributed to both physical (Nozoe et al., 2016) and chemical factors (Nozoe et al., 2012). Regarding the latter, the reduction of insoluble soil ferric oxide (Fe$_2$O$_3$) to soluble ferrous iron (Fe$^{2+}$) is coupled with the disintegration of easily decomposable components of rice bran to organic acids (Figure 2). Namely, Fe$_2$O$_3$, which has poor solubility, accepts an electron from organic materials. This results in Fe$_2$O$_3$ being reduced to soluble Fe$^{2+}$ during soil reduction (Tanji et al., 2003). Thus, the high concentration of Fe$^{2+}$ in soil solutions can suppress the growth of paddy rice (Nozoe et al., 2008). It was also suggested that the accumulation of Fe$^{2+}$ in soil solutions suppressed the growth of paddy weeds (Nozoe et al., 2010, 2009). During the process of soil reduction, phenolic acids (Tanaka et al., 1990) and short-chain fatty acids (Chandrasekaran & Yoshida, 1973) were produced, which inhibited the root elongation of *O. sativa* L. Therefore, multiple toxins including Fe$^{2+}$ and organic acids could be factors related to the growth suppression of *M. vaginalis*. The addition of rice bran also increased the electric conductivity (EC) of soil solutions, with high EC values associated with the accumulation of various ions derived from the decomposition of rice bran (Nozoe et al., 2012). The amounts of other metal oxides such as manganese oxide (MnO$_2$) in soil are smaller than that of Fe$_2$O$_3$, but the concentrations of these reduced substances like Mn$^{2+}$ certainly increase in soil solution (Inubushi et al., 1984). These metal ions are also the factors to increase the EC, and these can suppress the germination of *M. vaginalis*. Thus, EC can be a useful and convenient

![Figure 1. *Monochoria vaginalis* on pot (A) and in field under organic-farming condition (B).](image-url1)

![Figure 2. Outline for anaerobic production of organic acids and ferrous iron in the presence of rice bran.](image-url2)
indicator to evaluate the degree of suppression in plant growth.

Although the application of rice bran is practical for weed control, its use has been limited. The major factor responsible for this poor diffusion is its unstable performance. Nevertheless, the mechanism of this fluctuation has not been fully analyzed. Despite spreading the same amount of rice bran in fields, it has been observed that the suppressive performance by rice bran differ among soils. Soil solutions obtained from flooded soil with rice bran had contradictory properties that both promoted and suppressed germination (Nozoe et al., 2018). Promotive activity is one factor that makes the efficacy of rice bran unstable. The seeds of *M. vaginalis* require very little oxygen (O₂) for germination (Takeuchi et al., 2001). It was reported that germination increased with decreasing amounts of dissolved oxygen (DO) in soil solutions, and low DO content was attributed to O₂ removal by reducing agents in soil (Nozoe et al., 2018). Overall, all components of rice bran that was applied with transplanting do not disintegrate until the end of the cultivation period. For instance, hardly decomposable components, such as lignin, may accumulate due to incomplete decomposition under O₂-limited conditions (Bierke et al., 2008). There are many reports analyzing the concentrations of lignin in rice bran by using the acid detergent method. For instance, Reddy (1997), Ghodrat et al. (2017), and Asmare et al. (2010) reported the lignin contents as 6%, 11% and 13%, respectively. Rice bran contains antioxidants including ferulic acid (Butsat & Siriamornpun, 2010; Kikuzaki et al., 2002; Xu et al., 2001), and these antioxidants usually exhibit reducing properties (Cheng & Li, 2004). Therefore, the continuous application of rice bran might increase in the antioxidants, and thus it would intensify O₂ reduction. Thus, these factors may stimulate the germination of *M. vaginalis* seeds.

To improve the performance of weed control by rice bran, it is necessary to investigate why rice bran efficacy differs among various soil types. With respect to germination suppressing factors, Takijima (1964) reported that the high content of humus in paddy soil could reduce the toxicity of organic acids to rice growth. This implies that the humus could ameliorate the toxicity to weeds. As will be indicated below, the amount of humus in volcanic ash soils such as Andosol is greater than that in alluvial soils like Gray Lowland soil. Therefore, it can be speculated that the effects of rice bran on the germination of *M. vaginalis* is different according to soil types. Regarding enhancing factors, the antioxidant activity of the accumulated hardly decomposable components could promote germination. In this study, soil factors such as soil types and EC were investigated to determine the influence of *M. vaginalis* germination with rice bran. The promotive factors of germination caused by long-term application of rice bran were also analyzed.

## 2. Materials and methods

### 2.1 Seed collection

Seeds of *M. vaginalis* were collected from plants grown at the National Agricultural and Food Research Organization (NARO), Central Region Agricultural Research Center at Yawara experimental paddy field, Tsukubamirai City, Japan (36°00′27″ N, 140°01′19″ E) after rice was harvested in 2015. The seeds were air-dried and stored in a refrigerator at 5°C for 6 to 12 months.

### 2.2 Soil and rice bran collection

Eight soils were sampled from the plow layer (upper 10 cm) of paddy fields at five sites: Central Region Agricultural Research Center at Yawara experimental paddy field (soils I, II, III, and VI), Institute of Agricultural Machinery, NARO, Konoсу City, Japan (36°05′18″ N, 139°32′23″ E) (soil IV), Hokkaido Agricultural Research Center, NARO, Sapporo City, Japan (43°00′31″ N, 141°24′41″ E) (soil V), a farmer's paddy field, Ryugasaki City, Japan (35°55′18″N, 140°14′29″ E) (soils VII), and Tochigi Prefectural Agricultural Experiment Station, Utsunomiya City, Japan (36°36′57″ N, 139°51′51″ E) (soil VIII) (Table 1). The soil samples were air-dried and passed through a 2-mm mesh sieve. Commercial rice bran was used for the

### Table 1. Description of topsoil.

| Name  | Sampling site | Soil type        | pH (H₂O) | Total N (g kg⁻¹) | Total C (g kg⁻¹) | Farming system   |
|-------|---------------|------------------|----------|------------------|-----------------|------------------|
| I     | Tsukubamirai  | Gray Lowland soil| 6.1      | 2.0              | 23              | organic farming  |
| II    | Tsukubamirai  | Gray Lowland soil| 5.9      | 2.1              | 23              | organic farming  |
| III   | Tsukubamirai  | Gray Lowland soil| 5.5      | 1.9              | 21              | organic farming  |
| IV    | Kōnosu        | Gray Lowland soil| 6.5      | 2.2              | 24              | organic farming  |
| V     | Sapporo       | Andosol          | 6.2      | 4.6              | 76              | conventional    |
| VI    | Tsukubamirai  | Andosol          | 6.1      | 3.4              | 47              | organic farming  |
| VII   | Ryugasaki     | Andosol          | 5.8      | 3.9              | 60              | organic farming  |
| VIII  | Utsunomiya    | Andosol          | 5.6      | 5.9              | 80              | conventional    |

*soil: water (w/v) = 1: 2.5.
experiment. Granulated rice bran was powdered before the experiments. Total nitrogen (N) and total carbon (C) content was 20.8 (g kg\(^{-1}\)) and 410.6 (g kg\(^{-1}\)), respectively. The C:N ratio was 19.7:1.

2.3. Experiment 1: suppression of germination by rice bran

We conducted two consecutive procedures: (1) incubation of the flooded soil, and (2) seed incubation in collected soil solutions. The apparatus used for the incubation of flooded soil is shown in a photograph (Figure 3). The size of the polyethylene vessel used was 60 mm × 60 mm × 85 mm in height. A hole (3 mm in diameter) was made in the side of each vessel 1.5 cm from the bottom. A porous cup (3 mm in diameter and 9 cm in length; Daiki Rika Kogyo, Tokyo, Japan) was inserted into the hole and horizontally set. The space between the vessel and the porous cup was sealed with an epoxy adhesive.

Eight soil types were used in this experiment. A 100 g of each soil (Table 1) with the following amount of rice bran was placed into the polyethylene vessel. For all soils (except for soil IV), the amounts of rice bran added were 0%, 0.15%, 0.3%, and 0.45% to air-dried soil (w/w). The amounts of rice bran added to soil IV were 0%, 0.075%, 0.15%, and 0.225%, corresponding to half of the amount added to the other soils. Distilled water (DW) was added to the vessel, followed by thorough stirring to remove air in the soil. The depth of flooded water was maintained at >2 cm throughout the incubation period. The vessels were placed in incubator (LPH−350S; Nippon Medical and Chemical Instruments, Osaka, Japan) at 30°C for 7 days. The porous cup was connected to a flexible plastic tube (TYGON\textsuperscript{®}), and the soil solution obtained was introduced into a 10 ml evacuated test tube (VP-P100 K, TERUMO\textsuperscript{®}) after incubation. The amount of recovered solution was 6 mL. The EC of the soil solution was measured using a compact EC meter (B-771; HORIBA, Kyoto, Japan). The value of EC was expressed as the means of repetitions (same as below).

Thirty seeds of M. vaginalis were placed into the collected soil solution in the tube. The tube was shaken for the seeds to sink and was sealed with a flexible film (PARAfilm\textsuperscript{®}). This was followed by incubation at 30°C under a 12:12 light:dark period, and with illuminance of 27,000 lx. After a 2-day incubation period, the seeds of four repetitions were combined, and the germination percentage was calculated.

A total of 32 treatments [8 soils (I–VIII) × 4 sets of rice bran contents (0%, 0.15%, 0.3%, and 0.45%, or 0%, 0.075%, 0.15%, and 0.225%)] were examined. The number of seeds tested per treatment was 120 [30 per tube × 4 repetitions].

2.4. Experiment 2: promotion of germination by rice bran

To simulate a long-term application of rice bran, soil samples were prepared as follows. Soils I and VII were used in this experiment. The former was used because the values of chemical properties were middling among

![Figure 3. Apparatus used for incubation and recovering soil solution.](image)
the Gray Lowland soil samples (Table 1). The latter was chosen considering that it was sampled from an organic farming field and total C content was mediocre typical among Andosol samples. Following the volume of rice bran was mixed with 100 g of soil sample. The amount of rice bran to air-dried soil (w/w) was 0%, 0.2%, 0.4%, or 0.6%. Each treatment received four repetitions before being placed into the vessel (60 mm × 60 mm × 85 mm in height) (Figure 3) flooded with DW and was thoroughly stirred to remove air in the soil. The vessel was incubated at 30°C for 7 days. The depth of flooded water was maintained at >2 cm throughout the incubation period. After incubation, the soils were air-dried at room temperature for 10 days. This sequential procedure was repeated twice. The total amount of rice bran to air-dried soil (w/w) was 0%, 0.4%, 0.8%, and 1.2%. Following the procedure, the soils of four repetitions were combined. Five grams of obtained soil was mixed with 50 mL of DW (soil:water (w/v) = 1:10). The mixture was stirred several times with a spatula and immediately filtered. The filtrate of soil VII was also used for the determination of DO shown below. Thirty seeds of M. vaginalis and 6 mL of the filtrate were placed into a 10 mL test tube, which was repeated seven times. The tube was shaken for the seeds to sink, and it was sealed with a flexible film. This was followed by incubation at 30°C under a 12:12 light:dark period. After a 4-day incubation period, the seeds in seven repetitions were combined, and germination percentage was determined. The total number of treatments was 8 [2 soils (I and VII) × 4 amounts of rice bran (0%, 0.4%, 0.8%, and 1.2%)]. The total number of tested seeds per treatment was 210 (30 per tube × 7 repetitions).

2.5. Experiment 3: dissolved oxygen

To determine the factors relating the promoting effect of rice bran on germination, the filtrate (soil VII) obtained for the determination of germination (Experiment 2) was used. For determining the DO content, 250 mL of the solution was placed into a 250 mL of medium storage bottle. The total number of treatments was 5 [1 soil (soil VII) × 4 amounts of rice bran (0%, 0.4%, 0.8%, and 1.2%) + DW]. The bottle was closed with a screw cap and placed in an incubator at 30°C for 4 days. The DO of the solution was periodically measured using a DO meter (OM-51, HORIBA, Kyoto, Japan) equipped with an electrode (9551–20D, HORIBA, Kyoto, JAPAN). The experiment was performed without repetition.

2.6. Statistical analysis

Statistical analyses were performed with SPSS Statistics version 20 (IBM Japan, Tokyo, Japan). Simple linear regression models were applied to analyze correlations among parameters at significant level of P < 0.05 and 0.01.

3. Results and discussion

3.1. Experiment 1

3.1.1 Germination and soil

In M. vaginalis, seed dormancy that induced in seed development gradually released in chilling temperature of winter as well as in most summer annual weeds (Wang et al., 1996). In current experiment, the used seeds were stored in a refrigerator at 5°C for 6 to 12 months. It can be speculated the seed dormancy was released to some extent.

In this experiment, 0.15%, 0.3%, or 0.45% rice bran was added to the soil. These amounts correspond to the application of 0.15, 0.3, or 0.45 t of rice bran to a field of 1 ha × 1 cm in accordance with the following calculations. In Japanese paddy fields, the bulk density of soil is approximately 1 Mg m⁻³ (Shirato, 2005). If the bulk density of soil is 1.00 g cm⁻³, the soil weight of a field with a soil surface of 1 cm in depth is calculated to be 100 t ha⁻¹ (100 m × 100 m × 1 cm = 10⁸ cm³ = 10⁸ g = 100 t). When 1 t of rice bran is applied to this field and it is mixed with soil up to 1 cm in depth, the ratio of rice bran to soil by weight is 1%. Therefore, the application of 0.15%, 0.3%, and 0.45% of rice bran to soil corresponds to 0.15, 0.3, and 0.45 t ha⁻¹, respectively. Miura et al. (2015) demonstrated that the combination of mechanical weeding and the application of 1 t ha⁻¹ of rice bran to soil reduced more than 98% of the dry weight of M. vaginalis in interrow and 65–94% in intrarow spacing.

The addition of rice bran decreased the germination of M. vaginalis and it increased EC of all soil solutions significantly (Figure 4). These findings support the results of a previous study (Nozoe et al., 2012), indicating that EC can be used as an indicator to evaluate the effect of rice bran on germination.

First, the germination of M. vaginalis fluctuated due to soils even in the absence of rice bran (0% plot). In the previous report (Nozoe et al., 2018), we showed that the germination changed with soils, and this difference was attributed to an O₂ reducing power of soils. Namely, the germination in the soil with high reducing power was enhanced because the low content of O₂ was preferable for the germination. Second, the effectiveness of rice bran fluctuated according to soils. Although the addition of rice bran suppressed germination, the efficacy depended on the soil type. The addition of 0.45% of rice bran to soil V showed low suppression of germination. In contrast, 0.225% rice bran added to soil IV completely suppressed germination.
3.1.2 Relationship between germination and EC of soil solution

To analyze the relationship between the EC and germination, Figure 4 was restructured in Figure 5. Datasets used for Figure 5 were same as those in Figure 4. In all soils, EC showed a significant negative correlation with germination. As for the regression lines of four Gray Lowland soils, none of the seeds germinated when EC was ≥130 mS m⁻¹ (Figure 5A). In contrast, seeds in solutions from Andosols V and VI germinated even when EC was >130 mS m⁻¹ (Figure 5B). Thus, the solutions of the Andosols might have a different mechanism of suppression compared with those of the Gray Lowland soils.

![Figure 5](image-url)
The C content in Andosols was approximately 2–4 times greater than that in the Gray Lowland soils (Table 1), indicating that the humus content in the Andosols was greater than that in the Grey lowland soil. According to Takijima (1964), humus absorbed organic acids and the high content of humus in paddy soil reduced the toxicity of organic acids. The tolerance of germination over 130 mS m\(^{-1}\) of EC in the solution from Andosols may have been associated with the absorption of organic acids to humus (Figure 5B). Further investigations are required to identify the soil factors responsible for the germination in Andosols. Additionally, the critical value of EC (130 mS\(^{-1}\)) in the Gray Lowland soil was determined using seeds that were sampled in the same place and time. In fields, however, this value may fluctuate because seed banks consist of diverse seeds. Physiological activities such as dormancy levels of seeds would be factors responsible for the diversity. For instance, dormancy levels are affected by the environmental factors like temperature and humidity that seeds were exposed, and the levels change seasonally in the dormancy cycle. The environmental factors varied for each seeds depending on the produced year and buried depth in soil, and natural weather in last fallow season would influence the dormancy levels critically, suggesting the critical value might fluctuate from year to year. Thus, further investigations are also necessary to determine the critical value.

### 3.2. Experiment 2

The germination significantly increased with the increase in the amounts of rice bran (Figure 6). The increase in germination in soil I was associated with the increase in soil C and N. On the contrary, the germination was significantly correlated with neither the total C nor the total N in soil VII. It remains to be determined in relation to this difference. The soil samples were obtained after the addition of rice bran, flooding, and air-drying. It is speculated that the air-dried soil contained a certain amount of hardly decomposable organic components like lignin because the easily decomposable components were broken down during the flooding. Actually as related above, the lignin contents of rice bran ranged from 6% to 13% (Reddy 1997, Ghodrat et al. (2017), and Asmare et al. (2010)). The findings obtained in the study suggest that hardly decomposable organic components of rice bran were associated with the increase in germination. Tanji et al. (2003) analyzed EC of soil solution in the field where the rice straw was incorporated into soil. They indicated that the EC increased immediately after transplanting and decreased to almost nil at the second week after transplanting. The authors also confirmed this phenomenon in the field where rice bran was spread (unpublished data). Based on these reports, easily decomposable components of rice bran could disintegrate to organic acids during a few weeks after transplanting. Most organic acids further decomposed to methane (CH\(_4\)) and carbon dioxide (CO\(_2\)) (Figure 2). In contrast, hardly decomposable components remained in the soil even after cultivation and got incorporated in the whole plowed layer as residue. The soil weight of 1 ha plow layer at a 1-cm depth is estimated to be approximately 100 t ha\(^{-1}\). If 1 t of rice bran is applied and incorporated in a field with plow layer of 10 cm in depth, the ratio of rice bran to soil by weight is 0.1%. In this experiment, the amount of rice bran to soil was 0.4%, 0.8%, and 1.2%. These amounts, for instance, correspond to the consecutive application of 1 t ha\(^{-1}\) rice bran for 4, 8, and 12 years, respectively.

In current study, the soil samples were prepared only in a few weeks under laboratory conditions. The decomposition of rice bran in laboratory was speculated to be more drastic than that in field because the former proceed more rapidly and under more oxidative condition than the latter. Therefore, further study in relation to the difference in experimental performance between field and laboratory conditions is needed.

Regarding the increase in germination with the addition of rice bran, previous research has hypothesized several possible mechanisms. However, those were obtained only by laboratory experiments. For instance, Takeuchi et al. (2001) analyzed the germination in distilled water. They showed that the addition of rice seed to water raised the germination of dormant seed from 2.3% to 57.3%. They suggested that a water-extractable allelochemical in rice seed enhanced germination, although it has not been identified. Yokota et al. (2014) found that the rice hull extract promoted germination. They found that none of the sterilized seeds could germinate irrespective of the presence of rice hull extract. With the addition of inoculated bacterium and rice hull extract, the germination rate raised to 78%. They speculated that some bacteria were involved in the promotion because it was induced only when an unsterilized seed was incubated. They speculated that the digestion of seed coat by the bacteria broke the dormancy of the seed. As another factor to increase the germination of *M. vaginalis*, we showed that soil solution promoted the germination of *M. vaginalis* in a previous study (Nozoe et al., 2018). Soil solutions could reduce O\(_2\) content, and this activity was responsible for the promotion of germination because the seeds require little O\(_2\) for germination (Takeuchi et al., 2001).
Rice bran contains several antioxidant substances that are hardly decomposable in soil. For instance, oryzanols, tocopherols, and tocotrienols express powerful antioxidant activities (Lloyd et al., 2000). The ferulate esters of triterpene alcohol are the main components of oryzanols (Xu & Godber, 1999). Ferulic acid have certain reducing properties (Cheng & Li, 2004), which are present at relatively high concentrations in the cell walls of several plant species. Harukaze et al. (1999) analyzed the ferulic acid content in rice bran of 21 Japanese cultivars. They reported that ferulic acid was mainly present as ferulate esters and the mean content of bound ferulate in rice bran was 1.55 g kg⁻¹ (0.22–2.25 g kg⁻¹; ferulic acid basis). They also reported that the total bound phenolic content including ferulics was 12.2 g kg⁻¹, which was 7.9 times greater than that of the ferulic content. Most of these phenolics had O₂-reducing activity (Zengin et al., 2014). The processes involved in preparing the soil samples may have caused hardly decomposable organic components to get accumulated in the soil.
3.3. Experiment 3

After recording the lowest values on the first day of incubation, DO gradually increased (Figure 7A). Based on these data, integrated DO was calculated (Figure 7B). Integrated DO corresponded to the area of each treatment during the 4-day incubation period. The order of integrated DO was as follows: DW > 0% > 0.4% > 0.8% > 1.2%, and this order was opposite to that of germination (Fig. 6B).

To analyze the effect of DO on germination, Figure 8 was created by using both the data of germination in the presence of rice bran (Fig. 6B) and those of integrated DO (Figure 7B). There were significant and negative relationships between germination and integrated DO (P < 0.05). These findings suggest that the addition of rice bran to soil decreased the O₂ content in the soil solution, and that this decrease in O₂ is associated with the increase in germination because low O₂ content was preferable for germination.

In this study, the cumulated residue of rice bran was suggested to become one of the factors to enhance the germination of *M. vaginalis*. The next step of this study is to investigate whether the germination is stimulated in the field where the long-term application of rice bran has been continued. Yan et al. (2007) reported that the addition of fresh rice bran to soil decrease the DO content in flooded water because O₂ was utilized for the decomposition of rice bran, and this O₂ reduction was effective only about two weeks after the application of rice bran. It is necessary to investigate whether the decrease in O₂ by residue of rice bran continues more than 2 weeks after transplanting.

In this report, we showed that the efficacy of rice bran is different for Gray Lowland soils and Andosols. Additionally, rice bran has promoting as well as suppressive power for germination. These results can provide new and useful information to suppress the growth of *M. vaginalis* in rice organic farming. First, when the rice

![Figure 7](image1)

**Figure 7.** Changes in DO in soil solution and integrated DO. DO was determined in 250 mL of soil solution. ¹ indicates the amount of rice bran to soil (w/w).

![Figure 8](image2)

**Figure 8.** Relationship between integrated DO and germination of *Monochoria vaginalis*. Data were converted from Figures 6B-1 and Figures 7B. ¹ indicates the amount of rice bran to soil.
bran is applied on Andosol field, the efficacy of rice bran could be more unstable than Gray Lowland soil presumably because high humus content of Andosol. Thus, it is important to stabilize the efficacy of rice bran, especially in Andosol field. Second, the long-term application of rice bran could lead to the stimulation of germination. Utilization of rice bran with low content of lignin may be one of the measures to the problem because the amount of lignin in rice bran differs among rice varieties. Finally, management of field can be one of the useful measures to prevent the accumulation of hardly decomposable organic component in soil. For instance, plowing in fallow season would accelerate the decomposition of rice bran. Further study is needed to confirm the expression of these mechanisms under the field conditions of rice organic farming.

4. Conclusions

Although the same amount of rice bran was applied, the suppression of germination varied among the soil samples. In the solution recovered from flooded Gray Lowland soils, none of the seeds could germinate when the EC of solution was over 130 mS m⁻¹. In the solution recovered from the flooded Andosols, some of the seeds could germinate even when the EC of the solution was more than 130 mS m⁻¹. There may have been differences in the mechanism of suppression between the Gray Lowland soil and Andosol. To understand the effects of hardly decomposable organic components on germination, flooded soils with rice bran were incubated followed by air-drying. During the flooded incubation, the easily decomposable component was believed to be removed because of anaerobic decomposition. Seeds were incubated in the filtrate of the obtained air-dried soil and DW. The germination increased with the increase in rice bran suggesting that hardly decomposable organic component of rice bran promoted germination. The promotion of germination was attributed to the reduction of O₂ by antioxidants because germination was stimulated under hypoxic conditions.

Although several farmers apply rice bran to the surface of paddy fields to suppress the germination of M. vaginalis, its use has been limited because of several factors, and its fluctuation of efficacy is one of the important reasons. When rice bran was applied to the flooded soil, it exerted suppressive and promotive effects on the germination of M. vaginalis. The latter is the major reason that makes the efficacy of rice bran unstable. It was suggested that easily and hardly decomposable organic matter in rice bran was associated with the suppression and promotion of germination, respectively.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Takuhito Nozoe http://orcid.org/0000-0001-7972-9803
Akira Uchino http://orcid.org/0000-0002-9666-2222
Yasuhiro Usui http://orcid.org/0000-0003-3239-0907

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