Comparison of the effects of seed coating with tungsten and molybdenum compounds on seedling establishment rates of rice, wheat, barley, and soybean under flooded conditions

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ABSTRACT
Seed coating with molybdenum compounds improves seedling establishment for rice, wheat, barley, and soybean when such seeds were sown under flooded conditions. Tungsten belongs to the same chemical group as molybdenum in the periodic table, and similar to molybdenum, inhibits the generation of sulfide ions. Here, the effects of tungsten and molybdenum containing seed coatings on seedling establishment under flooded conditions were compared using rice, wheat, barley, and soybean. In rice, the effects of tungsten compounds on seedling establishment varied. Tungsten trioxide had little effect but tungstic acid and ammonium phosphotungstate significantly improved seedling establishment when the amounts were at least \(0.1\text{ to }0.2 \text{ mol kg}^{-1}\). Although the effect of tungsten coating varied depending on the compound used, ammonium phosphotungstate, along with other tungsten compounds, improved seedling establishment in a manner comparable with that of molybdenum compounds. For wheat and barley, ammonium phosphotungstate treatment resulted in a significant increase in establishment that was only slightly less than the results observed using molybdenum compounds. Tungstic acid and ammonium phosphotungstate treatments improved soybean establishment in a significant manner that was comparable with those of molybdenum compounds. Collectively, these results suggest that tungsten compounds, as well as molybdenum compounds, improve seedling establishment under flooded conditions.

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Materials and methods

Experiment 1: Effect of seed coating using various amounts of tungsten compounds on rice seedling establishment

Rice seeds (cv. Nikomaru) were sterilized at 10 °C, in a 1000-fold diluted solution of a commercial sodium hypochlorite solution containing less than 5% chlorine for 1 d, imbibed in 10 °C water for 4 d, and then in 30 °C water for .5 d. Seeds that germinated prior to planting were removed. Ungerminated seeds were soaked in a polyvinyl alcohol solution containing a 10%-diluted commercial laundry starch for 1 min, spin-dried, and then coated with one of three different tungsten compounds at amounts ranging from 0 to 2 mol W kg⁻¹ air-dried seeds. The treatments used were tungsten trioxide (referred to as WO hereafter), tungstic acid (WH), or ammonium phosphotungstate (WPNH). These compounds are easily obtainable and poorly soluble in water.

According to the method previously reported in Hara (2013c), moist topsoil from a paddy field equivalent to 100 g of dry soil was placed in pots (diameter and height, 8 cm). A solution containing ammonium sulfate (4 mmol kg⁻¹ dried soil) and potassium chloride (1 mmol kg⁻¹ dried soil) was added to each pot until the total amount of water was 1.5 times the weight of dry soil. The mixture was shaken for 1 h and then kept in a refrigerator. For each treatment, eight coated seeds were sown in the soil at a depth of 15 mm. The pots were then incubated in growth chambers at 30 °C with fluorescent lamps (ca. .1 mmol m⁻² s⁻¹, 12 h d⁻¹). Six replicates were used for each treatment. The water level was maintained at approximately 15 mm. The rate of seedling establishment was measured 3 wk after sowing. Seedlings were considered to be established when the third leaf appeared.

Experiment 2: Effect of seed coating using various tungsten compounds on rice seedling establishment

Seeds were not soaked and coated with reduced iron at an amount of half the weight of seeds with one of the following molybdenum or tungsten compound at an amount of .2 mol Mo or W kg⁻¹. Seed treatments were applied with water through a misting system. Molybdenum containing treatments included molybdenum trioxide (MoO), molybdcic acid (MoH), ammonium phosphomolybdate (MoPNH), potassium phosphomolybdate (MoPK), ammonium molybdate (MoNH), sodium molybdate (MoNa), potassium molybdate (MoK), magnesium molybdate (MoMg), calcium molybdate (MoCa), phosphomolybdic acid (MoPH), sodium phosphomolybdate (MoPNa), or siliconomolybdic acid (MoSiH). Tungsten containing treatments included WO, WH, WPNH, potassium tungstate (WK), ammonium metatungstate (WNHm), ammonium paratungstate (WNHp), phosphotungstic acid (WPH), sodium phosphotungstate (WPNa), silicotungstic acid (WSiH), or sodium silicotungstate (WSiNa).

As in Experiment 1, coated seeds were sown at a soil depth of 15 mm 1 d after coating. The pots were placed in growth chambers at 20 °C with fluorescent lamps. Each treatment was replicated six times. The rate of seedling establishment was measured 4 wk after sowing. Because of the number of treatments, materials for coating were divided into two groups and two separate trials were conducted.

Experiment 3: Effect of seed coating treatments using tungsten compounds on wheat and barley

Wheat (cv. Chikugoizumi) or barley (cv. Nishinokihara) seeds were pre-treated with polyvinyl alcohol solution containing a 10%-diluted commercial laundry starch for 1 min, spin-dried, and then coated with one of four molybdenum and three tungsten compounds at an amount of .5 mol Mo or W kg⁻¹. The treatments used were selected based on the results of experiment 1 and are referenced in Hara (2016). The treatments included MoO, MoH, MoPNH, MoPK, WO, WH, or WPNH.

According to the method previously reported in Hara (2016), pots were filled with wet soil equivalent to 100 g of dry soil. A solution containing ammonium sulfate (4 mmol kg⁻¹ dried soil) and potassium chloride (1 mmol kg⁻¹ dried soil) was added to each pot until the total amount of water was .7 times the weight of dry soil. For each treatment, eight seeds were sown immediately under the soil surface. The pots were then incubated in growth chambers at 20 °C under fluorescent lamps. Distilled water was added to each pot and maintained at a level of approximately 15 mm above the soil surface. Three days after sowing, water on the soil surface was removed using a pipette. When the bottom of the soil dried out, a small amount of water that could be easily absorbed by the soil was added to the soil surface. For this experiment, seedling establishment rates were measured at 2 wk after sowing. Seedling establishment was determined by the appearance of the second leaf. Each treatment was replicated six times.

Experiment 4: Effect of seed coating treatments using tungsten compounds on soybean

Soybean seeds (cv. Fukuyutaka) were treated with tungsten and molybdenum compounds as described in Experiment 3. Wet soil equivalent to 100 g of dry soil was placed in pots. A solution containing ammonium sulfate (4 mmol kg⁻¹ dried soil) and potassium chloride (1 mmol kg⁻¹ dried soil) was added to each pot until the total amount of water was .7 times the weight of dry soil. For each treatment,
eight seeds were sown immediately under the soil surface, and the pots were incubated in growth chambers at 25 °C with metal halide lamps (ca. .4 mmol m⁻² s⁻¹, 12 h d⁻¹). As in Experiment 3, distilled water was added to the pots to maintain a water level of approximately 15 mm above the soil surface. Two days after sowing, water on soil surface was removed using a pipette. A small amount of water that can be easily absorbed was added to the soil surface as the soil dried out. Seedling establishment rates were measured 3 wk after sowing. Seedling establishment was determined by the appearance of the second leaf. Six replicates were used for each treatment.

Results

Experiment 1: Effect of seed coating using various amounts of tungsten compounds on rice seedling establishment

Seedling establishment rates of less than 12% were observed for untreated seeds (Figure 1). Although seedling establishment rate was not improved when the seeds were coated with WO, a significant effect was observed with WH at .2–2 mol W kg⁻¹ and WPNH at .1–2 mol W kg⁻¹.

Experiment 2: Effect of seed coating using various tungsten compounds on rice seedling establishment

Seedling establishment rates for group one was improved when the seeds were coated with MoO, MoH, MoPNH, or WPNH, but no improvement was observed with WO, or WH (Figure 2(A)). Seedling establishment for group two was improved when the seeds were coated with MoNH, MoMg, MoPH, MoPNa, MoSiH, WNHN, WPH, WPNa, WSiH, or WSiNa, but no improvements were observed with MoNa, MoK, MoCa, WK, or WNHP (Figure 2(B)).

Experiment 3: Effect of seed coating treatments using tungsten compounds on wheat and barley

Wheat seedling establishment rate was improved when seeds were coated with MoO, MoH, MoPNH, MoPK, or WPNH, but not with WO or WH (Figure 3). Barley seedling establishment rate was also improved when the seeds were treated with MoO, MoH, MoPNH, MoPK, or WPNH, but not with WO or WH (Figure 4).

Experiment 4: Effect of seed coating treatments using tungsten compounds on soybean

Soybean seedling establishment rate improved when seeds were coated with MoO, MoH, MoPNH, MoPK, WH, or WPNH, but not when the seeds were coated with WO (Figure 5).

Discussion

For rice, WO seed coating had little effect on the seedling establishment (Figures 1 and 2(A)). The increase in seedling establishment with WPNH was significant when the treatment amount was no less than .1 mol W kg⁻¹. WH also resulted in moderate increase in establishment when the amount was no less than .2 mol W kg⁻¹. The effective rates of tungsten compounds are similar to those for molybdenum compounds reported by Hara (2013c). WNHN, WPH, WPNa, WSiH, and WSiNa showed significant improvements on seedling establishment. However, WNHP and WK showed no significant improvement effect (Figure 2(B)).

For wheat and barley, the effect on seedling establishment by WPNH was significant, but not for WO and WH (Figures 3 and 4). Even though there were improvements, the positive effect resulting from WPNH treatment tended to be lower than those of molybdenum compounds. For soybean, significant improvements occurred with WH and WPNH treatments, but not with WO (Figure 5).

Overall, for all crops, WPNH treatment resulted in the most significant improvement in seedling establishment, followed by WH. Once again, WO had no effect (Figures 1, 2(A), 3–5). Additionally, for rice and soybean, the results for WPNH and WH were comparable with those for molybdenum compound treatments (Figure 1, 2(A), and 5). However, for wheat and barley, treatments using tungsten compounds were less effective than those using molybdenum compounds (Figures 3 and 4).
Figure 2. Effect of seed coating with different molybdenum and tungsten compounds on seedling establishment of rice.
Notes: Rice seeds were coated with only reduced iron lacking molybdenum or tungsten compounds (no). A: The seeds were coated with reduced iron and molybdenum trioxide (MoO), molybdic acid (MoH), ammonium phosphomolybdate (MoPnH), potassium phosphomolybdate (MoPK), tungsten trioxide (Wo), tungstic acid (WH), or ammonium phosphotungstate (WPnH). B: The seeds were coated with reduced iron and ammonium molybdate (MoNH), sodium molybdate (MoNa), potassium molybdate (MoK), magnesium molybdate (MoMg), calcium molybdate (MoCa), phosphomolybdic acid (MoPH), sodium phosphomolybdate (MoPnNa), silicomolybdic acid (MoSiH), potassium tungstate (WK), ammonium metatungstate (WnHm), ammonium paratungstate (WnHp), phosphotungstic acid (WPH), sodium phosphotungstate (WPnH), silicotungstic acid (WSiH), or sodium silicotungstate (WSiNa). Error bars represent standard error (n = 6). Statistical significance was calculated using a Dunnett’s multiple comparison between treated and non-treated samples. Significance levels are reported as follows: **p < .01, *p < .05.

Figure 3. Effect of seed coating with different molybdenum or tungsten compounds on seedling establishment of wheat.
Notes: Wheat seeds were uncoated (no) or coated with molybdenum trioxide (MoO), molybdic acid (MoH), ammonium phosphomolybdate (MoPnH), potassium phosphomolybdate (MoPK), tungsten trioxide (Wo), tungstic acid (WH), or ammonium phosphotungstate (WPnH). Sown seeds were flooded for 3 d. Error bars represent standard error (n = 6). Statistical significance was calculated using a Dunnett’s multiple comparison between treated and non-treated samples. Significance levels are reported as follows: **p < .01, *p < .05.

Figure 4. Effect of seed coating with different molybdenum or tungsten compounds on seedling establishment of barley.
Notes: Barley seeds were uncoated (no) or coated with molybdenum trioxide (MoO), molybdic acid (MoH), ammonium phosphomolybdate (MoPnH), potassium phosphomolybdate (MoPK), tungsten trioxide (Wo), tungstic acid (WH), or ammonium phosphotungstate (WPnH). Sown seeds were flooded for 3 d. Error bars represent standard error (n = 6). Statistical significance was calculated using a Dunnett’s multiple comparison between treated and non-treated samples. Significance levels are reported as follows: **p < .01, *p < .05.
higher because of the higher temperature, and result in the observed improvements in rice and soybean seedling establishment compared to wheat and barley.

MoNH, MoNa, MoK, MoPH, MoPNa, MoSiH, WK, WNhm, WNHp, WPH, WPNa, WSiH, and WSiNa are water soluble. The minor improvement effect by MoNa, MoK, WK, and WNHp might be caused by functional molybdate or tungstate ions that easily diffuse in to the soil (Figure 2(B)). Although it is not immediately apparent why the use of polyacids and polyacid salts such as MoPX, MoSiX, WPX, and WSiX (X is H, Na, or K) improve seedling establishment, the effects are worth further investigation (Figure 2(B)). It is possible that differences in hydration number between WNhm and WNHp cause difference in reactivity (Figure 2(B)).

Taylor and Oremland (1979) proposed that tungstate and molybdate were likely to be similar in their ability to generate sulfide ions. In this study, the observed effects of tungsten were similar to molybdenum for improving seedling establishment with the exceptions of wheat and barley. Tungsten compounds are more expensive than molybdenum compounds. Moreover, molybdenum is an essential plant element, whereas tungsten is not. Therefore, although there were observed benefits from using tungsten containing compounds, molybdate compounds appear to be the better choice for seed treatments.

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Disclosure statement
No potential conflict of interest was reported by the author.

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