Response of Vegetable Seedling Emergence to Mustard (Sinapis alba ‘IdaGold’ and Brassica juncea ‘Pacific Gold’) Seed Meal

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Abstract. Mustard Seed Meals (MSMs) are by-products of biodiesel and an alternative to conventional herbicides for organic farming. However, MSMs might also suppress the emergence of vegetable seedlings. The objective of this study was to determine the response of vegetable seedling emergence to different MSM types and rates applied as an alternative herbicide. Six types of vegetable seeds, onion (Allium cepa), two cultivars of lettuce (Lactuca sativa ‘Black Seeded Simpson’ and ‘Buttercrunch’), mustard (Brassica juncea), kale (Brassica oleracea), and Mizuna (Brassica rapa var. japonica), were sowed in petri dishes containing germination mix. MSMs (Sinapis alba ‘IdaGold’ and B. juncea ‘Pacific Gold’) were incorporated into the germination mix at 0, 88, 176, or 265 g·m–2. Petri dishes were sealed for 1, 3, 5, or 7 days after sowing. For onion, ‘Pacific Gold’ had a greater suppressive effect on seedling emergence than ‘IdaGold’. For kale and Mizuna, ‘IdaGold’ and ‘Pacific Gold’ had similar suppressive effects on seedling emergence, while sealing delayed but did not decrease emergence percentage (EP) at the lower rate (88 g·m–2) compared with the control treatment. For ‘Buttercrunch’ lettuce, there were no differences in the suppressive effects between the two MSMs. For ‘Black Seeded Simpson’ lettuce, ‘Pacific Gold’ had more suppressive effects on seedling emergence than ‘IdaGold’ when sealed at the lower rate (88 g·m–2) for longer durations (7 days) or at higher rates (176 and 265 g·m–2) for shorter durations (1 and 3 days). These results suggest that MSMs might suppress vegetable seedling emergence when applied at high rates (176 and 265 g·m–2), and sealing for more than 7 days after sowing may strengthen the suppressive effect. Extending sealing duration at the medium rates could achieve similar weed control results to high rates without sealing.

Organic farming is rapidly increasing in U.S. agriculture. Weeds are listed as the number one problem for organic producers (Walz, 1999). Only a few organic herbicides are used in organic farming systems (Webber III et al., 2012). MSMs as by-products of biodiesel and industrial oil production are residues remaining after oil extraction. As an alternative method to chemical herbicides, utilization of MSM not only assists the biodiesel industry to be economically and environmentally viable but also offers a solution to organic agricultural production systems. Our previous study demonstrated the herbicidal efficacy of S. alba ‘IdaGold’ and B. juncea ‘Pacific Gold’, which varied with application rate and method and weed species (Wang et al., 2015).

The herbicidal activity of MSM is due to allelopathy induced by hydrolysis products of glucosinolates (GSLs) (Hoagland et al., 2008). Certain plants in the Brassicaceae family are known to possess allelopathic properties, and are used as cover crops in different cropping systems (Haramoto and Galloway, 2005). There are about 20 GSLs in Brassica species, with concentrations varying among species and also within different plant tissues (Kirkegaard and Sarwar, 1998). Sinapis alba ‘IdaGold’ seed meal is dominated by 4-hydroxybenzyl GSL (glucosinolate), whereas B. juncea seed meal is dominated by 2-propenyl GSL (sinigrin) (Hansson et al., 2008). GSLs hydrolyze or degrade quickly and volatiles may be released after incorporation of MSM in soil (Morra and Kirkegaard, 2002). For this reason, sealing after incorporating MSM into soil may increase the efficacy of MSM to suppress weed emergence. In our previous study using petri dishes, sealing did decrease weed emergence compared with the unsealed treatment (Wang et al., 2015). Plastic mulch, commonly used in commercial vegetable production, can provide a condition similar to sealing.

Early development of vegetable seedlings may be the most vulnerable part of the life cycle when exposed to allelopathic chemicals (Russo et al., 1997), and MSMs have been reported to have potential herbicidal, insecticidal, nematicidal, and fungicidal effects (Hansson et al., 2008). In a greenhouse experiment, onion was severely injured when MSM (S. alba) was applied at planting and at one-leaf stage at 110, 220, and 440 g·m–2, whereas redroot pigweed (Amaranthus retroflexus) was mostly killed by 70 and 280 g·m–2 MSM when surface applied at cotyledon stage or one-leaf stage (Boydston et al., 2011). Canola (Brassica napus) and mustard (S. alba) seed meals were used as organic sources of fertilizer to increase essential nutrients in the strawberry (Fragaria × ananassa) production, and greatly reduced summer annual weeds like large crabgrass (Digitaria sanguinalis), barnyardgrass (Echinochloa crus-galli), common purslane (Portulaca oleracea), and redroot pigweed at all rates of seed meals (Bañuelos and Hanson, 2010). In a field experiment, B. juncea ‘Pacific Gold’ and S. alba ‘IdaGold’ seed meal at 2,000 kg·ha–1 greatly reduced weed seedling emergence and biomass of Italian ryegrass (Lolium perenne spp. multiflorum), prickly lettuce (Lactuca serriola), redroot pigweed and wild oat (Avena fatua), which are major weeds in vegetable production systems (Handseni and Brown, 2011). Rice et al. (2007) also demonstrated that ‘Pacific Gold’ and ‘IdaGold’ greatly reduced the emergence and biomass of redroot pigweed.
common chickweed (Stellaria media), lettuce, and beet (Beta vulgaris). However, tomato (Lycopersicon esculentum) and pepper (Capsicum annum) seedling emergence in Pythium ultimum infested soils was improved by B. napus and B. juncea seed meals (Handiseni and Brown, 2011). ‘Pacific Gold’ and ‘IdaGold’ seed meals did not influence carrot (Daucus carota subsp. sativus) emergence when applied at 1 and 2 t·ha⁻¹ 36 d before planting, whereas carrot emergence decreased 40% in S. alba treatments when applied 15 d before planting (Snyder et al., 2009).

On the basis of previous findings and the potential of MSM in organic farming, the objectives of this study were to determine the effects of two types of MSM at a range of rates on the emergence of six vegetable seedlings under laboratory conditions. The ultimate goal is to minimize the potential phytotoxicity to vegetable crops, especially at emergence stage, when applying MSM for weed control in organic production systems.

Materials and Methods

Emergence of vegetable seedlings in petri dish. Two MSMs, S. alba ‘IdaGold’ and B. juncea ‘Pacific Gold’ (Farm Fuel Inc., Freedom, CA), which were derived from cold press with no heat, were incorporated uniformly into 10 g of germination mix formulated with Canadian Sphagnum peatmoss, vermiculite, starter nutrient charge (with Gypsum and dolomitic limestone (Sunshine Professional Growing Mix, BWI, Schulenburg, TX) at 0, 0.5, 1.0, or 1.5 g per petri dish (0%, 5%, 10%, or 15% w/w) and were evenly applied at the bottom of 10-cm petri dishes and 25 mL water was added. The above MSM rates were equivalent to 0, 88, 176, or 265 g·m⁻² or 0, 785, 1570, or 2364 lb·acre⁻¹. Onion ‘Texas Grano 1015Y’, mustard ‘Texas Grano 1015Y’, two lettuce ‘Black Seeded Simpson’ and ‘Buttercrunch’, mustard ‘Green Wave’, kale ‘Yates Blue Curled’, green ‘Mizuna’ were purchased from Morgan County Seeds (Barrett, MO). Ten onion, 10 kale, and 10 ‘Buttercrunch’ lettuce seeds were sowed in three separated parts of 1 petri dish, 10 mustard, 10 green and 10 ‘Black Seeded Simpson’ lettuce seeds were sowed in three separated parts of another petri dish. Seeds were sowed 2 mm below the substrate surface in each petri dish. To simulate the sealing condition of plastic mulch, all petri dishes were covered and sealed with parafilm immediately after sowing. Each MSM rate and plant seed combination was sealed for 1, 3, 5, or 7 d before uncovering. All petri dishes were placed on a shelf in the laboratory. Supplemental lighting was provided by two 40-W fluorescent light tubes (50 μmol·m⁻²·s⁻¹, 25-cm above shelf) using a 12-h photoperiod at an air temperature of 18 to 22 °C. The unsowed petri dishes (uncovered) were kept moist with a hand held sprayer. The number of emerged seedlings (vegetable seedlings with at least 5 mm radicle above substrate surface) was counted daily for 14 consecutive days after sowing.

Experimental design and statistical analysis. All experiments (all species) were conducted twice (Oct. to Nov. 2013 and Mar. to Apr. 2014) under the same conditions with the same experimental design. For each vegetable type, the petri dish experiment was arranged in a three-factor (MSM type, rate, and sealing duration) factorial design with two replications. The replication in time was treated as time block. For each species, the independent variables were analyzed with analysis of variance (ANOVA; Statistical Analysis System Version 9.3; SAS Institute, Cary, NC). For each type of vegetables, EP was calculated as: EP (%) = (no. of emerged seedlings/total no. of seeds) × 100%. In addition, emergence index (EI) was calculated as: \( EI = \sum_{i=1}^{n} \left( \frac{EP_i}{T_i} \right) \); where EP, is EP on day i (i ≥ 2), and Tᵢ is the number of days after sowing. Different from EP, EI reflects the emergence rate and sealing duration was significant, Duncan’s multiple range comparison was performed to distinguish the effects among application rates and sealing durations.

Results

The two experiments treated as a time block significantly affected the EI of all types of vegetables, except for Mustard. Therefore, results of EI from both experiments are presented in tables separately for all types of vegetables except for mustard. For mustard, results of Expt. 1 and Expt. 2 were pooled.

| Source          | Onion | Kale | Mizuna | Mustard | ‘Buttercrunch’ lettuce | ‘Black Seeded Simpson’ lettuce |
|-----------------|-------|------|--------|---------|------------------------|-------------------------------|
| Block           | <0.0001 | NS | 0.0065 | NS | <0.0001 | <0.0001 |
| Rate            | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Sealing duration | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Type            | <0.0001 | NS | 0.0176 | NS | 0.0367 | <0.0001 |
| Type × rate     | 0.0248 | 0.0008 | NS | 0.014 | NS | 0.0256 |
| Rate × sealing duration | NS | 0.0009 | <0.0001 | 0.0075 | 0.0055 | 0.0007 |
| Type × sealing duration | NS | NS | NS | NS | NS | NS |
| Type × rate × sealing duration | NS | NS | NS | NS | NS | NS |

Table 2. A summary of analysis of variance (ANOVA) of emergence index (EI) of six types of vegetables exposed to different types (‘IdaGold’ and ‘Pacific Gold’) and rates (0, 88, 175, and 265 g·m⁻² per dish) of mustard seed meal (MSM) and sealing durations (1, 3, 5, and 7 d). Block: time block of the two experiments conducted at different time periods.

Table 1. A summary of analysis of variance (ANOVA) of emergence percentage (EP) of six vegetable types exposed to different types (‘IdaGold’ and ‘Pacific Gold’) and rates (0, 88, 175, and 265 g·m⁻² per dish) of mustard seed meal (MSM) and sealing durations (1, 3, 5, and 7 d). Block: time block of the two experiments conducted at different time periods.
1 d in Expt. 1. For all sealing durations, ‘Pacific Gold’ at 88 g·m⁻² did not impact EI in Expt. 1.

‘Vates Blue Curled’ kale. The effects of MSM rate, sealing duration, the interaction between MSM type and rate, and the interaction between MSM rate and sealing duration significantly impacted EP and EI of kale seedlings, while the effects of the interaction among the three main factors (MSM type, rate, and sealing duration), the interaction between MSM type and sealing duration, and MSM type did not significantly affect EP and EI of kale seedlings (Tables 1 and 2). When there was no MSM incorporated into the germination mix, sealing decreased EI when sealed for 7 d in both experiments (Table 4). For both ‘IdaGold’ and ‘Pacific Gold’, EI generally decreased as rate increased for all sealing durations. There was no difference in EI between ‘IdaGold’ and ‘Pacific Gold’ under the same rate and sealing duration (Tables 2 and 4).

Mizuna. The effects of MSM type, rate, sealing duration, and the interaction between MSM rate and sealing duration were significant on EP and EI of Mizuna seedlings, while the interaction among three main factors (MSM type, rate, and sealing duration), the interaction between MSM type and sealing duration were not significant on EP and EI (Tables 1 and 2). When there was no MSM incorporated into the germination mix, sealing reduced EI when sealed for 3 to 7 d in Expt. 2 but not in Expt. 1 (Table 5). For both ‘IdaGold’ and ‘Pacific Gold’, EI was significantly decreased when sealed with 88 to 265 g·m⁻² of MSM from 1 to 7 d in both experiments except for 88 to 176 g·m⁻² of ‘Pacific Gold’ sealed for 1 d in Expt. 1.

‘Green Wave’ mustard. The effects of MSM rate, sealing duration, the interaction between MSM type and rate, and the interaction between MSM rate and sealing duration were significant on EP and EI of mustard seedlings, while the interaction among the three main factors (MSM type, rate, and sealing duration), the interaction between type and sealing duration, and MSM type were not significant on EP and EI of mustard seedlings (Tables 1 and 2). When there was no MSM incorporated into the germination mix, sealing decreased EI of mustard seedlings when sealed from 3 to 7 d (Table 6). For ‘IdaGold’, EI significantly decreased when sealed with 176 g·m⁻² for 1 and 5 d, and with 88 g·m⁻² for 3 and 7 d. For ‘Pacific Gold’, EI was significantly reduced when sealed with 88 g·m⁻² from 1 to 7 d. There was no difference in EI among all sealing durations. Type of MSM did not affect EI of mustard seedling.

‘Buttercrunch’ lettuce. The effects of MSM type, rate, sealing duration, and the interaction between MSM rate and sealing duration were significant on EP and EI of ‘Buttercrunch’ seedlings (Tables 1 and 2). When there was no MSM incorporated into the germination mix, sealing slightly reduced EI in Expt. 2 but not in Expt. 1 (Table 7). For ‘Pacific Gold’, EI was zero for all sealing durations in Expt. 2, regardless of MSM rate; in Expt. 1, EI was zero or at a very low value when sealed for 5 to 7 d. Similarly, ‘IdaGold’ at 176 g·m⁻² and 265 g·m⁻² also resulted in zero or very low values of EI. The three rates of ‘IdaGold’ and ‘Pacific Gold’ generally had similar impact on EI.

‘Black Seeded Simpson’ lettuce. The effects of MSM type, rate, sealing duration, and sealing duration and the interaction between MSM type and rate were not significant on EP and EI of ‘Buttercrunch’ seedlings (Tables 1 and 2). When there was no MSM incorporated into the germination mix, sealing slightly reduced EI in Expt. 2 but not in Expt. 1 (Table 7). For ‘Pacific Gold’, EI was zero for all sealing durations in Expt. 2, regardless of MSM rate; in Expt. 1, EI was zero or at a very low value when sealed for 5 to 7 d. Similarly, ‘IdaGold’ at 176 g·m⁻² and 265 g·m⁻² also resulted in zero or very low values of EI. The three rates of ‘IdaGold’ and ‘Pacific Gold’ generally had similar impact on EI.

Table 3. Effects of different types (‘IdaGold’ and ‘Pacific Gold’) and rates (0 to 265 g·m⁻²) of mustard seed meal (MSM) and sealing durations (1, 3, 5, and 7 d) on emergence index (EI) of ‘Texas Grano 1015Y’ onion seedlings at 14 d after sowing.

| Expt. 1: | MSM (g·m⁻²) | Sealing duration (d) |
|----------|--------------|----------------------|
| IdaGold  | 0 89.00 A a  | 76.45 A ab 61.30 A b 63.15 A B |
|          | 88 78.00 A B a 58.05 AB bc 41.05 AB bc 21.90 B c |
|          | 176 50.00 A b 25.80 B b 10.90 B c 1.50 B c |
|          | 265 20.15 B a 36.55 AB a 9.75 B a 1.50 B c |
| Pacific Gold | 0 81.05 A a 72.90 A a 67.65 A a 78.50 A a |
|          | 88 77.65 A a 38.25 A b 14.30 A c 6.65 A c |
|          | 176 35.90 B a 10.80 A b 0.00 A b 7.00 A b |
|          | 265 3.00 C a 0.35 A a 0.00 A a 0.35 A a |

Table 4. Effects of different types (‘IdaGold’ and ‘Pacific Gold’) and rates (g·m⁻²) of mustard seed meal (MSM) and sealing durations (1, 3, 5, and 7 d) on emergence index (EI) of ‘Vates Blue Curled’ kale seedlings at 14 d after sowing.

| Expt. 1: | MSM (g·m⁻²) | Sealing duration (d) |
|----------|--------------|----------------------|
| IdaGold  | 0 74.25 A a 67.95 A a 48.75 A ab 37.35 A b |
|          | 88 61.45 AB a 45.90 AB a 32.15 AB a 16.65 B a |
|          | 176 33.7 BC a 17.75 B b 9.35 BC b 0.00 B b |
|          | 265 11.80 C a 8.10 B a 4.75 C a 3.00 BC a |
| Pacific Gold | 0 75.95 A a 60.20 A ab 55.65 A a 28.70 A c |
|          | 88 12.40 B a 5.75 B a 7.05 B a 1.50 B a |
|          | 176 1.15 C a 0.00 B a 0.35 B a 0.00 B a |
|          | 265 0.00 C a 0.00 B a 0.00 B a 0.00 B a |

*Means followed by a different letter (upper case) within a column are significantly different at P ≤ 0.05. **Means followed by a different letter (lower case) within a row are significantly different at P ≤ 0.05.
Table 5. Effects of different types ('IdaGold' and 'Pacific Gold') and rates (0 to 265 g·m⁻²) of mustard seed meal (MSM) and sealing durations (1, 3, 5, and 7 d) on emergence index (EI) of ‘Mizuna’ green seedlings at 14 d after sowing.

| Expt. 2: Rates Sealing duration (d) |  |  |  |  |
|---------------------------------|---|---|---|---|
| MSM (g·m⁻²) | 1 | 3 | 5 | 7 |
| IdaGold 0 | 153.70 A a | 134.85 A a | 142.80 A a | 127.35 A a |
| 88 | 111.25 B a | 43.60 B ab | 55.05 B b | 19.55 B b |
| 176 | 24.20 C a | 10.15 B ab | 4.05 C b | 1.85 B b |
| 265 | 0.00 C a | 0.00 B a | 0.00 C a | 0.00 B a |
| Pacific Gold 0 | 152.05 A a | 170.40 A a | 161.65 A a | 148.70 A a |
| 88 | 117.10 AB a | 23.20 B b | 8.00 B b | 2.55 B b |
| 176 | 50.65 AB a | 17.85 B a | 21.30 B a | 1.05 B a |
| 265 | 16.10 A a | 10.60 B a | 0.00 B a | 0.00 B a |

EI of Mizuna seedlings (%)

Expt. 2:

| Rates Sealing duration (d) |  |  |  |  |
|----------------------------|---|---|---|---|
| MSM (g·m⁻²) | 1 | 3 | 5 | 7 |
| IdaGold 0 | 152.90 A a | 126.20 A b | 126.25 A b | 83.05 A c |
| 88 | 52.15 B a | 10.70 B b | 20.75 B ab | 10.95 B b |
| 176 | 0.75 C a | 2.30 B a | 2.30 BC a | 0.85 B a |
| 265 | 1.60 C a | 0.00 C a | 0.00 C a | 0.00 B a |
| Pacific Gold 0 | 153.90 A a | 122.15 A a | 107.75 A a | 124.75 A a |
| 88 | 93.60 B a | 58.50 B ab | 32.15 B b | 20.90 B b |
| 176 | 19.65 C a | 2.65 C ab | 8.20 C ab | 0.75 B b |
| 265 | 3.25 C a | 0.00 C a | 0.00 C a | 0.00 B a |

EI of Mizuna seedlings (%)

#Means followed by a different letter (upper case) within a column are significantly different at P ≤ 0.05.
#Means followed by a different letter (lower case) within a row are significantly different at P ≤ 0.05.

Table 6. Effects of different types ('IdaGold' and 'Pacific Gold') and rates (0 to 265 g·m⁻²) of mustard seed meal (MSM) and sealing durations (1, 3, 5, and 7 d) on emergence index (EI) of ‘Green Wave’ mustard seedlings at 14 d after sowing.

| Rates Sealing duration (d) |  |  |  |  |
|----------------------------|---|---|---|---|
| MSM (g·m⁻²) | 1 | 3 | 5 | 7 |
| IdaGold 0 | 138.9 A a a | 109.9 A b | 94.1 B b | 69.8 A c |
| 88 | 112.1 A a a | 52.1 B b c | 66.7 A b c | 29.7 B c |
| 176 | 67.9 B a a | 26.8 C b b | 10.4 B c c | 6.4 B c |
| 265 | 32.2 C a a | 12.7 C ab a | 1.9 B b a | 9.1 B b |
| Pacific Gold 0 | 125.5 A a a | 111.3 A a a | 93.2 B b a | 95.3 A B a |
| 88 | 115.2 AB a a | 21.3 B a b | 22.1 B b b | 13.1 B b |
| 176 | 87.7 B a a | 20.1 B a c | 19.5 B b c | 5.4 B b |
| 265 | 41.1 C a a | 6.7 B a a | 2.4 B a b | 1.7 B b |

#Means followed by a different letter (upper case) within a column are significantly different at P ≤ 0.05.
#Means followed by a different letter (lower case) within a row are significantly different at P ≤ 0.05.

Discussion

The efficacy of MSM depends on several factors, type of seed meal, application rates, and target plant species. ‘Pacific Gold’ seed meal mainly contains sinigrin (2-propenyl-ITC), whereas ‘IdaGold’ seed meal contains a large concentration of sinalbin (4-hydroxybenzyl GSL) (Borek et al., 2005; Hansson et al., 2008; Rice et al., 2007). 2-Propenyl-ITC was the dominant GSL hydrolysis product from ‘Pacific Gold’ seed meal, which is phytotoxic due to a nonspecific and irreversible reaction with sulfur-containing groups in proteins (Bending and Lincoln, 1999; Brown and Morra, 1997; Rice et al., 2007). Other studies have reported that SCN- was more persistent in the soil compared with 2-propenyl-ITC (Borek et al., 1995; Brown and Morra, 1993). Also, ‘Pacific Gold’ produces volatile allyl-ITCs that are toxic on contact, with a half-life of 16 h after soil incorporation (Petersen et al., 2001). SCN- produced by ‘IdaGold’ is transported and accumulates in plant tissues, which might not kill seedlings at shorter sealing durations (Stiehl and Bible, 1989), but may affect plant growth. Different responses of vegetable seedlings to the type, rate, and sealing duration of MSM treatments observed in this experiment may also be due to different sensitivity to GSL breakdown products that have been observed among plant species (Vaughn et al., 2006).

As discussed above, due to the different GSLs in the two different MSMs, the responses of vegetable seedling emergence to these MSM applications differed among species. For onion seedlings, ‘Pacific Gold’ had greater suppressive effects on seedling emergence than ‘IdaGold’ (Table 3). For kale and mustard seedlings, ‘IdaGold’ and ‘Pacific Gold’ had similar suppressive effects; however, ‘Pacific Gold’ delayed emergence of kale seedlings at 88 g·m⁻² when sealed for 3, 5, and 7 d (Tables 4 and 6). For Mizuna seedlings, ‘IdaGold’ had more suppressive effects than ‘Pacific Gold’ on seedling emergence, while sealing delayed but did not decrease emergence at a low rate (88 g·m⁻²) of MSMs compared with the control (Table 5).

Lettuce is particularly sensitive to Brassicaceae seed meal-derived allelochemicals (Rice et al., 2007). For ‘Buttercrunch’ seedlings, sealing durations did not provide additional reduction of emergence, and there were also no different suppressive effects between ‘IdaGold’ and ‘Pacific Gold’ (Table 7). For ‘Black Seeded Simpson’ seedlings, ‘Pacific Gold’ had more suppressive effects on ‘Black Seeded Simpson’ seedlings emergence than ‘IdaGold’ when sealed using the lower rate (88 g·m⁻²) of MSM for longer durations (7 d) or at higher rates (176 and 265 g·m⁻²) of MSM for shorter durations (1 and 3 d) (Table 8). Meyer et al. (2011) found that 0.5% (w/w) ‘IdaGold’ seed meal did not reduce lettuce seed germination, but all seed meal treatments containing ‘Pacific Gold’ significantly reduced germination when applied immediately after planting. Although the MSM did not affect lettuce seed germination at 1–5 weeks after planting, hypocotyl growth was reduced. In a field experiment, lettuce emergence was lower with 3% ‘Pacific Gold’ than 3% ‘IdaGold’ or B. napus seed meal when planted 28 d after seed meal treatments (Rice et al., 2007).

On the basis of the results of this study, there might be suppressive effects of MSMs at higher rates (176 and 265 g·m⁻²) on vegetable emergence. Suppressive efficacy of MSM would be enhanced by sealing the soil after application such as plastic mulches. MSM at medium rate with sealing may achieve similar efficacy to high rates of MSM.
of MSM without sealing. Also, MSMs are basically a nonselective type of weed control and its efficacy varies with crop species, application rate and method, and environmental conditions. Therefore, extensive field studies are needed to determine the rate and timing of applying MSM to suppress weed emergence for vegetable production with direct seeding or transplanting to avoid or minimize suppressive effects on seedling emergence of vegetable crops.

Table 7. Effects of different types ('IdaGold' and 'Pacific Gold') and rates (0 to 265 g m⁻²) of mustard seed meal (MSM) and sealing durations (1, 3, 5, and 7 d) on emergence index (EI) of 'Buttercrunch' lettuce seedlings at 14 d after sowing.

| Expt. 1:       | Rates (g m⁻²) | Sealing duration (d) | 1 | 3 | 5 | 7 |
|----------------|---------------|----------------------|---|---|---|---|
| MSM            |               |                      |   |   |   |   |
| IdaGold        | 0             | 141.65 A a           | 149.70 A a | 137.85 A a | 147.55 A a |
|                | 88            | 97.45 AB a           | 51.65 B a  | 48.90 B ab  | 16.00 B b  |
|                | 176           | 47.50 BC a           | 10.25 B b  | 8.10 B b    | 0.00 B b    |
|                | 265           | 3.55 C a            | 4.90 B a       | 0.00 B a   | 1.15 B a    |
| Pacific Gold   | 0             | 144.30 A a           | 150.30 A a | 134.80 A a | 119.70 A a |
|                | 88            | 99.20 B a           | 34.70 B ab  | 11.40 B b   | 6.20 B b    |
|                | 176           | 17.85 C a           | 5.90 B ab   | 0.75 B b    | 0.00 B b    |
|                | 265           | 0.00 C a            | 0.00 B a       | 0.00 B a   | 0.00 B a    |

Means followed by a different letter (upper case) within a column are significantly different at P ≤ 0.05.

Table 8. Effects of different types ('IdaGold' and 'Pacific Gold') and rates (0 to 265 g m⁻²) of mustard seed meal (MSM) and sealing durations (1, 3, 5, and 7 d) on emergence index (EI) of 'Black Seeded Simpson' lettuce seedlings at 14 d after sowing.

| Expt. 1:       | Rates (g m⁻²) | Sealing duration (d) | 1 | 3 | 5 | 7 |
|----------------|---------------|----------------------|---|---|---|---|
| MSM            |               |                      |   |   |   |   |
| IdaGold        | 0             | 135.15 A ab          | 109.00 A bc | 127.10 A ab | 99.05 A c |
|                | 88            | 35.40 B a           | 29.20 B ab  | 5.00 B b    | 4.70 B c   |
|                | 176           | 2.10 B a            | 1.15 B a     | 3.75 B a   | 0.00 B a   |
|                | 265           | 0.00 B a            | 0.00 B a     | 0.00 B a   | 0.00 B a   |
| Pacific Gold   | 0             | 138.85 A a           | 123.65 A a  | 116.05 A ab | 87.55 A b  |
|                | 88            | 0.00 B a            | 0.00 B a     | 0.00 B a   | 0.00 B a   |
|                | 176           | 0.00 B a            | 0.00 B a     | 0.00 B a   | 0.00 B a   |
|                | 265           | 0.00 B a            | 0.00 B a     | 0.00 B a   | 0.00 B a   |

Means followed by a different letter (upper case) within a column are significantly different at P ≤ 0.05.

Means followed by a different letter (lower case) within a row are significantly different at P ≤ 0.05.

Table 9. Effects of different types ('IdaGold' and 'Pacific Gold') and rates (0 to 265 g m⁻²) of mustard seed meal (MSM) and sealing durations (1, 3, 5, and 7 d) on emergence index (EI) of 'Black Seeded Simpson' lettuce seedlings at 14 d after sowing.

| Expt. 2:       | Rates (g m⁻²) | Sealing duration (d) | 1 | 3 | 5 | 7 |
|----------------|---------------|----------------------|---|---|---|---|
| MSM            |               |                      |   |   |   |   |
| IdaGold        | 0             | 144.30 A a           | 149.70 A a | 137.85 A a | 147.55 A a |
| Pacific Gold   | 0             | 138.85 A a           | 123.65 A a  | 116.05 A ab | 87.55 A b  |

Means followed by a different letter (upper case) within a column are significantly different at P ≤ 0.05.

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