Effect of Seed Selection Based on Seed Weight and Specific Gravity on Seed Germination and Seedling Emergence and Growth in Angelica acutiloba Kitagawa

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Abstract Angelica acutiloba Kitagawa (Touki) is a perennial medicinal plant used as a natural drug in Japan and in many other Asian countries. Seed germination and seedling growth are critical for species survival, plant quality and productivity. However, the seed characteristics (e.g., seed weight and specific gravity) and the optimal temperature, which affect the germination of Touki seeds and seedling growth, have not been reported. In the present study, a suitable method for classifying seeds based on the specific gravity and seed weight was applied. Experiments were conducted to examine the effect of seed weight and specific gravity on the germination of Touki seeds in the laboratory, and seedling emergence and growth in a closed system. Also, the effect of the temperature on seed germination was examined. The results showed that the optimal temperature for germination was 20.0°C. Selecting seeds based on the seed weight showed that by increasing the seed weight, the germination percentage increased and seedling growth was promoted. The root diameter and the values of the total plant dry weight were higher in the seedlings obtained from heavier seeds than in those obtained from lighter seeds. Root/shoot ratio was relatively higher in the seedlings obtained from heavier seeds than in those obtained from lighter seeds. Water uptake was affected by the seed weight. Lighter seeds absorbed water faster than heavier seeds. Selecting seeds based on the specific gravity enabled to increase the seed germination percentage, and seedling emergence and quality. The root/shoot ratio tended to be higher in the seedlings obtained from seeds with a higher specific gravity. Heavy seeds with a high specific gravity produced highly vigorous seedlings.

Key Words: Germination temperature, Medicinal plant, Seed characteristics, Touki

Introduction

Angelica is a genus including about 50 species of tall biennial and perennial herbs in the family Umbelliferae or Apiaceae. The plants are characterized by hollow fluted stems that reach a height of 0.9 to 2.1 m. Angelica is widely cultivated in Asia primarily for its medicinal roots and edible young leaves (Wood, 2006). This genus, however, has not been detected in the Viet Nam flora. One of the species that had been introduced into Viet Nam, A. acutiloba commonly known as ‘Touki’, originated from Japan (National Institute of Medicinal Materials, 1993). This species is presently cultivated in Viet Nam and used as raw material for the manufacture of various pharmaceutical products (Pham, 2000). Despite the increasing demand for this herb, cultivation and production techniques to achieve optimum plant yield have not been fully developed.

A. acutiloba is propagated by seeds. The seeds are sown in a cold frame immediately after ripening because of their short viability (Huxley, 1992). The seeds are usually sown in October and the plants are harvested in September of the following year. The seedling stage covers a long winter period with low temperatures (9.4°C, on average) that adversely affect seedling growth and consequently, plant development (Hua Li et al., 2006). Hence, one of the major challenges in A. acutiloba production is to obtain a high seed germination percentage and vigorous seedlings with highly productive and good quality roots.

Among the main factors affecting seed germination, seed weight plays a key role in the development of the juvenile phase of a plant’s life cycle (Khan, 2004). Twamley (1967) and Eriksson (1999) mentioned that seed weight within a species or even within an individual plant can vary considerably. In several species, larger seeds are associated with a higher seedling survival and more vigorous seedlings than smaller seeds (Baskin and Baskin, 1998; Mole and Westoby, 2004; Lehtilä and Ehrlen, 2005). Therefore, the seed size is widely recognized as an index of seed quality. However, Hendrix (1984) observed that smaller seeds of Pastinaca sativa L. (Apiaceae) germinated more rapidly than larger seeds.

Selection of seeds based on the specific gravity (SG) is commonly used to separate filled viable seeds from empty, mechanically and insect-damaged seeds or...
filled but dead seeds (hereafter referred to as “dead-filled”). SG separation is based on the principle that viable and dead-filled or empty seeds can be separated in liquid media according to differences in their specific gravity (Demelash et al., 2003). In the SG method, McLemore (1965) used n-pentane as flotation medium for longleaf pine seeds (Pinus palustris Mill.), while Brown (1967) used ether medium for Jack pine seeds (Pinus banksiana Lamb.) and Menon et al. (1985) used sugar medium for cashew seeds.

In addition to the selection of good quality seeds, recently, closed system techniques have been developed to produce uniform and high quality seedlings. Kozai and Chun (1999) and Kozai (2005) reported that in closed systems, the quality of the transplants was much higher than that in open systems (green house), resulting in higher yield and quality of harvested crops and reduced use of agrochemicals in the fields or green houses.

The objectives of the present study were to investigate the effects of the seed weight and specific gravity on seed germination, seedling emergence and mean germination time of A. acutiloba seeds. To analyze the effect of seed weight on the water uptake of seeds, the water absorption period during incubation was examined. In the study, the influence of the seed weight and specific gravity on the growth of the seedlings was also analyzed, particularly the roots in a closed transplant production system.

Materials and Methods

Seed collection

Dry seeds of A. acutiloba Kitagawa or ‘Touki’ (Toyama Medicinal Plant Center in Toyama Prefecture, Japan) were packed in a silver bag and stored at -20°C from August, 2002 to June, 2005.

Germination tests

To avoid fungal contamination, the surface of all the seeds was sterilized in sodium hypochlorite (NaOCl) containing 1% active chlorine for 20 minutes and then, washed thoroughly with distilled water prior to sowing.

Temperature conditions

To determine the optimal temperature for germination, the seeds were sown in Petri dishes (11-cm diameter) filled with 120 ml of Perlite (2 mm diameter) and 70 ml of distilled water. The sown seeds were incubated at five temperatures of 15.0, 17.5, 20.0, 22.5 and 25.0°C in darkness for 26 days. One hundred seeds were used per treatment and replicated three times.

Seed selection based on seed weight

Seeds were weighed (in mg) individually and classified into six grades: ≤1.5; 1.6 - 2.0; 2.1 - 2.5; 2.6 - 3.0; 3.1 - 3.5; ≥3.6 mg. Seed size (length and width; in mm) for each grade was measured with a digital caliper (0.01 -150 mm Code No 500 -110 SR-44, Mitutoyo, Japan). The seeds were cut longitudinally and the size of the embryo and thickness of the testa were measured under a stereomicroscope (SZH-I.I.K, Olympus optical Co., Ltd. Japan). Fifty seeds for each grade were used in germination tests with four replications. Each sample of 50 seeds was weighed before sowing. The seeds were sown in Petri dishes (6 cm × 1.5 cm) lined with filter paper (No 2 Advantec, Toyo Roshi Kaisha, Ltd, Japan) and 10 ml of distilled water was added. The seeds were incubated at 20.0°C in the dark. The water uptake of seeds for each grade was determined after the first 25 min and at 3, 6, 9, 12 h, and thereafter at two-day intervals, 1, 3, 5, 7, 9, 11, 13, 15, 17 days after sowing. The seeds were carefully blotted dry between absorbent tissue paper and weighed. The mean increase in fresh weight was calculated and converted into percentage using the formula:

\[
\text{Fresh weight increment (\%)} = \frac{\text{current weight} - \text{initial weight}}{\text{initial weight}} \times 100
\]

The seeds were incubated for 30 days and the germination was recorded every day starting on the 12th day after sowing. The protrusion of the radicle was used as a criterion for a germinated seed.

Seed selection based on specific gravity

Dry seeds were placed in a gauge glass containing 1 liter of tap water (1.00 SG) and stirred to facilitate the separation of floating and sunken seed fractions. The floating fraction that was collected and rinsed with water corresponded to <1.00 grade. The sunken fraction was sequentially retained in the gauge glass containing sodium chloride at 1.03, 1.06, 1.09 and 1.12 SG. Based on the specific gravity, the seeds were classified into six grades: SG<1.00; 1.00 ≤ SG<1.03; 1.03 ≤ SG<1.06; 1.06 ≤ SG<1.09; 1.09 ≤ SG<1.12 and SG ≥ 1.12. One hundred seeds per treatment with three replications were sown in plastic Petri dishes (14 cm × 2.5 cm) filled with 120 ml of Perlite (2 mm in diameter) and 70 ml of distilled water for the germination test.
Likewise, seeds were sown in 3-cm cell trays filled with Tsuchitaro soil containing N:P_{2}O_{5}:K_{2}O at a ratio of 120:1,000: 50 mg/L at pH 6.7 (Sumitomo, Japan) for the emergence test. The germination of the seeds and emergence of the seedlings were monitored every day starting on the 11th and 15th day after sowing, respectively. The seeds were incubated for 28 days for the germination test and 31 days for the emergence test under the same conditions as those used in the previous experiment. Protrusion of the radicle and epicotyl was used as criteria for a germinated seed and emerging seedling, respectively.

**Seedling growth**

After 17 to 21 days of incubation, germinated seeds were selected and transplanted to cell trays (2-cm diameter) filled with Tsuchitaro soil. Thirty two healthy seedlings were selected from each treatment after two weeks. These seedlings were grown in a chamber (Closed system - Taiyou kougyou, Japan) at a high carbon dioxide concentration (1000 ppm), 75% relative humidity, constant temperature (25 °C/18 °C day/night) and under a light period of 12 hours using fluorescent lamps. The light intensity over each tray was 250 μmol m^{-2}s^{-1}.

**Plant samples**

Plant height was measured once a week. Cotyledon length was measured at 2 weeks after transplanting. Leaf area was measured with an automatic area meter (AAM-8 Hayashidenko Inc., Tokyo, Japan) and the root diameter was measured with a digital caliper. Eight plants were harvested per treatment every 3 weeks. The plants were divided into three parts (i.e., leaf, petiole and stem, and root), dried at 70 °C for 48 hours in a convectional oven and weighed.

**Data analysis**

Seed germination and seedling emergence percentages were arcsine-transformed to meet the assumptions of ANOVA. Germination and emergence percentages, mean germination time (MGT) and mean emergence time (MET) were calculated with standard errors. MGT and MET were computed according to the formula (Bewley and Black, 1994):

\[
MGT = \frac{\sum (t \times n_i)}{\sum n_i} \quad \text{and} \quad \text{MET} = \frac{\sum (t \times n_j)}{\sum n_j}
\]

where \( t \) is the time (in days) starting from day 0 (the day of sowing); \( n_i \) is the number of seeds that completed germination on day \( t \); and \( n_j \) is the number of seeds with complete emergence of the seedlings on day \( t \).

Tukey test was used to compare the significant differences of the treatment means.

**Results**

**Effect of temperature on germination percentage and time**

The germination percentage ranged from 62.0% to 83.0% in the temperature range from 15.0 °C to 25.0 °C. The optimal temperature was 20.0 °C, at which the maximum percentage of germination (83.0%) was recorded. Significant difference (P<0.05) in the germination percentage was observed between 20.0 °C and 25.0 °C (Fig. 1A), while no significant difference was detected in the temperature range from 15.0 °C to 22.5 °C. Generally, the percentage of germination increased with the increase in the temperature when the seeds were incubated below 20.0 °C, but a further increase beyond 20.0 °C correspondingly decreased the germination percentage. The lowest germination percentage (62.0%) was observed in the highest temperature treatment (25.0 °C) used in the present experiment. The effect of the temperature on the germination time is shown in Fig. 1B. The lowest mean
germination time (15.9 days) was observed at 20.0°C, indicating a significantly faster germination compared to that at the other temperatures. Conversely, incubating seeds at temperatures lower or higher than 20.0°C increased the number of days needed to induce seed germination.

**Seed selection based on seed weight**

*Seed weight and seed size*

In this experiment, the seeds were classified into six grades, as shown in Table 1. The heavier seeds were generally larger than the lighter seeds, indicating the existence of a proportionate increase in seed mass as the seeds grew larger. The seed size (length × width) ranged from 3.86 × 1.20 mm to 6.26 × 2.40 mm, for the lightest seeds and heaviest seeds, respectively.

**Effect of seed weight on germination percentage and time**

Fig. 2A shows that seeds heavier than 1.5 mg generally displayed a significantly higher percentage of germination compared to the seeds weighing 1.5 mg or less after 30 days of incubation at 20.0°C. No significant difference in the germination percentage was found in the seeds belonging to the ≥ 1.6 mg grades. However, the germination percentage tended to be higher in the heavier seeds. The seed weight also influenced the time required for germination (Fig. 2B). The seeds weighing 1.6 - 3.5 mg germinated slightly faster than the seeds heavier than 3.5 mg and lighter than 1.6 mg.

**Effect of seed weight on water uptake during incubation**

Water uptake of seeds with different seed weight grades is illustrated in Fig. 3. The amount of water taken up by the seeds was determined by measuring the fresh weight of the seeds at 24 hours after incubation. The lightest seeds (≤ 1.5 mg) showed a higher water uptake (154%) than the heaviest (≥ 3.6 mg) seeds (121%). Rapid water uptake of seeds was observed during the first 25 minutes of incubation, as indicated by the sharp increase in fresh weight of the seeds. The fresh weight of the seeds increased significantly from the first 25 minutes to 1 day, then slowed down until the onset of germination and the seeds resumed water uptake after germination. Generally, the rate of water uptake by seeds decreased with increasing incubation period.

**Effect of seed weight on thickness of testa and embryo size**

Table 2 shows that there was a positive relationship
between the seed weight and thickness of the testa and embryo size. Thicker testa and larger embryo size were observed in heavier than lighter seeds. The thickness of the testa ranged from 16.7 ± 0.8 μm to 39.0 ± 1.2 μm and the embryo size (length × width) ranged from 355.0 × 62 μm to 608.0 × 120 μm for the lightest seeds and heaviest seeds, respectively.

**Effect of seed weight on seedling growth**

The effect of the seed weight on seedling growth and plant dry weight at 8 weeks after transplanting are presented in Table 3. Seedling height, leaf area and dry matter production were significantly affected by the seed weight. Seedlings that emerged from heavier seeds generally grew better than those from lighter seeds. Seeds weighing ≥ 3.6 mg led to significantly taller plants (7.76 cm) compared to the plants produced from lighter seeds (P<0.05). Likewise, seeds weighing ≥ 3.6 mg produced plants showing a significantly (P<0.05) higher average leaf area (42.63 cm²) and higher value of shoot weight (0.19 g per plant), compared to the plants obtained from seeds weighing less than 3.6 mg (other seed lots). The same trend was observed for the root growth (root diameter and root weight), and total plant dry weight. Seedlings obtained from heavier seeds displayed on enhanced root growth compared to those from lighter seeds. At 8 weeks after transplanting, the values of the root and shoot dry weight of the seedlings originating from the heaviest seeds were six times higher than those of the seedlings obtained from the lightest seeds. Similarly, a higher value of total plant dry weight was recorded in the plants obtained from the heaviest seeds (0.32 g per plant), compared to that in the plants obtained from the lightest seeds (0.04 g per plant). However, the root/shoot ratio was not significantly different among the seed weight values.

**Seed selection based on specific gravity**

**Effect of specific gravity on germination percentage and time**

The specific gravity of seeds significantly affected the germination percentage (Fig. 4A). Generally, seeds with a higher SG value showed a higher germination percentage than those with a lower SG value. The lowest germination percentage (61.7%) was recorded in seeds with SG <1.00, while the highest germination percentage (85.3%) in seeds with 1.06 ≤ SG<1.09. No significant differences were found in the range of SG values above 1.00. However, the SG value did not affect significantly the mean germination time (Fig. 4B).

**Effect of SG on seedling emergence**

Seedling emergence from the seeds ranged from 35.0% to 58.0% for varying SG values (Fig. 5A).

<table>
<thead>
<tr>
<th>Seed weight grade (mg)</th>
<th>Thickness of testa* (μm)</th>
<th>Embryo length* (μm)</th>
<th>Embryo width* (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 1.5</td>
<td>16.7 ± 0.8</td>
<td>355.0 ± 8.6</td>
<td>62.0 ± 2.3</td>
</tr>
<tr>
<td>1.6 - 2.0</td>
<td>21.0 ± 1.0</td>
<td>366.0 ± 8.5</td>
<td>68.0 ± 2.7</td>
</tr>
<tr>
<td>2.1 - 2.5</td>
<td>25.0 ± 0.7</td>
<td>441.0 ± 9.4</td>
<td>80.5 ± 2.4</td>
</tr>
<tr>
<td>2.6 - 3.0</td>
<td>28.0 ± 0.9</td>
<td>464.0 ± 9.3</td>
<td>97.0 ± 2.5</td>
</tr>
<tr>
<td>3.1 - 3.5</td>
<td>32.0 ± 1.0</td>
<td>502.0 ± 9.5</td>
<td>98.0 ± 2.5</td>
</tr>
<tr>
<td>≥ 3.6</td>
<td>39.0 ± 1.2</td>
<td>608.0 ± 15.9</td>
<td>120.0 ± 3.9</td>
</tr>
</tbody>
</table>

* Mean ± SE

<table>
<thead>
<tr>
<th>Seed weight grade (mg)</th>
<th>Plant height (cm)</th>
<th>Cotyledon length (cm)</th>
<th>Root diameter (mm)</th>
<th>Leaf area (cm²)</th>
<th>Dry weight Root (g plant⁻¹)</th>
<th>Shoot (g plant⁻¹)</th>
<th>Total (g plant⁻¹)</th>
<th>Root/shoot ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 1.5</td>
<td>4.2a</td>
<td>1.85a</td>
<td>1.81a</td>
<td>6.69a</td>
<td>0.02a</td>
<td>0.03a</td>
<td>0.04a</td>
<td>0.49a</td>
</tr>
<tr>
<td>1.6 - 2.0</td>
<td>4.68ab</td>
<td>1.90a</td>
<td>2.23a</td>
<td>8.39ab</td>
<td>0.02a</td>
<td>0.04a</td>
<td>0.06ab</td>
<td>0.56a</td>
</tr>
<tr>
<td>2.1 - 2.5</td>
<td>5.09b</td>
<td>2.13ab</td>
<td>2.13ab</td>
<td>11.27b</td>
<td>0.02a</td>
<td>0.05ab</td>
<td>0.08b</td>
<td>0.43a</td>
</tr>
<tr>
<td>2.6 - 3.0</td>
<td>5.38b</td>
<td>2.22b</td>
<td>2.22b</td>
<td>13.51bc</td>
<td>0.03b</td>
<td>0.07b</td>
<td>0.10b</td>
<td>0.56a</td>
</tr>
<tr>
<td>3.1 - 3.5</td>
<td>6.78c</td>
<td>2.43b</td>
<td>2.43b</td>
<td>27.31d</td>
<td>0.07c</td>
<td>0.11c</td>
<td>0.18bc</td>
<td>0.62a</td>
</tr>
<tr>
<td>≥ 3.6</td>
<td>7.76d</td>
<td>2.91c</td>
<td>2.91c</td>
<td>42.63e</td>
<td>0.12d</td>
<td>0.19d</td>
<td>0.32d</td>
<td>0.63a</td>
</tr>
</tbody>
</table>

Means in the same column with the same letter are not significantly different (P<0.05)
Mean separation was performed using the Tukey test. (HSD)

* cotyledon
²: diameter
Generally, the emergence percentage increased with increasing SG values (≥ 1.00). The highest percentage of seedling emergence was recorded in seeds with 1.06 ≤ SG<1.09, whereas the lowest in seeds with SG<1.00. On the other hand, seedlings emerged earlier from seeds with a higher SG value than from seeds with a lower SG value (Fig. 5B). Seeds with the highest SG value (≥ 1.12) led to the shortest mean emergence time (20.4 days) of seedlings, while those with the lowest SG value (<1.00) to the longest mean emergence time (23.4 days).

Fig. 4 Effect of seed specific gravity on: (A) germination percentage (B) mean germination time of Touki seeds, 28 days after incubation. Error Bar=SE.

Effect of SG on seedling growth

In the seedlings obtained from seeds with a higher SG values, growth and development were more vigorous than in those obtained from seeds with a lower SG value (Table 4). Generally, the leaf area, root diameter, root and shoot and total plant dry weight increased with increasing SG value. The seedlings obtained from other seeds with the highest SG value (≥ 1.12) correspondingly produced the largest leaf area (185.6 cm²) that was significantly different from those obtained from seeds with the lowest (<1.00) SG value. Seedlings obtained from seeds with SG ≥ 1.12 produced a larger root diameter (12.5 mm), higher root weight (2.14 g), shoot weight (1.26 g) and total plant dry weight (3.40 g) values compared to those obtained with SG<1.00. However, the SG value did not affect significantly the root/shoot ratio. The results of the study were validated when a similar experiment was conducted in 2005, and similar results were obtained (data not shown).

Discussion

Effect of temperature on germination percentage and time

The optimal temperature for germination of Touki seeds was 20.0°C and the germination percentage was not significantly different in the range from 15.0°C to 20.0°C, indicating that germination was possible at lower temperatures (15.0°C to 17.5°C), although the time required for germination increased. At a higher temperature (25.0°C), the germination percentage significantly decreased and the mean germination time increased (Fig. 1A&B), indicating that high temperature (25.0°C) was unfavorable for germination. These data corresponded well to the results obtained by Pham (2000), who reported that the germination percentage of Touki seeds was higher in the October
Effect of seed weight on seed germination and seedling growth

The results of the present experiment showed that there were variations among the lots of Touki seeds. Grading by seed weight was necessary for investigating the accurate germination rate of seeds and subsequent growth of the plants. The effect of the seed weight on seed germination and growth of Touki seedlings persisted throughout the duration of the experiment. Generally, the germination rate of seeds with varying weight values was not significantly different except for the lightest (≤ 1.5 mg) and heaviest seeds (≥ 3.6 mg). The results presented in Fig. 3 reveal a sharp increase in the fresh weight of seeds weighing ≤ 1.5 mg (lightest seeds) compared to the other seed lots. Small seeds can imbibe water faster and break the dormancy earlier. Seeds with a thinner testa take up more water at a rapid rate, hence, lighter seeds may start germinating earlier than heavier seeds (Susko and Doust, 2000). In our previous experiment using seeds with and without testa, germination of the seeds lacking testa (data not shown) occurred earlier. In the present experiment, Table 2 shows that the testa of heavier seeds was thicker than that of lighter seeds. These results coincided with the study of Jun and Yunzhi (1996), who reported that the seed testa may limit the ability of seed to absorb water.

In the results from our previous studies, Nojima et al. (2004) showed that the growth of Angelica acutiloba Kitagawa seedlings was more vigorous in a closed system than in a conventional growth chamber and green house (open system). Therefore, in the present study, a closed system was used. The results showed that seedlings obtained from heavier seeds grew better and faster than those from lighter seeds. Khan (2004) reported that seedling vigor (expressed in terms of seedling height, leaf area and dry weight) was significantly affected by the seed weight. Milberg and Lamont (1997) and Susko and Doust (2000) also reported that larger seeds contained higher amounts of reserve food in their endosperm or cotyledons than smaller seeds. This may lead to early development of an enlarged resource-gathering system (root or photosynthetic tissues) for the production of a faster-growing plant (Hewitt, 1998). Hendrix et al. (1991) also suggested that the seed biomass of Pastinaca sativa (Apiaceae) was significantly and positively correlated with the embryo length. These findings appear to be similar to our results, which indicated that the embryo size also increased with increasing seed weight. The largest embryo was obtained from the heaviest seeds (Table 2) and the cotyledon of the seedlings from heavier seeds was longer than that of the seedlings from lighter seeds (Table 3). The initial advantage for the seedlings from heavier seeds was to obtain higher growth parameters. However, further investigations should be carried out to analyze the effect of the seed weight on the subsequent growth of Touki plants. In many instances, there are no differences in early juvenile development at the adult stage (Reich et al., 1994). Nevertheless, in the present study, it was indicated that the seed weight was a suitable parameter for selecting seeds for germination. Heavier seeds led to a higher germination percentage and seedling growth ability. Based on the results of seed weight, selecting seeds based on SG may also improve seed germination and seedling growth. Accordingly, seed selection based on SG was conducted.

### Table 4: Effect of seed specific gravity on leaf area, root diameter, root, shoot, and total dry weight, and root/shoot ratio, 11 weeks after transplanting (Year 2004)

<table>
<thead>
<tr>
<th>Specific gravity (SG)</th>
<th>Leaf area (cm²)</th>
<th>Root diam.¹ (nm)</th>
<th>Dry weight</th>
<th>Root (g plant⁻¹)</th>
<th>shoot (g plant⁻¹)</th>
<th>Total (g plant⁻¹)</th>
<th>Root/shoot ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>SG &lt; 1.00</td>
<td>111.4a</td>
<td>9.6a</td>
<td></td>
<td>1.01a</td>
<td>0.75a</td>
<td>1.77a</td>
<td>1.35a</td>
</tr>
<tr>
<td>1.00 ≤ SG &lt; 1.03</td>
<td>113.6ab</td>
<td>10.5b</td>
<td></td>
<td>1.04b</td>
<td>0.81b</td>
<td>1.85ab</td>
<td>1.29a</td>
</tr>
<tr>
<td>1.03 ≤ SG &lt; 1.06</td>
<td>126.7ab</td>
<td>10.6b</td>
<td></td>
<td>1.36bc</td>
<td>0.96bc</td>
<td>2.31ab</td>
<td>1.42a</td>
</tr>
<tr>
<td>1.06 ≤ SG &lt; 1.09</td>
<td>143.9b</td>
<td>11.0b</td>
<td></td>
<td>1.53bc</td>
<td>0.96bc</td>
<td>2.48b</td>
<td>1.59a</td>
</tr>
<tr>
<td>1.09 ≤ SG &lt; 1.12</td>
<td>146.7b</td>
<td>11.1b</td>
<td></td>
<td>1.41bc</td>
<td>1.00bc</td>
<td>2.40ab</td>
<td>1.41a</td>
</tr>
<tr>
<td>SG ≥ 1.12</td>
<td>185.6c</td>
<td>12.5b</td>
<td></td>
<td>2.14c</td>
<td>1.26c</td>
<td>3.40c</td>
<td>1.70a</td>
</tr>
</tbody>
</table>

Means in the same column with the same letter are not significantly different (P<0.05). Mean separation was performed using with the Tukey test. (HSD). ¹: diameter
Effect of SG on seed germination and seedling emergence and growth

Menon et al., 1985 reported that 50% seed germination was recorded for the lowest SG value (1.03) and 90% germination for the highest SG value (1.09). Demelash et al. (2003) also reported that seed selection based on SG enhanced the germination of sunken seeds (Schinus molle L.) by 22.5% compared to the control. In our study, in the seeds with a higher SG value (≥1.00) the germination percentage and seedling emergence percentage were enhanced compared to the seeds with the lowest SG value (<1.00). In the floating fraction (SG <1.00), all the empty, dead-filled, insect-damaged and viable seeds were mixed. Seed germination and seedling emergence percentages for seeds with SG <1.00 were significantly lower than those for seeds with a higher SG value. The low germination capacity of these seeds (SG<1.00) may be due to the low level of accumulated substances in seeds, which led to a low ripening percentage. Seed germination and seedling emergence percentages for seeds belonging to the SG ≥ 1.00 grades were not significantly different from each other, suggesting that it is preferable to select the seeds first in water.

Statistical analysis showed that the standard error of seedling parameters within the same SG grade was high. Therefore, the variation in seedling parameters between the different SG grades was relatively low. This may be due to the mixing of seeds during the process of separation by SG, indicating the difficulty of using SG as a criterion for selecting Angelica acutiloba Kitagawa seeds for germination. This finding is also supported by Demelash et al. (2003), who indicated that some good seeds were included in the discarded fraction.

Prospects of the study for Viet Nam

Based on the results of the present study, we concluded that seed weight exerts a strong influence on seedling growth in Angelica acutiloba Kitagawa (Touki). However, in Viet Nam, seed selection based on the seed weight is very difficult due to the long time required for weighing the seeds individually, since automatic separators are not available yet. Table 1 shows that there was a positive relationship between the seed weight and seed size, suggesting that it is possible to obtain uniform seeds from a seed lot by sieving or by winnowing. The next process, separation of unwanted seeds (damaged seeds) by water floating, should be performed before sowing as it could be achieved and applied for large-scale production of Touki seeds at the Medicinal Plant Research Station in Viet Nam. Recently, the production of medicinal plants, particularly Angelica species, has been standardized, aiming at high quality and reduced pesticide use (Pham et al., 2004). Therefore, it is necessary to apply advanced technologies such as a closed transplant production system for Touki seedling production. This system has been reported to be most economically suitable when the plants are still small (Kim and Kozai, 2000). Production of uniform and high quality seedlings is essential for high productivity (Kozai, 2005). Finally, seed selection based on the combination of seed size and separation of damaged seeds by water floatation, sowing the seeds at 20 °C and growing seedlings in a closed system should enable to produce high quality Touki seedlings.

References


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*: In Vietnamese with English summary, **: In Vietnamese