Differences in Inhibition of Emergence by High Temperature between Lettuce Cultivars

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Seeds of 14 lettuce cultivars for spring or summer cultivation were sown in cell trays filled with seeding mixture and kept in growth cabinets at 20, 30, or 35°C for six days to study emergence inhibition at high temperatures. All cultivars commenced emergence on day three after sowing at 20°C, on day two at 30°C, and on days two to five at 35°C. Emergence rates on the day of emergence (at 35°C, on the day when many cultivars began to emerge) and the day after, and the final emergence rate were 52–97%, 77–98%, and 81–100%, respectively, at 20°C; 7–66%, 25–87%, and 61–98%, respectively, at 30°C; and 0–43%, 0–50%, and 1–63%, respectively, at 35°C. All cultivars showed emergence inhibition at 30°C or higher but the degree of inhibition varied greatly between them. The upper temperature limit for emergence, \( T_{50} \), depended greatly on the cultivar, ranging from 31°C for ‘Olympia’ to higher than 35°C for ‘Château’, ‘King Cisco’, and ‘Sacramento’. Comparison of the present results with those of previous reports suggests that breeding efforts over recent decades have generally improved the performance of lettuce emergence at increased temperatures.

Key Words: high temperature, intercultivar difference, \( Lactuca sativa \), seedling emergence.

Introduction

Cell trays are becoming popular as an economic tool for large-scale seedling raising in vegetable cultivation. However, when seeds (‘seed’ is used for the correct botanical term ‘achene’) are sown in the hot season, the emergence of lettuce (\( Lactuca sativa \) L.) seedlings from the soil is inhibited due to high temperature.

Optimum temperatures for lettuce seed germination (a radicle protruding out of a seed) range from 15–20°C (Gray, 1975) and the upper temperature limit for germination, judged as the temperature at which germination rates drop to 50% (\( T_{50} \)), lies between 26 and 33°C (Gray, 1975) or 26 and 32°C (Damania, 1986). Thompson et al. (1979) found significant inhibition of germination at temperatures above 23°C, which varied markedly between cultivars when comparing germination at temperature above 23°C with that at 0–20°C.

Because the rate of emergence is important for actual seedling raising, an emergence experiment with seeds sown in cell trays at high temperatures is needed. The cultivars used in the above-mentioned papers are hardly grown in Japan. Emergence comparison with currently popular cultivars at high temperatures is considered useful for practical seedling raising. Therefore, we scrutinized the emergence behavior of spring- and summer-sown lettuce cultivars presently cultivated in Japan at high temperatures.

Materials and Methods

Fourteen cultivars were tested: ‘Exceed’ and ‘Patriot’ (Nitto Nosan Seed Co., Ltd., Japan); ‘Olympia’ (Mikado Seed Growers Co., Ltd., Japan); ‘Kaiser’, ‘King Cisco’, ‘Gokuwase Cisco’, ‘Sacramento’, ‘Cisco’, and ‘Berkeley’ (Takii & Company, Ltd., Japan); ‘Casper’ (The Yokohama Nursery Co., Ltd., Japan); ‘Sunny Boy No. 1’ (Fujii Seed Co., Ltd., Japan); ‘Château’ and ‘Steady’ (Tsuruta Seeds Co., Ltd., Japan); and ‘Wase Salinas’ (Watanabe Seed Co., Ltd., Japan). ‘Berkeley’, ‘Cisco’, ‘Sacramento’, ‘Steady’, and ‘Wase Salinas’ are usually sown in spring, all others in summer. As space in the growth cabinets was limited, the cultivars were divided into two groups, experimental groups 1 and 2. To make all experiments comparable, ‘Cisco’ was included in both groups.

Seeding mixture (N : P\(_2\)O\(_5\) : K\(_2\)O = 150 : 1000 : 150 mg L\(^{-1}\); Yosaku N-150, Chisso Asahi Fertilizer Co., Ltd., Japan) for raising vegetable seedlings filled each of the 128 cells in a cell tray (Landmark Plastic Co., USA) divided into four, and one seed was placed in every cell at 5 mm depth. No seeds were specially treated.
by seed companies and were sown within the term of guarantee. For each cultivar, three of the divided trays (sown 32 seeds) were used. The trays were watered after sowing and transferred to three thermostatic growth cabinets (light period, 12 h per day, PPF, 75 µmol·m⁻²·s⁻¹ on average; LH-200, Nippon Medical & Chemical Instruments Co., Ltd., Japan), with a divided tray of each cultivar placed in each of the cabinets. Temperature was set at 20°C, 30°C, and 35°C. Emergence tests were repeated twice, with each emergence temperature applied to a total of six of the divided trays of each cultivar.

Emergence was checked between 9:00 and 10:00 every morning during six days after sowing. The number of seedlings emerging more than about one mm was counted. The fresh weight of the above-ground seedling parts was measured on day six after sowing. To define intercultivar differences in emergence inhibition, the temperature (T₅₀) at which the emergence rate on day six after sowing dropped to 50% was determined for each cultivar by interpolation on the graphs; T₅₀ is referred to as upper temperature limit for emergence.

Results

1. Emergence rates and seedling growth

At 20°C, all nine cultivars of experimental group 1 (Fig. 1) began to emerge on day three after sowing and the emergence rate was 70% or higher for seven cultivars, excluding ‘King Cisco’ and ‘Sacramento’, but on day five, the rate was 80% or higher for all cultivars and exceeded 90% for six of the cultivars on day six. In contrast, at 30°C (Fig. 2) seedlings began to emerge on day two at rates that varied greatly between cultivars,
ranging from 7% for ‘Sacramento’ to 64% for ‘Gokuwase Cisco’. The differences remained large on day three (25% for ‘Olympia’ to 87% for ‘Gokuwase Cisco’) but gradually narrowed afterwards; five cultivars showed an emergence rate of 90% or higher on day six. At 35°C (Fig. 3), emergence was clearly inhibited in all cultivars, ranging from 0 to 43% on day two after sowing. Even on day six, rates did not exceed 40–63% for ‘Exceed’, ‘Kaiser’, ‘King Cisco’, ‘Gokuwase Cisco’, ‘Sacramento’, and ‘Château’, and remained as low as 1–4% for ‘Olympia’, ‘Cisco’, and ‘Berkeley’.

The results for experimental group 2 were similar. At 20°C (Fig. 4), all cultivars began to emerge on day three at an emergence rate of 85% or higher for most; the lowest rate was 78% for ‘Steady’. The rate rose to 93% or higher for all cultivars on day five. The initial emergence rate at 30°C (Fig. 5) varied strikingly between the cultivars as it did in group 1; it ranged from 17% for ‘Steady’ to 66% for ‘Casper’ on the day of emergence (day two). At day six, emergence rates of ‘Casper’, ‘Sunny Boy No. 1’, and ‘Patriot’ exceeded 95% while the other cultivars showed emergence rates of 73% or higher. In the 35°C treatment (Fig. 6), emergence rates were 7% or lower for all cultivars on day two and remained low even on day six: 6–18% for ‘Casper’, ‘Sunny Boy No. 1’, and ‘Patriot’ and 2–4% for ‘Cisco’, ‘Steady’, and ‘Wase Salinas’. Emergence rates of ‘Cisco’ varied little between the experimental groups at 20°C and 35°C. At 30°C, the rate varied somewhat but not dramatically: 23–28% on day two after sowing, 69–73% on day four, and 79–93% on day six.

The fresh weight of seedlings from all cultivars on
day six was highest in the 30°C and lowest in the 35°C treatment. The coefficients of variation (excluding cultivars with emergence rates of 5% or lower) depended on the cultivar, ranging from 0.18 to 0.38 in the 20°C treatment, 0.24 to 0.49 at 30°C, and 0.18 to 0.48 at 35°C. Most cultivars showed the smallest coefficient of variation at 20°C, at which intercultivar differences were also minimum. At 30°C, ‘Olympia’ and ‘Steady’ exhibited particularly large coefficients of variation of 0.48–0.49.

2. Upper temperature limit for emergence ($T_{50}$)

To quantitatively compare the effect of high temperature on the emergence of lettuce seedlings of different cultivars, the upper temperature limits for emergence, $T_{50}$, were determined, using the upper temperature limit for germination, a conventional indicator in germination experiments, as a reference. Because $T_{50}$ for ‘Cisco’, which was included in both experimental groups, was the same (32°C) in both groups, the results are combined and summarized in Table 1. There are large intercultivar differences in $T_{50}$, ranging from 31°C for ‘Olympia’ to higher than 35°C for ‘Château’, ‘King Cisco’, and ‘Sacramento’.

**Discussion**

Examination of emergence performance of 14 lettuce cultivars usually sown in spring and summer revealed that the emergence rates at six days after sowing were 79% or higher for all cultivars at 20°C and for all of them but ‘Olympia’ and ‘Steady’ at 30°C, with little difference between the two temperatures in some
At 35 °C, however, emergence rates were low, ranging from 1 to 63%. The initial rate of emergence was highest at 20 °C for all cultivars: 52–97% on the day of emergence (day three after sowing) and 77% or higher on the following day (day four after sowing). Emergence commenced one day earlier at 30 °C, but initial emergence rates were lower at 30 °C than at 20 °C, ranging from 7 to 66% on the day of emergence (day two after sowing) and from 25 to 87% on the following day (three days after sowing). Thus, 20 °C appeared to be the optimum emergence temperature within the range of 20–35 °C tested, for all cultivars. This result agrees with the optimum germination temperature of 15–20 °C for lettuce seeds in Petri dishes reported by Gray (1975).

Borthwick and Robbins (1928) studied the germination rates of 20 lettuce cultivars and found at 29 °C, germination rates of 90% or higher in only one cultivar, 80% or higher in five cultivars, and lower than 10% in eight cultivars. In the 30 °C treatment in the present study on day six, more than 50% of the cultivars tested exceeded the emergence rate of 90%. Therefore, the emergence inhibition of the lettuce tested around 30 °C in the present experiment is less than the germination inhibition of that used by Borthwick and Robbins (1928).

Thompson (1936), Harrington and Thompson (1952), Gray (1975) and Thompson et al. (1979) reported that the upper temperature limit for germination, $T_{50}$, of lettuce was between 23 and 33 °C. Damania (1986) also demonstrated that $T_{50}$ of germination depended on the cultivar and ranged from 26 to 32 °C; however, from the present results, $T_{50}$ for seedling emergence was inferred to be 33 °C or higher for many cultivars, and even above 35 °C for ‘King Cisco’, ‘Sacramento’, and ‘Château’. Thus, the lettuce cultivars tested here appear to be more tolerant to high temperatures with respect to seed performance than the cultivars examined in previous studies. This is perhaps a result of the progress in breeding cultivars that are better adapted to the conditions they encounter when sown in spring or summer.

The upper temperature limit for emergence ($T_{50}$) allowed us to classify the cultivars into four groups: ‘Olympia’ with a $T_{50}$ of 31 °C; ‘Berkeley’, ‘Casper’, ‘Cisco’, ‘Patriot’, ‘Steady’, ‘Sunny Boy No. 1’, and ‘Wase Salinas’ with a $T_{50}$ of 32–33 °C; ‘Exceed’, ‘Gokuwase Cisco’, and ‘Kaiser’ with a $T_{50}$ of 35 °C, and ‘Château’, ‘King Cisco’, and ‘Sacramento’ with a $T_{50}$ higher than 35 °C. Generally, cultivars for sowing in summer did not have higher upper temperature limits for emergence than cultivars for sowing in spring. Information obtained in this paper will be useful in choosing appropriate cultivars for lettuce seedling raising at high temperatures.

**Table 1.** Upper temperature limit ($T_{50}$) for emergence.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>$T_{50}$ in °C</th>
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</thead>
<tbody>
<tr>
<td>Berkeley</td>
<td>33 °C</td>
</tr>
<tr>
<td>Casper</td>
<td>33 °C</td>
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<tr>
<td>Château</td>
<td>&gt; 35 °C</td>
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<tr>
<td>Cisco</td>
<td>32 °C</td>
</tr>
<tr>
<td>Exceed</td>
<td>35 °C</td>
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<tr>
<td>Gokuwase Cisco</td>
<td>35 °C</td>
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<tr>
<td>Kaiser</td>
<td>35 °C</td>
</tr>
<tr>
<td>King Cisco</td>
<td>&gt; 35 °C</td>
</tr>
<tr>
<td>Olympia</td>
<td>31 °C</td>
</tr>
<tr>
<td>Patriot</td>
<td>33 °C</td>
</tr>
<tr>
<td>Sacramento</td>
<td>&gt; 35 °C</td>
</tr>
<tr>
<td>Steady</td>
<td>32 °C</td>
</tr>
<tr>
<td>Sunny Boy No. 1</td>
<td>32 °C</td>
</tr>
<tr>
<td>Wase Salinas</td>
<td>32 °C</td>
</tr>
</tbody>
</table>

Results of both experimental groups are combined in this table.

cultivars. At 35 °C, however, emergence rates were low, ranging from 1 to 63%. The initial rate of emergence was highest at 20 °C for all cultivars: 52–97% on the day of emergence (day three after sowing) and 77% or higher on the following day (day four after sowing). Emergence commenced one day earlier at 30 °C, but initial emergence rates were lower at 30 °C than at 20 °C, ranging from 7 to 66% on the day of emergence (day two after sowing) and from 25 to 87% on the following day (three days after sowing). Thus, 20 °C appeared to be the optimum emergence temperature within the range of 20–35 °C tested, for all cultivars. This result agrees with the optimum germination temperature of 15–20 °C for lettuce seeds in Petri dishes reported by Gray (1975).

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**Literature Cited**


