Host plant resistance in Japanese chrysanthemums against *Frankliniella occidentalis* (Thysanoptera: Thripidae) during the non-flowering stage

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Abstract

Leaf damage caused by *Frankliniella occidentalis* and its population growth were investigated with the vegetative plants of two Japanese chrysanthemum cultivars, Yuki-no-izumi and Kan-komichi in greenhouses. Significant differences were found in the levels of leaf damage and thrips population growth between the two cultivars. On Kan-komichi, which had significantly less damage to leaves, the size of the thrips population was smaller than that on Yuki-no-izumi, indicating a clear difference in host plant resistance to *F. occidentalis* between the two cultivars. Life history characters of the thrips were individually determined on the two cultivars in a laboratory. Most thrips larvae that fed on the leaves of Kan-komichi died before prepupation. This high mortality can contribute to a higher resistance demonstrated by that cultivar in the greenhouse experiment.

Key words: *Frankliniella occidentalis*, chrysanthemum, cultivar, resistance

INTRODUCTION

The western flower thrips, *Frankliniella occidentalis* (Pergande) is a common pest of various crops in fields and greenhouses worldwide (Gerin et al., 1994; van Dijken et al., 1994). *F. occidentalis* causes not only feeding damage on their host plants but also transmits the tomato spotted wilt virus (TSWV) (Allen and Broadbent, 1986; Kato and Katayama, 1998). This thrips species was first found in Chiba and Saitama Prefectures of Japan in 1990 (Hayase and Fukuda, 1991) and quickly spread throughout the country (Katayama, 1997a).

Chrysanthemum, *Dendranthema grandiflora* Tzvelev, is the most economically important flowering crop in Japan. Annually, over two billion stems are produced, making it the largest yield of all cut flowers grown domestically (MAFF, 1999). However, chrysanthemums frequently incur serious damages from *F. occidentalis* (Katayama, 1997b). Pest controls on floricultural crops including chrysanthemums should achieve complete eradication because very low or zero damage is required for their commercial value (van Lenteren and Woets, 1988; de Kogel et al., 1998). In addition, *F. occidentalis* populations on floricultural plants tend to increase rapidly at the flowering stage since the thrips prefer flowers to other plant tissues (Murai, 1991; Katayama, 1997a, b). Therefore, the thrips on cultivated chrysanthemums must be eliminated before flowering. In Japan, some insecticides are commonly used for controlling *F. occidentalis* on chrysanthemums in the non-flowering stage. But chemical control is not always sufficient to suppress *F. occidentalis* thoroughly due to its characteristic bionomics (i.e., the eggs are laid in the plant tissues, the pupal stages are spent in the soil and the active life stages exhibit a thigmotactic behavior with individuals, hiding deeply in the buds and flowers) (Brodersgaard, 1994). Moreover, too much application of chemical insecticides can induce a *F. occidentalis* population to develop insecticide resistance.

Host plant resistance has been considered as a key method for pest regulation in crop plants (Schoonhoven et al., 1998). Thus, the chrysanthemum cultivars resistant against *F. occidentalis* can be very useful for accomplishing thrips control in the non-flowering stages. Varietal differences in resistance to *F. occidentalis* were studied on chrysanthemums cultivated in the Netherlands (e.g., van Dijken, 1992; de Jager et al., 1993, 1995a, b; van Dijken et al., 1994; de Kogel et al., 1997, 1998). However, such variation has not been investigated

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in Japanese chrysanthemums, although we have numerous varieties.

In preliminary observations with Japanese chrysanthemums planted in open fields, varietal differences in leaf damage by *F. occidentalis* were found, although the experimental data were not recorded. Therefore, the first objective of this paper was to show experimentally that Japanese chrysanthemums in the non-flowering stage have varietal differences in resistance to *F. occidentalis*. Leaf damage and thrips population growth were evaluated with the vegetative intact plants of two chrysanthemum cultivars in greenhouses. The two cultivars were selected from the preliminary observations mentioned above: one cultivar had received much damage and the other slight damage. Furthermore, increased knowledge of host plant resistance mechanisms can be helpful in screening and breeding resistant chrysanthemum cultivars (de Jager et al., 1995b). Thus, in this study, life history characters of *F. occidentalis* including survival, developmental time, fertility and longevity were also measured on the two cultivars in a laboratory.

**MATERIALS AND METHODS**

**Insects and plants.** The *F. occidentalis* population was collected from chrysanthemum flowers cultivated in Kurahashi-jima Island of Hiroshima Prefecture in 1996. *F. occidentalis* stock culturing was conducted in a laboratory under conditions of 25±1°C, 60±10% R.H. and a 16L–8D photoperiod. The thrips were maintained with the technique invented by Loomans and Murai (1997), although soaked broad beans without seed coats were supplied as food instead of pollen. The diets were replaced every two days in principle.

Chrysanthemums used for the current study were two domestic cultivars, Yuki-no-izumi (YI) and Kan-komichi (KK) produced by Seikoen. These chrysanthemums bloom from late October to early November under natural day length in the western region of Japan. At the middle of May in 2000, cuttings of the chrysanthemums were planted in plastic cases with vermiculite (50 cm length, 35 cm width, 10 cm depth). Three weeks later, each rooted cutting was moved in a plastic pot (7.5 cm dia., 7 cm height) and held in the greenhouse air-conditioned at a maximum temperature of 30°C with natural light. The chrysanthemums during the vegetative stage were basically used for the experiments.

**Greenhouse experiment—Resistance of intact chrysanthemum plants.** Two greenhouses (4×5 m) were used for the test. Sixty potted chrysanthemum plants per cultivar were placed in two plastic cases (50 cm length, 35 cm width, 10 cm depth) and introduced in the greenhouse. Twenty female adults of *F. occidentalis* (within 7 day after emergence) collected randomly from the stock culture were released on the top of each chrysanthemum plant in June 16, 2000. The temperatures in the two greenhouses were kept at 20–30°C throughout the test. The numbers of thrips, all leaves and damaged leaves on which silvery scars had been made by feeding thrips (referred to as “silver damage”), were counted per plant 32 days after thrips release (July 18, 2000). Silver damage was assessed as the ratio of the number of silver-damaged leaves to the number of all leaves per plant, and is referred to as “silver damage rate.” All plants were placed in a refrigerated room (ca. 5°C) for 15 min to anesthetize the thrips on the leaves prior to counting.

**Laboratory experiment 1—Survival and development of juvenile thrips.** This experiment was carried out in a climate cabinet programmed for a constant temperature of 25±0.5°C and a 16L–8D photoperiod. Newly hatched thrips larvae within 12 h were individually placed on mature leaf disks (1.6 cm dia.) or immature leaves (ca. 1.5 cm length in the leaf blade) of the cultivar YI or KK in small glass cylindrical cages (2.5 cm dia., 2.5 cm height). In this study, fully expanded leaves on the middle of the chrysanthemum plants were used as “mature leaves” and unexpanded ones obtained from just below the top of plants were “immature leaves.” The glass cages were sealed with filter papers (2.5 cm dia.) and Sealon Films (Fuji Photo Film Co., Ltd.). The thrips in the glass cages were observed daily to monitor survival and moltings. The leaves were replaced every two or three days. Floral petals derived from each chrysanthemum cultivar were also tested for thrips larvae to compare with the leaves.

**Laboratory experiment 2—Fertility and longevity of thrips adults.** Experimental conditions were identical to that for laboratory experiment 1. Each pair of *F. occidentalis* adults (within 12 h from emergence) was confined in a cylindrical glass cage with a mature leaf disk or an immature
leaf of cultivar YI or KK. Twenty five pairs were used for each test. The thrips were observed and transferred to fresh leaves at 24 h intervals until death. The leaves removed from the glass cages were placed in separate plastic petri dishes (9 cm dia., 1.5 cm height) and kept in an incubator regulated at 25±0.5°C and a 16L–8D photoperiod for seven days. The number of *F. occidentalis* larvae that hatched from the eggs oviposited in the leaves was accumulated per thrips female as her fertility. Longevity was estimated as the length of time from the beginning of the test to thrips death.

**Statistical analyses.** Silver damage rates and the number of thrips per plant were compared between the two cultivars by Mann-Whitney’s *U* test. The data for silver damage rate were subjected to the following arcsine transformation (Zar, 1999) before the test:

\[
p' = \frac{1}{2} \left[ \arcsin \sqrt{\frac{X}{n+1}} + \arcsin \sqrt{\frac{X+1}{n+1}} \right]
\]

where *p*′ is the transformed data (in degrees), *X* is the number of silver-damaged leaves per plant, and *n* is the number of all leaves per plant.

Based on the data obtained in laboratory experiment 1, survivals during the immature stage of *F. occidentalis* were calculated as follows:

Prepupation rate (%)
= \( \frac{\text{No. of thrips prepupae}}{\text{No. of thrips larvae tested}} \times 100 \)

Emergence rate (%)
= \( \frac{\text{No. of thrips adults}}{\text{No. of thrips prepupae}} \times 100 \)

Survival rate (%)
= \( \frac{\text{No. of thrips adults}}{\text{No. of thrips larvae tested}} \times 100 \)

These proportion data were first examined with a chi-square test for independence. If significant differences were indicated, the data were submitted to the arcsine transformation described above and then compared with each other by a Tukey-type multiple comparison test (Zar, 1999). Developmental time, fertility and longevity were statistically analyzed with Kruskal-Wallis test followed by a nonparametric Tukey-type multiple comparison test (Zar, 1999).

**RESULTS**

**Greenhouse experiment—Resistance of intact chrysanthemum plants**

Variatel differences were found both in the levels of silver damage and thrips population growth on the intact plants of the two chrysanthemum cultivars. The silver damage rate of the KK cultivar was significantly lower than that of YI (Mann-Whitney’s *U* test, *Z*\(_C\)=7.280, *p*<0.001) (Fig. 1). The mean number of thrips per plant was also significantly smaller on KK than YI (Mann-Whitney’s *U* test, *Z*\(_C\)=4.872, *p*<0.001) (Fig. 2). The chrysanthemum plants of YI and KK had 27.3 leaves and 23.6 leaves on the average at the end of the test, respectively.

**Laboratory experiment 1—Survival and development of juvenile thrips**

Prepupation rate, emergence rate and survival rate of *F. occidentalis* are presented in Table 1. Prepupation rates on the mature and immature leaves of the KK cultivar were significantly lower than those of YI (chi-square test, \( \chi^2 = 105.4, \text{d.f.}=5, p<0.001 \) and Tukey-type multiple comparison test, \( q=10.60 \) (KK mature leaves vs. YI mature leaves),
9.147 (KK mature leaves vs. YI immature leaves), 9.215 (KK immature leaves vs. YI mature leaves), 7.968 (KK immature leaves vs. YI immature leaves), $k = 6$, $p < 0.001$). Survival rates were also significantly lower on KK than on YI (chi-square test, $\chi^2 = 103.5$, d.f. = 5, $p < 0.001$ and Tukey-type multiple comparison test, $q = 10.46$ (KK mature leaves vs. YI mature leaves), 8.968 (KK mature leaves vs. YI immature leaves), 9.204 (KK immature leaves vs. YI mature leaves), 7.921 (KK immature leaves vs. YI immature leaves), $k = 6$, $p < 0.001$). On the other hand, more than 90% of the thrips larvae reared with chrysanthemum flowers successfully developed into adults regardless of cultivar. Table 2 shows developmental times in larval and prepupal plus pupal stages of *F. occidentalis* on the leaves and flowers of two chrysanthemum cultivars. The periods on mature and immature leaves of KK were not investigated because most thrips larvae supplied the KK leaves had died before prepupation, as described in Table 1. Both the female and male larvae on the YI leaves required longer times to complete their development than those on the flowers (Kruskal-Wallis test, $H_c = 42.41$ (female), 28.13 (male), d.f. = 3, $p < 0.001$ and nonparametric Tukey-type multiple comparison test, $q = 3.699$, $k = 4$, $0.001 < p < 0.005$ (female: YI mature leaves vs. YI flowers), $q = 4.364$, $k = 4$, $p < 0.001$ (female: YI immature leaves vs. YI flowers), $q = 3.052$, $k = 4$, $0.01 < p < 0.05$ (male: YI mature leaves vs. YI flowers), $q = 4.434$, $k = 4$, $p < 0.001$ (male: YI immature leaves vs. YI flowers)) although no significant difference existed in the prepupal plus pupal stage (Kruskal-Wallis test, $H_c = 6.790$ (female), 3.752 (male), d.f. = 3, $p > 0.05$).

**Laboratory experiment 2—Fertility and longevity of thrips adults**

The results of individually rearing *F. occidentalis* adults are summarized in Table 3. Fertility, i.e., mean number of progenies produced by one female of *F. occidentalis*, was smaller on the mature leaves of YI and KK than on the corresponding immature leaves (Kruskal-Wallis test, $H_c = 75.87$, d.f. = 3, $p < 0.001$ and nonparametric Tukey-type multiple

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**Table 1. Survival in immature stage of *Frankliniella occidentalis* on the leaves and flowers of two chrysanthemum cultivars at 25°C and a 16L–8D photoperiod**

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Diets supplied</th>
<th>No. thrips tested</th>
<th>Prepupation rate (%)</th>
<th>Emergence rate (%)</th>
<th>Survival rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YI Mature leaves</td>
<td>35</td>
<td>91.4 a</td>
<td>93.8 a</td>
<td>85.7 a</td>
<td></td>
</tr>
<tr>
<td>KK Mature leaves</td>
<td>27</td>
<td>7.4 b</td>
<td>50.0</td>
<td>3.7 b</td>
<td></td>
</tr>
<tr>
<td>YI Immature leaves</td>
<td>28</td>
<td>85.7 a</td>
<td>91.7 a</td>
<td>78.6 a</td>
<td></td>
</tr>
<tr>
<td>KK Immature leaves</td>
<td>20</td>
<td>10.0 b</td>
<td>50.0</td>
<td>5.0 b</td>
<td></td>
</tr>
<tr>
<td>YI Flowers</td>
<td>25</td>
<td>96.0 a</td>
<td>100 a</td>
<td>96.0 a</td>
<td></td>
</tr>
<tr>
<td>KK Flowers</td>
<td>28</td>
<td>92.9 a</td>
<td>100 a</td>
<td>92.9 a</td>
<td></td>
</tr>
</tbody>
</table>

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*a* YI: Yuki-no-izumi, KK: Kan-komichi.

b (No. of thrips prepupae/No. of thrips larvae tested)×100.

c (No. of thrips adults/No. of thrips prepupae)×100.

d (No. of thrips adults/No. of thrips larvae tested)×100.

b,c,d Percentages followed by the same letter within columns are not significantly different at 5% level by Tukey-type multiple comparison test (Zar, 1999) following chi-square test. Percentage data were subjected to the arcsine transformation (Zar, 1999) before the tests.

e Emergence rates on the KK leaves were not included in the statistical analyses because sample sizes were too small.

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Fig. 2. Numbers of *Frankliniella occidentalis* on two chrysanthemum cultivars, Yuki-no-izumi (YI) and Kan-komichi (KK) in the non-flowering stage (mean±SE). An asterisk indicates significant difference between cultivars by Mann-Whitney’s U test ($p < 0.001$). Bars on top of the columns represent standard errors.
Table 2. Developmental time in immature stage of *Frankliniella occidentalis* on the leaves\(^a\) and flowers of two chrysanthemum cultivars at 25°C and a 16L–8D photoperiod

<table>
<thead>
<tr>
<th>Diets supplied</th>
<th>Developmental time (days)(^b)</th>
<th>Larval stage</th>
<th>Prepupal plus pupal stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\varphi)</td>
<td>(\delta)</td>
<td>(\varphi)</td>
</tr>
<tr>
<td>Mature leaves (YI)(^c)</td>
<td>5.8±0.9 (21) (a)</td>
<td>5.1±0.6 (9) (a)</td>
<td>3.4±0.5 (21) (a)</td>
</tr>
<tr>
<td>Immature leaves (YI)</td>
<td>7.0±0.9 (8) (a)</td>
<td>5.8±1.1 (14) (a)</td>
<td>3.4±0.5 (8) (a)</td>
</tr>
<tr>
<td>Flowers (YI)</td>
<td>4.2±0.4 (10) (b)</td>
<td>3.9±0.5 (14) (b)</td>
<td>3.6±0.8 (10) (a)</td>
</tr>
<tr>
<td>Flowers (KK)</td>
<td>4.1±0.5 (21) (b)</td>
<td>3.6±0.5 (5) (b)</td>
<td>3.1±0.4 (21) (a)</td>
</tr>
</tbody>
</table>

\(^a\) Data on the leaves of the cultivar KK were not obtained because most thrips larvae reared with the KK leaves had died before prepupation, as described in Table 1.

\(^b\) Mean±SD.

\(^c\) YI: Yuki-no-izumi, KK: Kan-komichi.

\(^d\) Figures in parenthesis indicate sample sizes. Means followed by the same letter within columns are not significantly different at 5\% level by nonparametric Tukey-type multiple comparison test (Zar, 1999) following Kruskal-Wallis test.

Table 3. Fertility and longevity of *Frankliniella occidentalis* adults\(^a\) on the leaves of two chrysanthemum cultivars at 25°C and a 16L–8D photoperiod

<table>
<thead>
<tr>
<th>Cultivars(^b)</th>
<th>Diet and oviposition substrate supplied</th>
<th>Fertility(^c) (progenies/(\varphi))</th>
<th>Longevity (days)(^d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(\varphi)</td>
<td>(\delta)</td>
</tr>
<tr>
<td>YI</td>
<td>Mature leaves</td>
<td>11.0±4.7 (b)</td>
<td>16.8±4.1 (ab)</td>
</tr>
<tr>
<td>KK</td>
<td>Mature leaves</td>
<td>0.5±1.0 (c)</td>
<td>10.8±3.8 (c)</td>
</tr>
<tr>
<td>YI</td>
<td>Immature leaves</td>
<td>46.7±15.6 (a)</td>
<td>13.8±3.8 (bc)</td>
</tr>
<tr>
<td>KK</td>
<td>Immature leaves</td>
<td>45.7±22.6 (a)</td>
<td>17.7±5.0 (a)</td>
</tr>
</tbody>
</table>

\(^a\) Twenty five pairs of thrips females and males were used for each test.

\(^b\) YI: Yuki-no-izumi, KK: Kan-komichi.

\(^c\) Mean±SD. Means followed by the same letter within columns are not significantly different at 5\% level by nonparametric Tukey-type multiple comparison test (Zar, 1999) following Kruskal-Wallis test.

comparison test, \(q=4.410\) (YI mature leaves vs. YI immature leaves), 7.093 (KK mature leaves vs. KK immature leaves), \(k=4, p<0.001\). In fact, the thrips females reared with the KK mature leaves produced hardly any progenies and their longevity was significantly shorter than those with the other diets (Kruskal-Wallis test, \(H_c=33.24\), d.f.=3, \(p<0.001\) and nonparametric Tukey-type multiple comparison test, \(q=4.392\) (KK mature leaves vs. YI mature leaves), 5.262 (KK mature leaves vs. KK immature leaves), \(k=4, p<0.001\)).

**DISCUSSION**

The greenhouse experiment shows that the KK cultivar had significantly less silver damage than YI and the thrips population growth was depressed more highly on KK than on YI (Figs. 1 and 2). These differences are not likely to have been induced by environmental conditions of temperature and relative humidity in greenhouses used for the test because neither of these parameters differed between the two greenhouses: the mean values during the test were 24.9°C and 79.4% for YI and 24.5°C and 75.7% for KK, respectively. Thus, the results suggest that the KK cultivar during the non-flowering stage has a higher resistance to *F. occidentalis* than YI. Further, laboratory experiment 1 indicated that few thrips larvae developed into adults both on the mature and immature leaves of KK. This means that it is highly unlikely that the thrips population can increase on vegetative plants of KK. Therefore, higher resistance of the KK cultivar to *F. occidentalis* probably results from a re-
markably high mortality of the thrips larvae on the KK leaves.

Painter (1951) classified the cause of host plant resistance to herbivores as “non-preference” (renamed “antixenosis” by Kogan and Ortmann (1978)), “antibiosis” and “tolerance.” More than 200 reports on resistance to arthropod pests in vegetables have shown that tolerance was involved in about 10% of the cases, whereas the remaining cases were equally attributed to either antixenosis or antibiosis (Schoonhoven et al., 1998). Since the laboratory experiments were performed focusing only on the antibiosis of chrysanthemum leaves to *F. occidentalis*, antixenosis should also be investigated to clarify the whole mechanism of resistance.

It should be noted that the numbers of *F. occidentalis* per plant decreased on both cultivars as compared with the initial 20 thrips released (Fig. 2). Similar findings have been reported on the chrysanthemum cultivars tested by de Jager et al. (1993) and van Dijken (1992) although the thrips populations on those with flowers increased considerably. In the first laboratory experiment, most of the juvenile thrips that fed on the chrysanthemum flowers, in contrast to those that fed on the leaves, completed their development on both cultivars, resulting in high survival rates and shorter developmental periods (Tables 1 and 2). Further, Katayama (1997a) revealed that *F. occidentalis* female adults reared with chrysanthemum flowers oviposited over 20 times as many eggs as those with the leaves. van Dijken (1992) concluded from his study that chrysanthemum plants without flowers are less suitable host plants than those with flowers regardless of its cultivar. Accordingly, reduction in the thrips number on the vegetative chrysanthemum plants tested in this study may also be explained by low suitability for the thrips diets and/or oviposition substrates, although more research has to be done.

In Japan, so many chrysanthemum cultivars have been produced by private breeders, companies and research institutions that some of them probably possess similar or higher resistance to *F. occidentalis* compared to the cultivar KK. As mentioned above, however, the results shown in de Jager et al. (1993) and van Dijken (1992) suggested that even those chrysanthemum flowers derived from resistant cultivars can be infested by *F. occidentalis*. Also, the thrips has a behavioral habit to be strongly attracted to plant flowers including chrysanthemums (Tommasini and Maini, 1995). Therefore, additional control agents would be required to protect the chrysanthemum plants from *F. occidentalis* at the flowering stage, especially those cultivated in open fields.

Variation in host plant resistance of chrysanthemums has been found for other arthropod pests, e.g., *Liriomyza sativae* Blanchard (Webb and Smith, 1969; Schuster and Harbaugh, 1979a, b), *L. trifolii* (Burgess) (Oetting, 1982; Broadbent and Blom, 1983; de Jong and van de Vrie, 1987; de Jong and Rademaker, 1991; Suenaga et al., 1995), *Myzus persicae* (Sulz.) and *Tetranychus telarius* (L.) (Markkula et al., 1969), *Ostrinia nubilalis* (Hübner) (Schultz and Coffelt, 1986, 1988, 1989), *Spodoptera exigua* (Hübner) (Yoshida and Parrella, 1991) and *Thrips palmi* Karny (Kubota et al., 1984; Miyashita, 1990). Furthermore, de Jager et al. (1995a) showed that chrysanthemum resistance to *F. occidentalis* was positively correlated to the resistance to *Thrips tabaci* Lindeman. They suggested, therefore, that the chrysanthemum cultivars resistant to *F. occidentalis* have a high probability of being resistant to other insect pests. This can be useful information for breeding Japanese chrysanthemum cultivars with resistance to various insect pests.

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