Psylliodes chalcomerus (Coleoptera: Chrysomelidae: Alticinae), a flea beetle candidate for biological control of yellow starthistle Centaurea solstitialis

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Summary

Yellow starthistle, Centaurea solstitialis (YST), is an invasive noxious weed in USA, Chile, Australia, and South Africa. Several insect species have been introduced against this weed, but with limited success. Thus, other biological agents are being sought. Among them, a flea beetle, Psylliodes chalcomerus Illiger, with stem-boring larvae and leaf-feeding adults, seems one of the most promising. Several “biotypes” of this species have been collected on different host plants (YST, Onopordum acanthium, and Carduus nutans). Biological and morphological features of these biotypes were studied in the field and laboratory. The results suggested that each biotype is closely associated with its respective host plant. Field studies in natural conditions revealed negative correlation between plant biomass and insect infestation, suggesting high impact on the target plant, which is encouraging for biocontrol.

Keywords: Carduus nutans, Centaurea solstitialis, Onopordum acanthium, Psylliodes chalcomerus, Psylliodes chalcomera.

Introduction

Yellow starthistle, Centaurea solstitialis L. (YST), is an invasive noxious weed in the western USA, Chile, Australia, and South Africa. It originated in the Palaeartic (Maddox 1981, Sheley et al. 1999). YST is highly invasive in mediterranean and grassland habitats where it can dominate local plant communities, displacing forage and native plants (Carlson et al. 1990, DiTommaso 1998). It also causes the lethal disease, nigropallidal encephalomalacia in horses (Cordy 1978). Conventional chemical control strategies have been inadequate and thus research on biological control of yellow starthistle was initiated (Rosenthal et al. 1994). Since 1984, a number of insect species were released, all of which attack flowerheads. Lack of effective control indicates the need to broaden the search to find agents that attack roots, stems and leaves (Turner & Fornasari 1995). Thus, other potential biological agents are being evaluated. Among them, flea beetles of the genus Psylliodes, which have stem-boring larvae and leaf-feeding adults, appeared to be very interesting. During field explorations in the northern Caucasus (Russia) and central Italy, larvae and adults of Psylliodes chalcomerus Illiger were repeatedly collected from YST, from Scotch thistle, Onopordum acanthium L., and from musk thistle, Carduus nutans L., which are also considered invasive weeds. Although this nominal species has previously been evaluated (Dunn & Rizza 1976, 1977) and released in USA for biological control of C. nutans (Dunn & Campobasso 1993), it appeared to us that host-specific cryptic species or biotypes may exist.
Material and methods

Field collections, experiments and observations were conducted in Krasnodar territory (Russia) and in the Latium region (central Italy). Laboratory studies were conducted at Biotechnology and Biological Control Agency facilities within ENEA (Italian Institute for the Environment, the Energy and the New Technologies, Rome, Italy), and in the Zoological Institute, Russian Academy of Sciences (St Petersburg, Russia). Plants for the laboratory experiments were grown in greenhouses. Host plants were mostly grown from seeds collected in natural conditions in Russia and Italy and also obtained from USDA–ARS Exotic Invasive Weeds Research Unit, Western Regional Research Centre, Albany, California. Safflower, Carthamus tinctorius L., plants were grown from seeds of two varieties obtained from CDFA, Sacramento, California.

For insect rearing, biological observations and experiments, individual plants were covered with transparent cages. In certain experiments, separate leaves (leafstalks wrapped with wet cotton and placed in a small plastic tube filled with water) were used to feed individual adults in Petri dishes. In this case, host plant leaves were changed every second day and eggs laid were collected, counted and transferred onto wet filter paper in small Petri dishes. Newly eclosed larvae were collected daily.

Adult feeding specificity was tested with two main methods. First, survival and oviposition of individual females in choice/no-choice conditions were recorded in Petri dishes with host and/or non-host plant leaves (as described above). Second, adult feeding, oviposition and progeny survival were checked in choice/no-choice conditions on potted plants.

Most biological observations were made in artificial climate chambers with 15 h light : 9 h dark and constant temperatures of 15, 20, and 25°C. Host-specificity tests with potted plants were conducted in greenhouse conditions (temperature ranging from 22 to 27°C). Other details of the methods are given with the results. Data were analyzed by conventional statistics (in the text and tables, means and SD are given).

Results

Russian populations

Adults of two biotypes of P. chalcomerus were collected in Krasnodar territory in 2001–2002:

1. the “YST-biotype”: “Volna location”, Temryuk region, ca. 10 km S Taman (45°07′36″N, 36°41′35″E), feeding on Centaurea solstitialis, and
2. the “Onopordum-biotype”: “Krasnyj Oktyabr location”, Temryuk region, near Krasnyj Oktyabr village (45°10′59″N, 37°39′55″E), feeding on Onopordum acanthium.

Adult fecundity and longevity

To estimate adult fecundity and longevity, beetles of both biotypes were placed individually in Petri dishes and fed with leaves of their respective host plant. Ten adults of each biotype were monitored at constant temperatures of 20 and 25°C from 11 April 2002 until death. Life duration, daily and lifetime fecundity showed significant differences between the YST and Onopordum biotypes (p<0.01, two-way ANOVA test) at both studied temperatures (Table 1).

Duration of development

In the YST-biotype the duration of egg development at 15, 20, and 25°C was, respectively, 17 ± 3.2, 9.9 ± 1.0, and 7.4 ± 1.0 days. In the Onopordum-biotype, it was 15 ± 4.5, 8.9 ± 0.9, and 7.2 ± 0.9 days at the same temperatures. Thus, the rate of egg development in both biotypes was linearly dependent on temperature, while in the Onopordum-biotype embryos developed slightly (insignificantly) faster. In both biotypes, the total duration of development of one generation (from egg to adult) was 30–40 days at constant temperature of 25°C.

Host specificity

No-choice tests with individual females were conducted in Petri dishes simultaneously and with the same methods that were used for the estimation of life duration and fecundity. All specificity tests were conducted at 20°C. Three plant species were used: YST, O. acanthium, and Carthamus tinctorius (10 females per treatment).

Females of the YST-biotype, when fed with O. acanthium or safflower, demonstrated much lower life duration and lifetime fecundity, compared to the controls, i.e. females of the YST-biotype fed with YST at the same conditions (Table 2). As for the Onopordum-biotype, YST and O. acanthium seem to be more or less equally suitable for adult feeding. When fed with safflower, however, both survival and fecundity were much lower. As for the

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Longevity (days)</th>
<th>Fecundity (eggs laid)</th>
<th>Daily fecundity (eggs/female/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C</td>
<td>25°C</td>
<td>20°C</td>
</tr>
<tr>
<td><em>Psylliodes</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>YST-biotype</td>
<td>79±13</td>
<td>20±9</td>
<td>231±19</td>
</tr>
<tr>
<td>Onopordum-biotype</td>
<td>23±4</td>
<td>37±11</td>
<td>55±15</td>
</tr>
</tbody>
</table>

Table 1. *P. chalcomerus* adult fecundity and longevity in laboratory conditions.
embryo’s survival (percentage of hatching larvae in relation to the total number of eggs), in both biotypes it was significantly higher when fed on their “native” host plant.

No-choice tests with adults in potted plants in greenhouse conditions gave generally the same results (Table 3). In all cases, where *Psylliodes* adults were placed in cages with their “native” host plants, adults intensively fed, survived longer and obviously laid eggs (larvae, pupae and adults were found). In most of these cases, the plants were almost dead or heavily damaged. Neither of two biotypes survived for a long time or reproduced on safflower. The YST-biotype was able to feed on *O. acanthium*, although with lower survival, and to reproduce on this plant. The *Onopordum*-biotype also fed and reproduced when adults and larvae were forced to feed on YST. However, in both cases feeding and reproduction was much less intensive than on the “native” host, as indicated from the lower rate of damage.

Finally, the host specificity of both biotypes was tested with the possibility of choice. To do this, eight adults were placed in a cage with six plants (two plants of each test plant species). Under choice conditions, beetles demonstrated approximately the same range of host specificity: successful development on the “native” host plant, oviposition and some larval development on the closely related host, and no damage nor reproduction on safflower (Table 4). In combination, these data suggest that both biotypes are fairly host-specific, although YST seems to be rather acceptable for the *Onopordum*-biotype.

**Impact of YST-biotype on the host plant**

On 26–27 May 2001, field sampling was conducted at “Volna location”. Height, weight, diameter of the stem, and number of *Psylliodes* larvae were recorded for each YST plant separately. Mean values (n = 94) were: height, 69 ± 20 cm; stem diameter, 5.3 ± 1.7 mm; weight, 20.5 ± 12.3 g; *Psylliodes* infestation, 2.6 ± 2.1 larvae per plant. When estimating impact on the host, only plants with stem diameter ≥ 3 mm were selected, to exclude small plants from overcrowded patches. Statistical treatment revealed a significant negative correlation between plant weight and *Psylliodes* infestation (r = –0.30, n = 79, p < 0.001). During 16–17 July 2001 field sampling was conducted at “Primorskij location” (Krasnodar territory, Russia). Means (n = 150) were: height, 39 ± 16 cm; stem diameter, 2.7 ± 1.4 mm; weight, 4.9 ± 7.9 g; *Psylliodes* infestation, 1.7 ± 1.9 larvae per plant. Statistical treatment also revealed a

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**Table 2.** Survival and lifetime fecundity of the *Centaurea solstitialis* (yellow starthistle, YST) and the *Onopordum*-biotype of *Psylliodes chalcomerus* when fed with YST, *O. acanthium* and safflower (no-choice tests in laboratory conditions). Data for each biotype indicated by different letters in the same column are significantly (p < 0.05) different by ANOVA test (means) or by χ² test (percentages).

<table>
<thead>
<tr>
<th><em>Psylliodes</em></th>
<th>Host plant</th>
<th>Survival (days)</th>
<th>Lifetime fecundity (eggs/female)</th>
<th>Embryo survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YST-biotype</td>
<td>YST</td>
<td>79±13 a</td>
<td>231±19 a</td>
<td>72.8 a</td>
</tr>
<tr>
<td></td>
<td><em>O. acanthium</em></td>
<td>20±9 b</td>
<td>15±11 b</td>
<td>27.5 b</td>
</tr>
<tr>
<td></td>
<td>Safflower</td>
<td>25±5 b</td>
<td>7±3 b</td>
<td>4.5 b</td>
</tr>
<tr>
<td><em>Onopordum</em>-biotype</td>
<td>YST</td>
<td>32±9 a</td>
<td>33±16 a</td>
<td>21.4 b</td>
</tr>
<tr>
<td></td>
<td><em>O. acanthium</em></td>
<td>23±4 a</td>
<td>55±15 a</td>
<td>51.8 a</td>
</tr>
<tr>
<td></td>
<td>Safflower</td>
<td>9±2 b</td>
<td>8±2 b</td>
<td>52.0 a</td>
</tr>
</tbody>
</table>

**Table 3.** No-choice test with adults of *Psylliodes chalcomerus* in potted plants in greenhouse conditions (5 beetles per plant, 2–3 plants per each biotype/host combination).

<table>
<thead>
<tr>
<th><em>Psylliodes</em></th>
<th>Test plant</th>
<th>Adult survival during one month</th>
<th>Plant state in one month</th>
<th>New generation recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>YST-biotype</td>
<td>YST</td>
<td>100%, n = 15</td>
<td>Dead plants</td>
<td>Larvae, pupae, adults</td>
</tr>
<tr>
<td></td>
<td><em>O. acanthium</em></td>
<td>40%, n = 15</td>
<td>Medium damage</td>
<td>Larvae, pupae, adults</td>
</tr>
<tr>
<td></td>
<td>Safflower</td>
<td>0%, n = 15</td>
<td>Light to medium damage</td>
<td>Absent</td>
</tr>
<tr>
<td></td>
<td><em>O. acanthium</em></td>
<td>100%, n = 9</td>
<td>Dead plants</td>
<td>Larvae, pupae, adults</td>
</tr>
<tr>
<td><em>Onopordum</em>-biotype</td>
<td>YST</td>
<td>67%, n = 9</td>
<td>Medium damage</td>
<td>Larvae, pupae, adults</td>
</tr>
<tr>
<td></td>
<td>Safflower</td>
<td>0%, n = 9</td>
<td>Light damage</td>
<td>Absent</td>
</tr>
</tbody>
</table>

* Yellow starthistle, *Centaurea solstitialis*

**Table 4.** Host-specificity tests for biotypes of *Psylliodes chalcomerus* with possibility of choice.

<table>
<thead>
<tr>
<th><em>Psylliodes</em></th>
<th>Plant state in one month</th>
<th>New generation development</th>
</tr>
</thead>
<tbody>
<tr>
<td>YST-biotype</td>
<td>Dead plant</td>
<td>Larvae, pupae, adults</td>
</tr>
<tr>
<td></td>
<td><em>Onopordum</em></td>
<td>Medium damage</td>
</tr>
<tr>
<td></td>
<td>Safflower</td>
<td>Light damage</td>
</tr>
<tr>
<td><em>Onopordum</em>-biotype</td>
<td>YST</td>
<td>Light damage</td>
</tr>
<tr>
<td></td>
<td>Safflower</td>
<td>Heavy damage</td>
</tr>
</tbody>
</table>

* Yellow starthistle, *Centaurea solstitialis*
negative correlation between plant weight and *Psylliodes* infestation \((r = -0.32)\), but because of the relatively small number of plants with stem diameter \(\geq 3\) mm \((n = 35)\) the significance of the correlation was lower \((p = 0.06)\).

**Italian populations**

*Psylliodes chalcomerus* (Carduus-biotype) was collected at two locations near Rome in 2002;

1. Martignano, near Martignano lake, 35 km N of Rome \((42°4'60"N, 12°16'0"E)\), feeding on *Carduus nutans*, and

2. Vivaro, 45 km SE of Rome \((41°40'60"N, 12°46'60" E)\), feeding on *C. nutans*.

Host specificity was evaluated in greenhouse conditions. In no-choice tests, single potted plants of *C. nutans*, YST, safflower, and *O. acanthium* were enclosed in \(23 \times 23 \times 100\) cm cages (five replicates per plant species/variety). Six adults were put in each cage and allowed to oviposit. In 20 days, insects were removed and plants were carefully inspected for feeding damage. High leaf damage was recorded only on *C. nutans*, YST was moderately damaged, while safflower and *O. acanthium* were only slightly damaged.

In 50 days from the beginning of the experiment, all plants were harvested and cages inspected. New generation adults were recorded only on *C. nutans* \((n = 10)\), YST \((n = 1)\), and *O. acanthium* \((n = 2)\), while no progeny were recorded on both safflower varieties.

In choice conditions, three different situations were presented to the insects (Table 5). Each set of plants was potted together and placed in a \(30 \times 30 \times 120\) cm cage. Three replicates were made of each set. Ten adults were put in each cage and allowed to feed and oviposit during 20 days. Then the insects were removed from the cages. Inspection of the plants showed extensive feeding and oviposition on *C. nutans* plants in all treatments, while only one *O. acanthium* plant showed feeding attack on the stem. In 34 days after the beginning of the experiment, all plants were harvested and dissected under a binocular microscope to find larvae (Table 5).

**Table 5.** Results of indoor choice tests with *Psylliodes chalcomerus*.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plants used</th>
<th>Leaf damage</th>
<th>Stem damage by larvae</th>
<th>Total larvae on three plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>YST</td>
<td>low</td>
<td>low</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td><em>C. nutans</em></td>
<td>high</td>
<td>high</td>
<td>278</td>
</tr>
<tr>
<td></td>
<td>Safflower</td>
<td>absent</td>
<td>absent</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>YST</td>
<td>absent</td>
<td>low</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td><em>C. nutans</em></td>
<td>high</td>
<td>high</td>
<td>121</td>
</tr>
<tr>
<td></td>
<td>Safflower</td>
<td>absent</td>
<td>absent</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>YST</td>
<td>absent</td>
<td>low</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td><em>C. nutans</em></td>
<td>high</td>
<td>high</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td><em>O. acanthium</em></td>
<td>low</td>
<td>absent</td>
<td>7</td>
</tr>
</tbody>
</table>

*a* Yellow starthistle, *Centaurea solstitialis*

**Taxonomic and morphological notes**

*Psylliodes chalcomerus* Illiger was described from Portugal (Illiger 1807). It was subsequently recorded in most of Europe, except for the extreme north (Gruev & Döberl 1997). In eastern Europe, and Russia in particular, it is known to occur from taiga (Yakovlev 1902) to steppes (Ogloblin 1925) and in all mountain regions including the Carpathians (Zybenko 1958), Crimea (Shapiro 1961) and Caucasus (Yablokoff-Khnzorian 1961, Yaroshenko 1982, 1986). Further east it is reliably recorded in western Kazakhstan. Other eastern records, for example the Russian far east and China (Gruev & Döberl 1997) need to be verified. The polymorphic nature of this species has been known for some time. Several varieties and aberrations have been described (Gruev & Döberl 1997), but their taxonomic status also needs further study.

We compared males and females from different “biotypes” in an attempt to find reliable diagnostic characters. Study of external morphology did not reveal such characters, despite the fact that specimens collected from *Onopordum* seem slightly larger than those from YST. This result is not unusual, since many, especially closely related, species of flea beetles are nearly indistinguishable externally. Most flea beetle species have unique genitalia, which have been used extensively for diagnostic purposes (Konstantinov 1998). The distribution of several characters of the male genitalia in specimens under consideration has been studied in detail. These include the shape of the median lobe, particularly the apex from ventral, lateral and dorsal views; a relative depth, width and general shape of ventral groove (Figs 1–3). For well-established species these characters would have enough diagnostic states, but in our case, significant intrapopulational variability effectively leaves no characters to separate the YST-biotype from those on *Onopordum* and *Carduus*. The same is true for the female genitalia. The tigna and vaginal palpi (Figs 4, 5) are similar in all the specimens, while the spermatheca are of two distinct shapes which differ in the width of the receptacle: one with the receptacle wide near the middle, the other with the receptacle much thinner (Figs 6–9). However, both shapes occur in the YST-biotype and the *Onopordum*-biotype.
Discussion

Laboratory investigations on the biology of the three biotypes of *Psylliodes chalcomerus* (i.e. two Russian populations associated with YST and *O. acanthium*, and two Italian populations both associated with *C. mutans*), in combination with the results of field observations, suggested that there is rather strict specificity of larval and adult feeding by all considered biotypes, while those that were found on YST and *C. mutans* seem to be more specific than those found on *O. acanthium*. Such intraspecific differentiation has been observed in other phytophagous insects (Bush 1969, Phillips & Barnes 1975, Fox & Morrow 1981, Via 1990). For example, the leaf beetle *Lochmaea caprea* L., which has been extensively investigated, includes up to five races differing in their host specificity and other biological and morphological characteristics. The authors (Mikheev & Kreslavsky 1986, Kreslavsky et al. 1987) suggest that more strictly specialized biotypes may originate from less specialized by a single or a few mutations. A similar case of “race” formation based not on host, but on habitat specificity shift, was recently reported for another leaf beetle, *Galerucella nymphaeae* L. (Nokkala & Nokkala 1998).

As for its biocontrol potential, estimation of the impact on the host in field conditions and measurement of host-plant specificity in laboratory experiments suggest that the YST-biotype of *P. chalcomerus* could be promising for YST biocontrol because of its relatively strict host specificity and the fact that it attacks both leaves and stems of the target plant. We also conclude that the other biotypes of *P. chalcomerus* undoubtedly deserve further, broader investigations to determine if they could be suitable agents to control *O. acanthium* and *C. mutans*. The hope is that such investigations, including genetic and taxonomic aspects, will clarify the biological and taxonomic status of *Psylliodes chalcomerus* biotypes.

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