# A survey of pesticide use in horticulturally-grown carnivorous plants, with a review of arthropod pests

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Abstract: Arthropod pests are sometimes reported from horticulturally-grown carnivorous plants. While it is broadly known which pest groups are involved, little work has been done to characterize them specifically, which can be important when implementing control strategies. Pesticide recommendations are available through books and other media, but pesticides have not been systematically tested for phytotoxic effects in carnivorous plants so growers may worry about using them. In response to these issues, we conducted a survey of carnivorous plant growers to understand what pests they encounter, which pesticides they use, and if any of those pesticides have caused issues to the plants, the results of which are reported herein. We also provide a summary of different arthropod pests recorded from carnivorous plants in order to provide context for these pests and their control, and to encourage growers to document pests they encounter to fill in knowledge gaps.

## Introduction

Carnivorous plants are well known for their ability to consume insects and other arthropods and most popular and scientific literature about them focuses on this phenomenon (Ortuño-Mendieta *et al.* 2021; Mithöfer 2022). However, carnivorous plants can also be attacked by herbivorous arthropods. Commercial and private individuals that grow carnivorous plants are generally intolerant of pest infestations as arthropod feeding can reduce plant vigor, cause stunted or deformed leaves, which may impair the ability of plants to capture prey, kill leaves outright, reduce seed production, reduce overwintering viability, or reduce the ability to sell plants (D'Amato 1998; Hewitt-Cooper 2016).

Within popular literature, most pest groups are discussed at higher taxonomic levels such as family or superfamily, e.g., aphids or whiteflies (Hanna 1979; Lecoufle 1990; D'Amato 1998; Meyers-Rice 2001; Romanowski 2002; Hewitt-Cooper 2016; ICPS 2022a). A few works have summarized the current knowledge of arthropod herbivores associated with specific carnivorous plants (e.g., Mithöfer 2022), but there is no comprehensive list of herbivorous arthropod species associated with all carnivorous plants. Important traits, such as pesticide susceptibility or the ability to transmit plant pathogens, can vary between species and within higher groups (e.g., not all aphids can transmit all plant viruses) so this lack of detail may negatively impact pest control solutions and outcomes.

Information about pest control methods for carnivorous plants is available to growers through various resources including books, social media, and video-sharing websites. While these sources often contain useful knowledge, they can have potential issues. For example, they can become outdated as older pesticides are phased out or when newer, safer pesticides become available, books can go out of print and become difficult to find, and internet resources can become inaccessible due to changes in individual website policies, trends in social media, users deleting content, and even changes in national and international laws (Peters 2023; Skvarla & Fisher 2023).

While pesticides are used to control pests, they can also be toxic to plants, a phenomenon known as phytotoxicity (OEPP/EPPO 2014; Sharma *et al.* 2019). Some plants are more or less sensitive to different chemicals, so pesticides that are safe for one plant may have phytotoxic effects on another (Getter 2015; Steil 2022). Temperatures above 26.6°C (80°F) and high humidity, which are the preferred growing conditions for many carnivorous plants, also increase the risk of phytotoxic effects (Getter 2015). Additionally, carnivorous plants are intolerant of minerals in their water and similar substances may be present in some pesticides as "inert ingredients" (materials included in pesticide formulations that are not the active ingredient). Therefore, growers may be concerned about whether pesticides are safe to use on carnivorous plants. Such concerns are not unfounded. One book about growing American pitcher plants (*Sarracenia* spp.) even advised that "if you must use an insecticide, do so at half strength, through even this may be enough to damage immature pitchers" (Romanowski 2002). Replicated phytotoxicity assessments are regularly conducted for pesticides applied to crops and ornamental plants, but, as far as we are aware, none have been done and reported for carnivorous plants. This is likely due to the specialty nature of carnivorous plants and their relatively small market share compared to more conventional ornamental plants.

In order to assess current trends of pesticide use among carnivorous plant growers and determine if pesticide phytotoxicity trials are warranted, we reviewed books and online information sources (e.g., YouTube, specialty websites) for information regarding pesticide recommendations. We also surveyed growers about their pest issues and pesticide use. To put this information into context, we provide a review of arthropod pests associated with carnivorous plants and indicate knowledge gaps that growers can help fill.

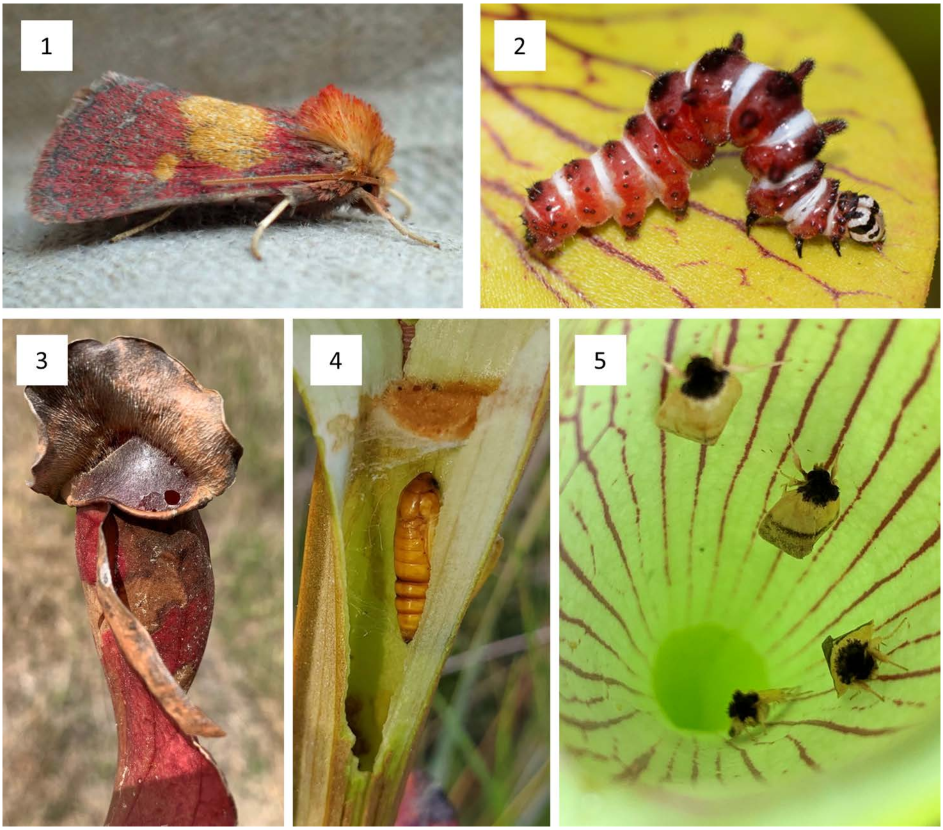
## Materials and methods

Books about carnivorous plants were screened for information about arthropod pests and associated control methods. An extensive literature search was conducted using Google Scholar for scientific articles that referenced arthropods that feed on carnivorous plants. GenBank was searched for plant virus sequences (Benson *et al.* 2013). Internet searches were executed using the common or scientific names of plants (e.g., sundew or *Drosera*), arthropod groups (e.g., aphid or Aphididae), and/or "virus". Taxon-specific websites were searched for host records as well (García Morales *et al.* 2016; Blackman & Eastop 2023; Robinson *et al.* 2023; Ulitzka 2023).

A survey of carnivorous plant growers was conducted to determine which arthropod pests growers encounter, which pesticides growers have used on their plants, and if any of those pesticides have caused adverse reactions in plants. The survey was advertised on multiple carnivorous plant Facebook groups and on Reddit through the r/SavageGarden subreddit in early February 2023. It was also sent directly to a few commercial nurseries located in the United States, although personally identifiable information was not gathered and it could not be assessed whether the nurseries responded to the survey or not. The survey was approved by the Pennsylvania State University Internal Review Board (STUDY00021775).

**Pest Review**

Chewing pests. This group includes a variety of herbivorous arthropods that chew on plants, including various caterpillars and beetles. They are best studied in American pitcher plants (*Sarracenia* spp.), which host three species of pitcher plant moths: *Exyra fax*, which specializes on *S. purpurea* (Fig. 1), *E. ridingsii*, which feeds on *S. flava* and sometimes *S. minor*, and *E. semicrocea*, which feeds on all *Sarracenia* species, although it is less common in *S. purpurea* and *S. psittacina* (Jones 1907, 1921; Folkerts & Folkerts 1996; Schnell 2002; McPhearson & Schnell 2011). Folkerts and Folkerts (1996) provided identification keys to *Exyra* caterpillars, adults, and feeding damage. As



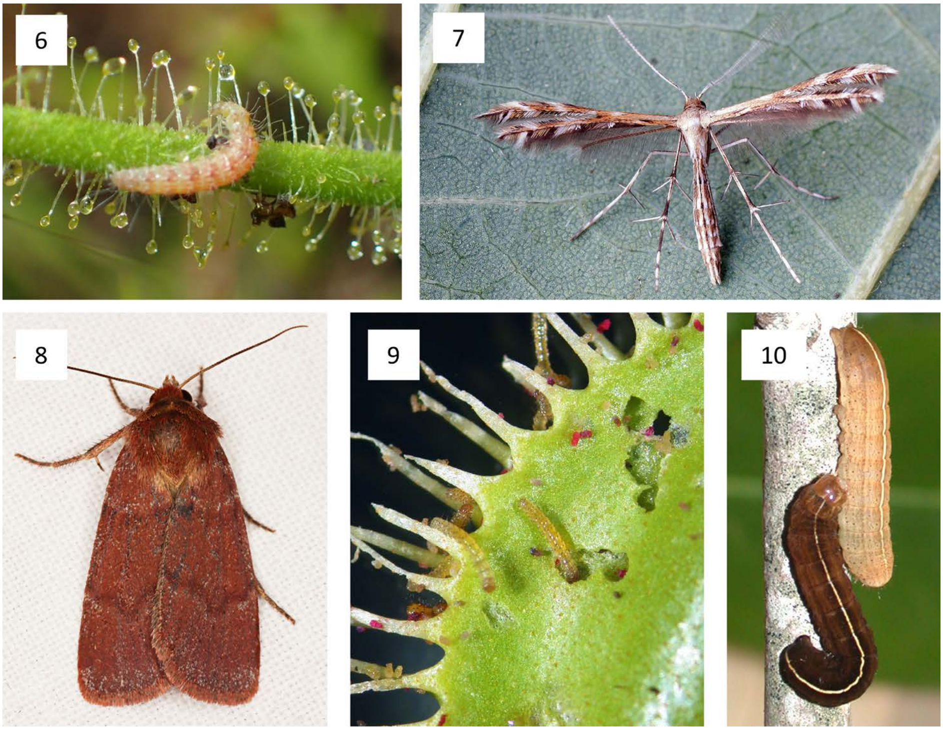

Figures 1–5: Pitcher plant moths. (1) Adult *Exyra fax.* (2) *E. semicrocea* caterpillar. (3) *Sarracenia purpurea* pitcher colonized by *E. fax*. Note the damaged tissue and webbed up pitcher opening. (4) *Exyra* pupa inside of a dissected *Sarracenia* pitcher. (5) Adult *E. semicrocea* sheltering within a *Sarracenia* pitcher. Figures 1, 2, 3, and 5 by Chris Buelow, Ashley Bosarge, Paul Dennehy, and Chrisaggie, respectively, via iNaturalist, used under CC BY-NC 4.0 Deed licenses. Figure 4 by Laura Gaudette via iNaturalist, used under a CC BY 4.0 Deed license.

caterpillars, these moths feed inside *Sarracenia* pitchers (Fig. 2, Front Cover). This causes direct damage via tissue loss but also causes the pitchers to fall over and prevents them from trapping prey (Fig. 3, Back Cover). Pupae develop within the pitchers they feed on and adult moths are also often found inside of the pitchers (Figs. 4–5). Most studies have found that caterpillar feeding negatively impacts plant growth and size (Atwater *et al.* 2006; Moon *et al.* 2008; Carmickle & Horner 2019), although one found that it did not (Ricci *et al.* 2017). More than 80% of pitchers at a site can be colonized by *Exyra* moths, so their impact is not inconsequential where they occur (Moon *et al.* 2010; Carmickle & Horner 2019). Two polyphagous moth species, *Choristoneura parallela* and *Morrisonia confusa*, also feed on *Sarracenia* pitchers (Jones 1908; Lamb & Kalies 2020). Jones (1908) reported that "larvae [of *C. parallela*] of different ages were found in localities widely separated, so their occurrence in this food-plant was evidently not accidental", while in contrast *M. confusa* has only been found on *Sarracenia* once. Beyond the pitchers, the bagworms *Basicladus tracyi* feed on the flower petals and *Endothenia hebesana* feed on the developing seeds (Jones 1908, 1911; Romanowski 2002; Schnell 2002). Southern *E. hebesana* pupate in the flower while northern individuals bore into the flower stalk, so Folkerts (1999) suggested that the species *E. daeckeana* may need to be resurrected for the northern population. These flower- and seed-feeding species do not impact the overall health of individual plants, but *Endothenia* feeding can significantly reduce seed yield. This does not impact natural regeneration in wild *Sarracenia* populations (Rymal & Folkerts 1982; Folkerts 1992; USFW 1994) but could be of concern to growers producing *Sarracenia* seed.

Tropical pitcher plants (*Nepenthes* spp.) are well defended chemically by various secondary metabolites and also fibrous tissue in the leaves and stems, so few herbivorous insects feed on them (Tan *et al.* 2020). Two species are known to feed on *N. bicalcarata*: a weevil (*Alcidodes* sp.) that feeds on young pitchers and prevents them from maturing into prey-capturing organs (Merbach *et al.* 2007) and a butterfly larva (species unknown) bores a hole in young pitchers just before they open, which causes digestive fluid to drain out and allows the caterpillar to feed on the empty pitcher (Clarke 1997). Another moth, *Eublemma radda*, has been recorded on *N. bicalcarata*, *N. gracilis*, *N. mirabilis*, and *N. rafflesiana* but the relationship is less detrimental (Beaver 1983; Clarke 1998). The caterpillars live in and graze on the inside wall of *Nepenthes* pitchers, which causes clear windows to appear. Damaged pitchers will collapse after a few weeks, although the pitchers seem to function for just as long as uncolonized pitchers so the effect on prey capture and plant health may be negligible (Clarke 1997, 1998). Similarly, *Phyllocnistis nepenthae* caterpillars mine the pitchers but this does not affect prey capture or pitcher longevity (Tan *et al.* 2020). Generalist caterpillars have been noted to feed on *Nepenthes* leaves, including tussock moths and bagworms, but these cause localized and minimal damage (Hewitt-Cooper 2016; Tan *et al.* 2020). African cotton leafworm (*Spodoptera littoralis*) caterpillars that were experimentally fed *Nepenthes* leaves did not grow (Dávila-Lara *et al.* 2021; Rahman-Soad *et al.* 2021), so herbivory by non-specialists on *Nepenthes* is likely self-limiting and not much of a concern to growers. Pitcher blue butterflies (*Deudorix kessuma*), which are native to southeast Asia, are specialists on *Nepenthes* seed pods (Tan *et al.* 2020). Florida pink scavenger moths (*Anatrachyntis badia*), which are generalist seed feeders found it in Southeast United States and California, have also been recorded on *Nepenthes* seed pods (Tan *et al.* 2020). Neither species affects the overall health of infested plants but may reduce seed production.

Sundews (*Drosera* spp.) are fed upon by the caterpillars of a few moth groups. The genus *Buckleria* includes six species, three of which are known to feed on sundews (Figs. 6–7; Table 1).

*Buckleria* caterpillars avoid becoming trapped by sticky glandular hairs of sundews by licking the mucilage off the hairs, thus rendering the trap safe, before consuming the leaf (Osaki & Tagawa 2020). The caterpillars also feed on the flowers and flower stalk and it has been hypothesized that rapid flower closure in response to mechanical stimuli exhibited by some sundews may be a defense against *Buckleria* feeding (Matthews 2009; Tagawa *et al.* 2018). Herbivory damage by *Buckleria* in some areas can be high (Kataoka & Nishimoto 2007). Sundew dart moths (*Hemipachnobia monochromatea*) are found in Northeastern North America west to Alberta (Fig. 8). Early instars feed on sundews while later instars can host switch onto cranberry, blueberry, and sheep laurel (Hooker 1919; Wagner 2011; MPG 2023; Robinson *et al.* 2023), but they have otherwise been little investigated. Carnation tortrix (*Cacoecimorpha pronubana*) are highly polyphagous moths native to the Mediterranean region that were first recorded in the United Kingdom around 100 years ago. In 2012, they were found feeding on nursery-grown Cape sundews (*D. capensis*) in Essex, U.K, so this is an interesting interaction where neither the host plant nor the herbivore are native to the region where they were found to interact (Signorile 2012). *Spodoptera apertura* are found in Africa,




Figures 6–10: Lepidoptera that feed on carnivorous plants. (6) European sundew moth (*Buckleria paludum*) caterpillar feeding on *Drosera*. (7) *B. paludum* adult. (8) Adult sundew dart moth. (9) Early instar and (10) mature Venus flytrap moth caterpillars. Figure 6 by Hugo Innes via iNaturalist, used under a CC BY 4.0 Deed license. Figures 7 and 8 by Cossus and Michael H. King, respectively, via iNaturalist, used under CC BY-NC 4.0 Deed licenses. Figures 9 and 10 by Bo Sullivan, used with permission.

Australia, and southeast Asia and have been reported to feed on tobacco (*Nicotiana*) but also on *Drosera* in India (Sevastopulo 1941; Robinson *et al.* 2023).

Venus flytraps (*Dionaea muscipula*) host Venus flytrap cutworm moths (*Hemipachnobia subporphyrea*) (Figs. 9–10). This species was described in the late 1700's but not observed again until 1974, when it was rediscovered in North Carolina. Since then, only five additional populations have been found, with five total populations in North Carolina and one in Maryland (Hall & Sullivan 2000; Hall *et al*. 2023). One survey found that Venus flytraps at ten additional sites had feeding damage characteristic of *H. subporphyrea*, but their presence has not been confirmed by finding larvae or adults (Hall & Sullivan 2006). In fact, only a handful of adult specimens have ever been collected (24 as of 2000; Hall & Sullivan 2000). Caterpillars have been found on commercial Venus flytraps cultivated in semi-natural conditions, where they produced extensive damage in 1986, but have only recently been observed in the wild (Hall & Sullivan 2000; Hall pers. comm.). A population in Maryland exists where Venus flytraps do not occur and lab-reared caterpillars successfully fed on sundews and a later instar caterpillar fed on creeping blueberry (*Vaccinium crassifolium*), so

Table 1. Information about *Buckleria* species, including associated host plants.

| **Species** | **Plant hosts** | **Range** | **Year described** | **References** |
|---|---|---|---|---|
| *Buckleria brasilia* | *Drosera graminifolia* | Brazil | 2006 | Gielis 2006 |
| *Buckleria girardi* | | central and western Africa | 1992 | Gibeaux 1992; De Prins & De Prins 2021 |
| *Buckleria madecassea* | | Madagascar | 1994 | Gibeaux 1994; De Prins & De Prins 2021 |
| *Buckleria negotiosus* | | South Africa, Zimbabwe | 1926 | Meyrick 1926; Gielis 2008; De Prins & De Prins 2021 |
| *Buckleria paludum* | *D. burmanni*, *D. rotundifolia*, *D. serpens**, *D. spatulata* | Europe, Asia, Australia | 1841 | Ustjuzhanin & Kovtunovich 2017; Tagawa *et al.* 2018; Osaki & Tagawa 2020; Robinson *et al.* 2023 |
| *Buckleria parvulus* | *D. brevifolia*, *D. filiformis*, *D. tracyi* | eastern United States, primarily the southern coastal plain | 1921 | Matthews 2009 |
| *Trichoptilus scythrodes*‡ | *D. peltata* complex | Australia | 1886 | ALA 2023a, b; Hobern 2020, 2021, pers. comm. 2023 |

* Tagawa *et al.* (2018) reported *B. paludum* from *D. toyoakensis*, which Schlauer *et al.* (2019) synonymized with *D. serpens*. That change is reflected here.

‡ According to Donald Hobern, *Trichoptilus scythrodes* has male genitalia that are similar to *B. paludum* and has a COI barcode sequence that is 6% different from that species, so should be transferred to *Buckleria* as *B. scythrodes*. As a formal transfer has not been published, we retain it within *Trichoptilus* here but include it in the table as we expect it will be moved in the future.

they may host switch like the closely related sundew dart (see above). However, in North Carolina, Venus flytrap cutworm moths have not been found in areas that support only sundews but not Venus flytraps, so Venus flytraps are likely a necessary host in that state (Hall *et al*. 2023). The species is globally rare and one of the most imperiled insects in North America, although the U.S. federal government and other international agencies (e.g., the International Union for Conservation of Nature) have not recognized it as endangered so it has few formal protections. Due to their scarcity and limited range, Venus flytrap cutworms are not an issue for most growers.

Butterworts (*Pinguicula* spp.) in Mexico are eaten by pyrgomorphid grasshoppers (species not reported) and terrestrial mollusks. Most plants (74.3%) had low-levels of herbivore damage (0.5-3% of total leaf area), although some individual plants lost up to 40% of the total leaf area (Alcalá *et al.* 2010; Ortuño-Mendieta *et al*. 2021). Chewing herbivores have not been reported from wild butterworts elsewhere in the world, although slugs are reported to feed on cultivated butterworts in popular literature (Hewitt-Cooper 2016).

Root-boring insects attack the rhizomes of pitcher plants. Perhaps the best known are pitcher plant borer moths (*Papaipema appassionata*) (Figs. 11–12). While this species occurs throughout eastern North America, they are most common and abundant in the Great Lakes region (Lamb & Kalies 2020). Pitcher plant borer moths feed on *Sarracenia purpurea* throughout their range and have also been found on *S. alata*, *S. flava*, and *S. rubra* in the Southeast (Jones 1908; Schnell 2002; Brou 2005; Lamb & Kalies 2020). As the caterpillars bore through pitcher plant rhizomes, orange-brown excrement builds up around the base of the plant and indicates an infestation. The boring damage can be extensive and result in wilting pitchers and plant death (Jones 1908; Kalies 2020).

Black vine weevils (*Otiorhynchus sulcatus*) (Figs. 13–14) are another root-feeding pest that attack *Sarracenia* and *Darlingtonia* (Rice 2001). This species is native to Europe but was introduced to North America by 1831, where it is now widespread. It has also been introduced into New Zealand, mainland Australia and Tasmania, Japan, and Chile (Moorhouse *et al.* 1992). Young black vine weevil larvae feed on fine roots, while older larvae bore through the roots themselves. When


Figures 11–14: Root-boring pests that feed on pitcher plants. (11) Pitcher plant borer moth caterpillar in a *Sarracenia* rhizome and (12) an adult moth. (13) Black vine weevil larva and (14) adult. Figure 11 by Teá Montagna via iNaturalist, used under CC BY 4.0 Deed license. Figures 12 and 14 by Denis Doucet and David Cappaert, respectively, via iNaturalist, used under a CC BY-NC 4.0 Deed license. Figure 13 by Peggy Greb, USDA Agricultural Research Service, via Bugwood.org, used under a CC BY 3.0 US Deed license.

they feed on pitcher plant rhizomes, this can cause wilting pitchers and kill infested plants. The preferred larval hosts include the roots of yews (*Taxus* spp.) and rhododendron (*Rhododendron* spp.), but black vine weevils are relatively polyphagous and have been recorded from 150 species of plants (Moorhouse *et al.* 1992). During experimental feeding trials, weevil larvae fed on 101 of 108 offered hosts (Masaki *et al.* 1984), so the potential host range is likely larger than currently known. While they have not been recorded from carnivorous plants, other *Otiorhynchus* species are also polyphagous root-feeders that have been spread around the world through commercial horticulture, so may be pests on pitcher plant rhizomes if given the opportunity.

Adult *Otiorhynchus* weevils are nocturnal and feed on plant leaves at night, which produces a characteristic notching along leaf edges. While this feeding is rarely heavy enough to stress the plant, it can help identify an infestation of larvae in the roots, which might otherwise be missed until the plant dies. Female weevils are flightless and are usually introduced into a new area through infested plants, so inspecting new plants before incorporating them into the landscape can help prevent infestations. Keeping pitcher plants in water baths and eliminating bridges across the water (e.g., sticks, fallen pitchers) will help keep weevils out of potted pitcher plants if they are already present in the landscape. Once weevils are established in the rhizome, manually removing them can be effective. Entomopathogenic nematodes (*Steinernema* and *Heterorhabditis* spp.) are commercially available and can control weevil larvae but may be slow to produce results. Biorational pesticides such as *Bacillus thuringiensis gallariae* (Btg) can be applied when adults are present to kill them when they feed on plant leaves. Imidacloprid applied as a soil drench is effective against larvae, but other broad-spectrum insecticides such as carbaryl and malathion are not (Frank *et al.* 2020a).

<u>Sucking pests</u> include a variety of groups, such as true bugs like scale insects and aphids, as well as thrips and even arachnids like spider mites. Different groups feed on the phloem, xylem, or contents in individual plant cells, so pesticides can have variable control depending on the pest group, how the pesticide is applied, and the pesticide mode of action. Signs and damage vary by pest, but often consist of stunted plant growth; leaf curling, yellowing, browning, or stippling; and the production of honeydew and the associated growth of sooty mold.

Aphids are soft-bodied true bugs that feed on plant phloem using piercing-sucking mouthparts (Figs. 15–16). They are mostly a northern temperate group and are not well represented in tropical regions (Blackman & Eastop 2023). While more than 5,700 species occur worldwide (Favret 2023), fewer than 300 are considered serious pests. Aphids have been reported from *Cephalotus*, *Dionaea*, *Drosera*, *Drosophyllum*, *Genlisea*, *Heliamphora*, *Nepenthes*, *Pinguicula*, *Sarracenia*, and *Utricularia* in popular literature (Lecoufle 1990; D'Amato 1998; Fleischmann 2012; ICPS 2022). However, only a few have been identified to species from a limited number of carnivorous plant hosts in the scientific literature (Table 2).

Aphid feeding can cause direct damage to plants, which often manifests in carnivorous plants as twisted or stunted leaves (D'Amato 1998; Hewitt-Cooper 2016). They also produce honeydew, which is a sugary waste product that can grow black sooty mold. However, in most horticultural and agricultural systems, the majority of damage associated with aphids is due to the plant pathogens they vector rather than direct feeding damage (Dedryver *et al.* 2010). Carnivorous plants are not agronomically valuable so have not been systemically surveyed for plant pathogens (Miguel *et al.* 2016). In consequence, only a few aphid-vectored pathogens are known from them (Table 3). Of these, both *Cucumber mosaic virus* and *Beet western yellows virus* have wide host ranges (1200 and 150 species, respectively; Zitter & Murphy 2009, Yoshida & Tamada


Figures 15–18: Aphids and aphid-vectored virus damage in carnivorous plants. (15) Aphids feeding on a *Drosera rotundifolia* flower stalk. (16) Aphid mummies on a *Sarracenia* pitcher. Mummies are made by parasitoid wasps and indicate that beneficial biocontrol agents are attacking the aphids. When mummies are present, broad-spectrum pesticides should be avoided. (17) Discoloration on a *Sarracenia* phyllodia and (18) pitcher caused by *Cucumber mosaic virus*. Figure 15 by Tero Karppinen via Flickr, used under a CC BY 2.0 Deed license. Figure 16 by u/Plutoniumburrito via reddit, used with permission. Figures 17 and 18 by Adam Gaupp via The Sarracenia Forum, used with permission.

2019), so finding them in carnivorous plants is perhaps not surprising (Figs. 17–18). These widespread viruses have only been reported from carnivorous plants in two and one locality, respectively, but it's not clear if the lack of reports is due to a lack of survey effort or because they rarely infect carnivorous plants.

Scale insects includes a number of related groups, including hard scales (Diaspididae), soft scales (Coccidae), and felt scales (Eriococcidae). They all feed on plant liquids using piercing-sucking mouthparts, lack wings (except for adult males), and are often treated as a single group in popular literature. However, there are important differences between them that can impact control solutions when infestations occur.

Hard scales are sedentary insects that do not move after they settle down to start feeding. Most life stages are covered by a hard wax scale or test, which protects them from natural enemies, adverse weather, and pesticides. Only the crawlers, which are the youngest stage that hatches from the eggs, lack a waxy test and can move. Because they are so small, crawlers can move from plant to plant by being blown about on the wind, being moved by birds, or crawling from nearby

| Table 2. Aphid species recorded from carnivorous plants. | | | | | |
|---|---|---|---|---|---|
| **Species** | **Plant hosts** | **Carnivorous plant hosts** | **Geographic range of aphid** | **Area recorded from CPs** | **References** |
| *Aphis droserae* | *Drosera* | *Drosera loureirii*, *D. peltata*, *D. rotundifolia* | China, Taiwan, Germany | China, Taiwan, Germany | Takahashi 1921; Tao 1991; Barjadze *et al.* 2017; Blackman & Eastop 2022 |
| *Aphis franeulae* sensu lato | varies by subspecies, including *Epilobium angustifolium*, *Capsella bursa-pastoris*, *Lysimachia vulgaris*, *veronica beccabunga* | *Drosera rotundifolia* | Cosmopolitan | Germany | Müller 1978 |
| *Aphis nasturtii* | Polyphagous | *Drosera intermedia*, *D. rotundifolia* | Cosmopolitan except Australasia | Germany, Switzerland | Müller 1978; Lampel & Tinguely 1998; Holman 2008; Blackman & Eastop 2022 |
| *Aphis triglochinis* | Polyphagous on aquatic/semi-aquatic plants | *Drosera anglica*, *D. intermedia*, *D. rotundifolia* | Northern, Central, and Eastern Europe, northern Asia, possibly Japan | Germany, Great Britain, Latvia, The Netherlands, Sweden | Holman 2008; Blackman & Eastop 2022 |
| *Cavariella aegopodii* | Usual hosts are various Apiaceae | *Drosera rotundifolia* | Cosmopolitan | Germany | Müller 1987; Holman 2008 |
| *Aulacorthus solani* | Polyphagous | *Sarracenia purpurea* | Cosmopolitan | The Netherlands | Piron 2017; Blackman & Eastop 2022 |

| Table 2. Continued | | | | | |
|---|---|---|---|---|---|
| **Species** | **Plant hosts** | **Carnivorous plant hosts** | **Geographic range of aphid** | **Area recorded from CPs** | **References** |
| *Hyalomyzus jussiaeae* | Usual host is *Ludwigia* but may colonize other aquatic/ semi-aquatic plants | *Drosera capilaris* | Eastern North America and Central America | Florida | Nielsson & Habeck 1971; Blackman & Eastop 2022 |
| *Macro-siphum jeanae* | *Sarracenia* | *Sarracenia purpurea* | Manitoba | Manitoba | Robison 1972; Blackman & Eastop 2022 |
| *Macro-siphum* sp. near *jeanae* | *Darlingtonia* | *Darlingtonia californica* | California | California | Nielsen 1990; Blackman & Eastop 2022 |
| *Myzus lytheri* | Usual host is *Lythrum* but may colonize other aquatic/ semi-aquatic plants | *Drosera rotundifolia* | Europe, Africa, central Asia, North America | Poland | Szelegiewicz 1966, 1968; Holman 2008; Blackman & Eastop 2022 |
| *Neomyzus circum-flexus* | Polyphagous | *Sarracenia purpurea* | Cosmopolitan | The Neth-erlands | Piron 2017; Blackman & Eastop 2022 |
| *Rhopalo-siphum nymphaeae* | Polyphagous on aquatic/semi-aquatic plants | *Drosera anglica*, *Utricularia* | Cosmopolitan | Czech Republic | Homan 1991, 2008; Blackman & Eastop 2022 |

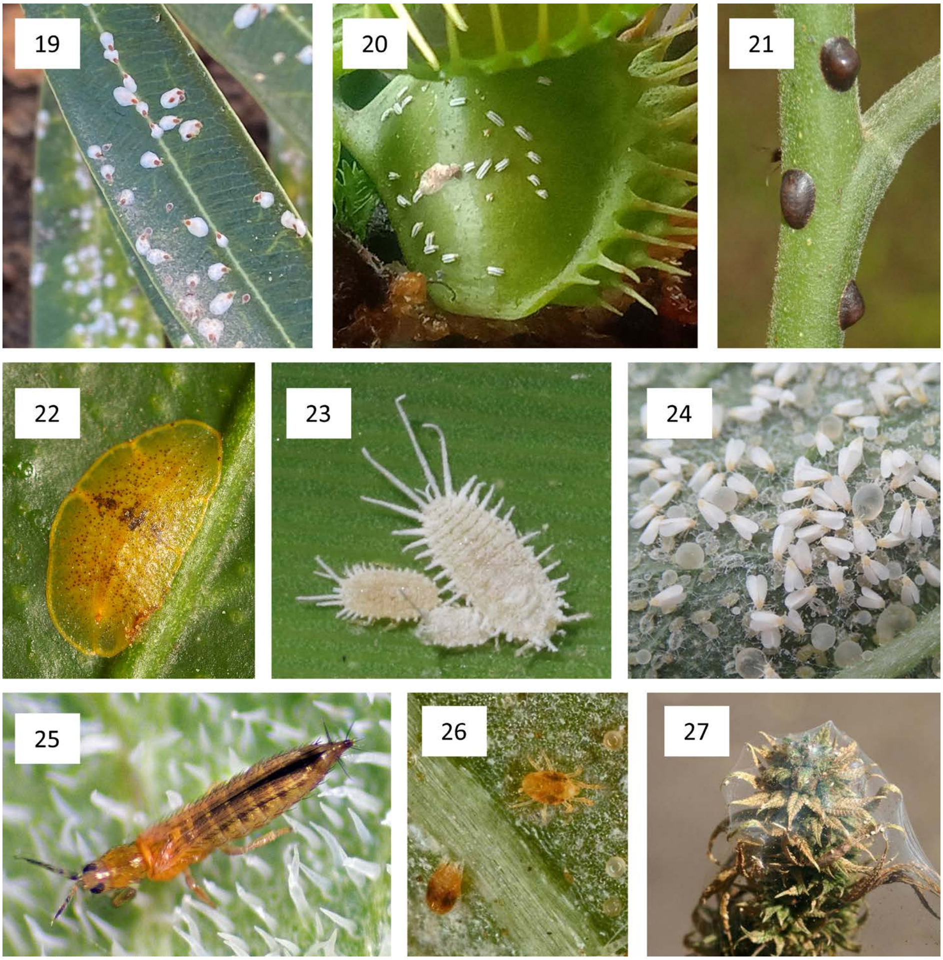
infested plants. Hard scale feeding can result in weakened and stunted plants, yellowing or discolored leaves, or even plant death. Unlike many other plant-feeding insects with piercing-sucking mouthparts, hard scales do not feed on sap from the phloem. Rather, they rupture individual plant cells and consume the contents. This makes control using systemic insecticides difficult as insecticides are usually not translocated into the cells where scales feed. So foliar insecticides are applied when the crawlers are present. Different hard scale species may be univoltine (one generation

| Table 3. Aphid-vectored plant viruses reported from carnivorous plants. | | | |
|---|---|---|---|
| **Virus** | **Plant host** | **Reported from** | **Reference** |
| *Beet western yellows virus* | *Nepenthes mirabilis* | France | Miguel *et al.* 2016 |
| *Cucumber mosaic virus* | *Sarracenia* sp. | Germany | GenBank accession number MW582807.1 |
| *Sarracenia purpurea virus* | *Sarracenia purpurea* | Germany | Barckhaus & Weinert 1975; Jackson *et al.* 2008 |
| *Turnip mosaic virus* | *Utricularia* sp. | | GenBank accession number AB701736.1 |

per year) or multivoltine (multiple generations per year) and crawlers may be present at different times of the year, so identifying hard scales to species can be important for timing control measures. Dentate scale (*Velataspis dentata*) and false oleander scale (*Pseudaulacaspis cockerelli*) (Fig. 19), both of which are polyphagous and have broad host ranges, have been recorded from *Sarracenia purpurea* in Georgia (Tippins 1968; Beshear *et al.* 1973). *Chrysomphalus nepenthivorus* are only known from specimens that were intercepted in the United States on "several hybrids of *Nepenthes*" exported from Thailand (Smith-Pardo *et al.* 2012). Hard scales that occur on *Nepenthes* elsewhere in the world are likely polyphagous pest species, but none have yet been identified to species. Hard scales have also been reported from *Darlingtonia*, *Dionaea*, and *Genlisea*, but the species on these hosts are unknown (Lecoufle 1990; Fleischmann 2012) (Fig. 20).

Soft scales are somewhat similar in appearance to hard scales but are more variable. Some species are flat and lack a waxy covering while others are highly rounded; some species have legs and can move while others lack legs after the crawler stage; and some species are similar in size to hard scales while others are larger and more conspicuous. Unlike hard scales, soft scales feed in the phloem and produce honeydew like aphids. A number of polyphagous species are important pests in greenhouses and on indoor plants. Nigra scale (*Parasaissetia nigra*), a polyphagous species known from more than 400 plant hosts (Fig. 21), has been collected from greenhouse-grown *Nepenthes* in South Africa (Krüger & Douglas-Smit 2013). A specimen of Florida wax scale (*Ceroplastes floridensis*), which occur throughout the Southeastern United States, was collected on *Sarracenia minor* from an unknown location in 1876 (Gimpel *et al.* 1974). Finally, a photograph of what appears to be brown soft scales (*Coccus hesperidum*, Fig. 22) on *Heliamphora* was published by Hewitt-Cooper (2016).

Felt scales are similar in appearance to mealybugs but are not covered in as much wax, so that most of the pink, red, purple, or green body can be seen. All life stages have legs and are capable of moving. Most species are feed on a limited host range and a few are important pests of ornamental plants (Skvarla & Schneider 2022). The only felt scale known to feed on carnivorous plants is *Acanthococcus droserae*, which has been collected from wild sundews in Florida and Georgia (Miller *et al.* 1992). Felt scales feed on sap in the phloem (Wu *et al.* 2022), so in the unlikely event that they become pests on cultivated sundews in the Southeastern United States, systemic insecticides should control them.




Figures 19–27: Examples of sucking pests that feed on carnivorous plants. (19) False oleander scale infestation on a non-carnivorous plant. (20) Hard scales on a *Dionaea muscipula* trap. No scale species have been documented from Venus flytraps, so this is likely a new, undescribed host association. (21) Nigra scale infestation on a non-carnivorous plant. (22) Brown soft scales are among the most important soft scale species in greenhouses. (23) Obscure mealybugs, (24) greenhouse whiteflies, (25) western flower thrips, and (26) two-spotted spider mites are polyphagous pests of many different plant species that can be especially problematic on plants grown in indoor settings. (26) Individual two-spotted spider mites are small and difficult to see, but infestations can create large amounts of webbing that covers a plant. Figures 19, 21, 22, and 23 by Matt, donnamareetomkinson, bikingbirder, and James Bailey respectively, via iNaturalist, used under CC BY-NC 4.0 Deed licenses. Figure 20 by Ro Ja via Facebook, used with permission. Figures 24 and 27 by Whitney Cranshaw, Colorado State University, via Bugwood.org, used under a CC BY 3.0 US Deed. Figure 25 and 26 by David Cappaert via Bugwood.org, used under a CC BY-NC 3.0 US Deed license.

Mealybugs are small, slow-moving, soft-bodied insects that are covered in soft waxy filaments. Like aphids and soft scale insects, they feed on plant sap via the phloem. Mealybug feeding can weaken plants and cause stunting and malformed leaves. They also produce honeydew, which can result in the growth of sooty mold. While mealybugs can be pests on outdoor plants, they are often well controlled by natural enemies that prey on and parasitize them. A number of species are pests in greenhouses and on indoor plants, where they can escape the pressure of natural enemies. Obscure mealybugs (*Pseudococcus viburni*) are a polyphagous pest species that have been recorded from *Nepenthes mirabilis* and *Sarracenia purpurea* in the scientific literature (Ben-Dov 1994; Gimpel & Miller 1996) (Fig. 23). Growers have also noted mealybugs on *Darlingtonia*, *Drosera*, *Heliamphora*, and *Nepenthes* (Lecoufle 1990; ICPS 2022; CPN 2023), although the species involved are unknown. It is likely that polyphagous species can feed on most carnivorous plants so other host genera may be at risk. Mealybugs like to squeeze into tight spaces at the bases of leaves and between other plant parts and are somewhat protected by their waxy covering, so foliar insecticides may not always provide adequate control but systemic insecticides often do.

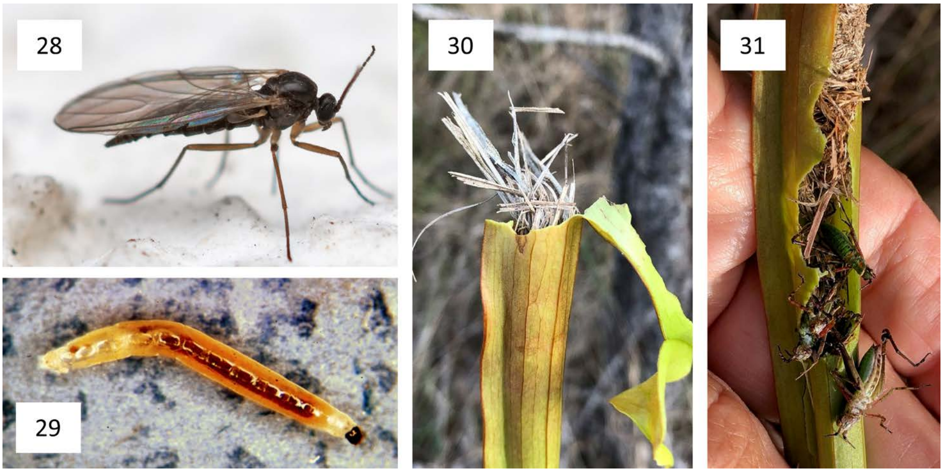
Whiteflies are small (1–3 mm) true bugs with piercing-sucking mouthparts related to aphids and scale insects (Fig. 24). Like scale insects, newly hatched whiteflies are mobile while older immature are immobile once they settle down in a spot. Whitefly "pupae" appear as round, shiny black objects that are often fringed with wax. Adult whiteflies are small, white, and active. They fly up from the host plant when disturbed but are poor fliers so settle back onto the plant quickly. Whiteflies are often well controlled by natural enemies on outdoor plants but, like aphids, the population can sometimes grow to damaging levels before natural enemies bring it down again. Whitefly population growth is often worse on indoors plants or in protected culture where natural enemies may not exist. Whiteflies feed on sap, so damage manifests as yellowing or dying leaves and stunted growth. They also produce honeydew, which can result in the growth of sooty mold. Some species vector plant-pathogenic viruses (Fiallo-Olivé *et al.* 2020), although none of the viruses are known to infect carnivorous plants. No whiteflies have been recorded from carnivorous plants in scientific literature. They are rarely mentioned in popular sources, although they have been reported to feed on *Pinguicula* (ICPS 2022).

Thrips are small (0.5–14 mm, most <5 mm), elongate insects that can be a variety of colors including yellow, orange, red, black, and black with white stripes. Adults have strap-like wings covered in a fringe of hairs and can fly, while immatures lack wings and may be different colors than adults. More than half of the 6200 thrips species found worldwide feed on fungi, pollen, or other insects so are either innocuous or are beneficial pollinators and predators. In fact, while most butterworts are pollinated by other insect groups, *Thrips meridionalis* are important pollinators of *Pinguicula vallisneriifolia* (Zamora 1999; Lustofin *et al.* 2020). Although the remaining thrips species feed on plant tissue, less than 1% are considered pests (Kawale 2021). While some pest species have a narrow host range, others are extremely polyphagous. For example, western flower thrips (*Frankliniella occidentalis*) have been recorded to feed on more than 250 host plants and their full host range is likely much broader (Fig. 25). (Reitz *et al.* 2020). Regardless of the food source, thrips feed using the "punch and suck" method where they push their mouth cone into the food and suck out the contents. Plant-feeding species feed on individual plant cells, so feeding damage generally appears as stippling on leaf and flower surfaces but extensive damage may appear as large, silvery patches. Thrips may also leave behind black frass droplets that resemble drops of motor oil or varnish on plants leaves. In addition to direct feeding damage, western flower thrips and a handful of other species transmit various *Tospovirus* species, including *Tomato spotted wilt virus*, which has a host range of nearly 2000 plant species and has caused numerous epidemics in various horticultural and floricultural crops worldwide (Parrella *et al.* 2003; Riley *et al.* 2011). *Tomato spotted wilt virus* has not been recorded from carnivorous plants but, similar to aphid-vectored plant pathogens, this is likely due to a lack of surveillance rather than an inability to infect carnivorous plants. Similarly, thrips in general have been noted to feed on *Darlingtonia*, *Nepenthes*, and *Sarracenia* (D'Amato 1998; Hewitt-Cooper 2016) but no thrips species in particular have been record from carnivorous plants. This is partly due to the difficulty in identifying thrips to species. While guides to commonly encountered species (e.g., Hodges *et al.* 2009; Bethke *et al.* 2014) can help narrow down possible identifications, thrips can only be reliably identified after being mounted on a slide and examined under a microscope by an expert.

Spider mites are small (<1 mm) plant-feeding mites that are red, green, or translucent in color (Fig. 26). Despite their small size, they are often visible with the naked eye due to their color contrasting with the infested plant. Under optimal conditions, spider mites can mature from egg to adult in five to twenty days, so populations can often explode quickly (Fasulo & Denmark 2009). Spider mites suck the contents out of individual plant cells, which kills the cells. Damage appears as stippling or bleaching and badly damaged leaves will eventually turn yellow, bronze, or grey. Spider mites also spin silk webbing over host plants, which can become extensive when infestations are large and indicate an infestation (Fig. 27). Two-spotted spider mites (*Tetranychus urticae*), which are the most important polyphagous pest species, reproduce best under hot, dry conditions so are the biggest issue outdoors during the summer and fall. However, outdoors they are often well controlled by a variety of natural enemies and dislike the humid conditions of a bog garden. Indoors, spider mites can occur year-round and can be difficult to control as there are no natural enemies present to help control them. This dynamic is reflected in the survey results, where all ten reports of spider mites were from indoor plants and there were no reports of spider mites affecting outdoor plants. Spider mites have specifically been reported from *Dionaea*, *Nepenthes*, and *Sarracenia* (Lecoufle 1990; D'Amato 1998; ICPS 2022) but the exact species involved are unknown. Polyphagous species like two-spotted spider mites can likely feed on most carnivorous plants.

Other small, red mites that may occur on carnivorous plants are beneficial, so care should be taken to identify mites before control methods are implemented. For example, concrete mites (*Balaustium* spp.) and whirligig mites (*Anystis* spp.) are common predators that are frequently found in open, sunny spots, such as the sides of buildings and on trees and plants. Both groups feed on small, soft-bodied arthropods and eggs so can help suppress pest populations outdoors. They are typically larger (1–2 mm) and more active than spider mites and do not spin webs.

<u>Soil mites</u> is a catchall term for any mite found in soil, but most frequently refers to oribatid mites, which are sometimes called moss mites as they are ubiquitous in moss, leaf litter, and other and other damp areas. They can sometimes colonize indoors plants, especially those grown in high organic media that stays damp. Most oribatid mites are detritivores that feed on decaying plant material and pose no danger to living plants. They may even be beneficial as they can help regulate algae, fungi, and similar organisms growing in the substrate. However, *Scheloribates* mites have a broader feeding biology compared to other oribatids. While an uncommon occurrence, *Scheloribates* have been known to infest and cause direct feeding damage to greenhouse-grown and indoor house plants (R. Norton pers. comm., pers. obs.). The damage is thought to be related to mite feeding on necrotic tissue that then spreads to healthy tissue, but the phenomenon has not been well investigated. *Scheloribates* infestations have not yet been associated with carnivorous plants but




Figures 28–31. Other insects associated with carnivorous plants. (28) Adult and (29) larval fungus gnats can be common in damp areas and are often associated with plant pots. (30) *Sarracenia* pitchers are sometimes colonized by nesting *Isodontia* wasps, which (31) pack their nests with paralyzed katydids. Nesting rates are generally low so should not affect the overall health of the plant. Figure 28 by Whitney Cranshaw, Colorado State University, via Bugwood.org, used under a CC BY 3.0 US Deed license. Figure 29 by Fero Bednar and figures 30 and 31 by Janet Wright, via iNaturalist, used under CC BY-NC 4.0 Deed licenses.

given their broad feeding biology it is likely that they colonize and feed on them. So, in most cases, oribatid infestations are only a nuisance because of their presence but in rare cases infestations can cause direct damage to plants.

Dark-winged fungus gnats are small (1–11 mm, most <5 mm), dark colored flies (Fig. 28). The larvae feed on fungi in moist areas, so they are common in forests, swamps, lawns with thick thatch, decaying vegetation, damp leaf litter, and other outdoor areas that support fungal growth (Fig. 29). In homes, dark-winged fungus gnats are usually associated with plant pots with consistently damp substrate that allows fungi to grow. In most cases, dark-winged fungus gnats are only a nuisance because of their presence. However, populations can build up such that larvae can damage otherwise healthy seedlings by feeding on root hairs and, in extreme circumstances, boring into plant stems (Frank *et al.* 2020b). Adults and larvae can also vector plant fungal pathogens (Harris *et al.* 1996). While no studies have specifically examined the impact of dark-winged fungus gnat infestation on carnivorous plants, they likely follow a similar pattern where low populations are merely a nuisance but high populations may damage plants, especially seedlings, through direct feeding and possibly pathogen transmission.

Grass-carrying wasps (*Isodontia* spp.) are medium sized (16–20 mm) wasps that are usually dark in color but may have a red abdomen or legs and/or thick golden hairs. Sixty-two species occur worldwide (Pulawski 2003). Female wasps build nests by packing strands of grass into pre-existing holes and tight spaces, such as hollow stems, beetle and carpenter bee holes in wood and dead trees, window tracks, folded patio umbrellas, and similar areas (Fig. 30). These grass nests are then provisioned with paralyzed crickets, katydids, and other orthopterans for the young wasps to eat (Fig. 31). *Isodontia apicalis* (=*Chlorion harrisi*), *I. mexicana*, and *I. philadelphica* have been

| Table 4. Insecticide recommended for pest control on carnivorous plants in literature and online. | | | |
|---|---|---|---|
| **Insecticide type** | **Insecticide active ingredient** | **Insecticide class** | **Reference(s)** |
| **Systemic** | Acephate | Organophosphate | D'Amato 1998; California Carnivores 2022b; ICPS 2022a |
| | Acetamiprid | Neonicotinoid | Hewitt-Cooper 2016 |
| | Imidacloprid | Neonicotinoid | Sarracenia Northwest 2010; California Carnivores 2022b; Brandwood 2020; ICPS 2022a; CPN 2023 |
| | Thiacloprid | Neonicotinoid | Hewitt-Cooper 2016 |
| **Contact** | "Sevin" | Various* | D'Amato 1998; ICPS 2022a, 2023 |
| | Abamectin | Avermectin | ICPS 2022a |
| | Bacillus thuringiensis (Bt) | Biological | Sarracenia Northwest 2019; ICPS 2022a, b; California Carnivores 2023 |
| | Bifenazate | Bifenazate | ICPS 2022a |
| | Bifenthrin | Pyrethroid | California Carnivores 2022b; ICPS 2022a |
| | Cyfluthrin | Pyrethroid | CPN 2023 |
| | Diazanon | Organophosphate | D'Amato 1998 |
| | Horticultural oil | Oils | Succulent Flytraps 2019 |
| | Insecticidal soap | - | Hewitt-Cooper 2016 |
| | Isopropyl alcohol | - | California Carnivores 2022b, 2023; ICPS 2022a |
| | Malathion | Diazanon | D'Amato 1998 |
| | Neem | Botanical | Sarracenia Northwest 2010 |
| | Permethrin | Pyrethroid | Sarracenia Northwest 2010 |
| | Pyrethrin | Pyrethrin | Sarracenia Northwest 2010; California Carnivores 2022a, b, 2023; ICPS 2022a |
| | Spinosad | Spinosyns | ICPS 2022a, 2023 |

*Sevin products have historically used carbaryl as the active ingredient. However, in recent years some products have been changed to bifenthrin, zeta-cypermethrin, and other active ingredients recorded to nest in *Sarracenia alata*, *S. flava*, *S. jonesii*, *S. leucophylla*, and *S. minor* in eastern North America (Hubbard 1896; Jones 1904; Rau 1935; Fish 1976; Rymal & Folkerts 1982; Rodenas 2012; Rice 2007; Harvard Forest 2021). Colonization of *Sarracenia* by grass-carrying wasps is low, up to 2.5% of pitchers and often less (Jones 1904; Fisher 1976; Rymal & Folkerts 1982), so while the nests stop individual pitchers from capturing prey, the wasps are not a threat to the overall health of a plant. Grass-carrying wasps are not defensive and generally fly away unless grabbed or handled, so growers can leave nests without worry of stings or remove them if they want to allow a pitcher to continue to capture prey.

**Published pesticide review.**

Only four systemic pesticides were recommended for use in books and other media (Table 4), all of which act as contact pesticides as well. The systemic pesticides were all broad-spectrum products that can control a wide variety of pests. Most (3 of 4) were neonicotinoids. More than half of the 15 contact pesticides recommended in books and other media were biorational products that targeted specific groups of pests (e.g., Bt) or had low residual activity (e.g., soaps and oils). The modes of action were varied.

Most popular books suggested using broad spectrum products that could be used against all or most arthropod pests. They sometimes lack specifics or were vague, such as recommending to "control [thrips] with an insecticide" (Hewitt-Cooper 2016). Recommendations in other media such as nursery websites and YouTube videos were more specific and often recommend specific pesticides for specific pests or carnivorous plant groups.

**Survey results.**

Seventy-eight survey responses from 52 respondents were received from 1–14 February 2023, of which 47 responses from 25 finished surveys could be analyzed. Of the 25 respondents that completed the survey, 21 were from the United States, two were from the United Kingdom, and one each were from the Philippines and Singapore. Most respondents grew more than 100 individual plants (Table 5). Most pests were reported from plants grown in indoor settings, with a variety of carnivorous plant taxa and pests reported (Tables 6 and 7). Spider mites were the pest reported most frequently (10 reports), followed by aphids (9), scale insects (7), mealybugs (5), thrips (5), soil mites (4), and dark-winged fungus gnats (2).

Table 5. The number of carnivorous plants grown by the survey respondents.

| Number of plants grown | Number of respondents |
|---|---|
| 1–9 | 0 |
| 11–50 | 7 |
| 51–100 | 5 |
| >100 | 13 |
| Total | 25 |

Respondents reported the use of 14 products used to control pests: one was not a pesticide, five were biorational pesticides, and eight were broad spectrum pesticides (Table 8). The most commonly reported active ingredient, either alone or in combination with other active ingredients, was imidacloprid with 18 responses (40.9% of the total). All other products were reported six or fewer times (13.6% of total or less).

Only two of 25 respondents reported adverse effects of pesticides to plants. One reported that Compo Triple Action was harmful to *Dionaea muscipula*, *Drosera capensis*, and *Pinguicula lusitanica* and one that BioAdvanced 3-in-1 was harmful to an unnamed *Drosera* species.

| Table 6. Reported arthropod pests of carnivorous plants grown indoors. | | | | |
|---|---|---|---|---|
| | ***Cephalotus*** | ***Dionaea*** | ***Drosera*** | ***Heliamphora*** |
| Aphids | | 2 | 1 | 1 |
| Dark-winged fungus gnats | | | | |
| Mealybugs | 1 | | 1 | 1 |
| Scale insects | 1 | | | 2 |
| Soil mites | 2 | | | |
| Spider mites | 2 | 2 | | 3 |
| Thrips | | | | |
| Total | 6 | 4 | 2 | 7 |
| | ***Nepenthes*** | ***Pinguicula*** | ***Sarracenia*** | **Total** |
| Aphids | | 1 | | 5 |
| Dark-winged fungus gnats | | 1 | | 1 |
| Mealybugs | | | 1 | 4 |
| Scale insects | | | 2 | 5 |
| Soil mites | | 2 | | 4 |
| Spider mites | 3 | | | 10 |
| Thrips | 4 | | | 4 |
| Total | 7 | 4 | 3 | 33 |

| Table 7. Reported arthropod pests of carnivorous plants grown outdoors. | | | | |
|---|---|---|---|---|
| | ***Darlingtonia*** | ***Dionaea*** | ***Drosera*** | ***Nepenthes*** |
| Aphids | 1 | 2 | 1 | |
| Scale insects | | | | 1 |
| Total | 1 | 2 | 1 | 1 |
| | ***Pinguicula*** | ***Sarracenia*** | **Total** | |
| Aphids | | | 4 | |
| Dark-winged fungus gnats | 1 | | 1 | |
| Mealybugs | | 1 | 1 | |
| Scale insects | | 1 | 2 | |
| Thrips | | 1 | 1 | |
| Total | 1 | 3 | 9 | |

| Table 8. Pesticides and associated that reported by survey respondents. | | | | |
|---|---|---|---|---|
| **Product** | **Active ingredients** | **Plants used on** | **Number of responses** | **Number of responses that product harmed the plant?** |
| Rubbing Alcohol | 91% isopropyl alcohol | *Drosera* | 1 | |
| Avid | Abamectin | *Nepenthes* | 1 | |
| Orthene | Acephate | *Sarracenia* | 2 | |
| Azamax | Azadirachtin | *Cephalotus*, *Heliamphora* | 2 | |
| Bti | Bacillus thuringiensis israelensis | *Pinguicula* | 2 | |
| Compo triple action | Deltamethrin, Tebuconazole, Abamectin | *Dionaea*, *Drosera*, *Pinguicula* | 4 | 4 |
| | Dimethoate 4EC | *Nepenthes* | 6 | |
| Bayer Rose & Flower | Imidacloprid | *Cephalotus, Drosera* | 2 | |
| BioAdvanced Fruit, Citrus & Vegetable Insect Control | Imidacloprid | *Cephalotus*, *Heliamphora* | 5 | |
| BioAdvanced 3-in-1 | Imidacloprid, Tau-fluvalinate, Tebuconazole | *Dionaea*, *Drosera*, *Heliamphora*, *Pinguicula*, *Nepenthes*, *Sarracenia* | 11 | 1 (Drosera) |
| Neem | Neem oil | *Dionaea*, *Nepenthes*, *Sarracenia* | 5 | |
| | Pyrethrin | *Nepenthes* | 1 | |
| Monterey | Spinosad | *Nepenthes* | 1 | |
| Captain Jack's Dead Bug Brew | Spinosad | *Nepenthes*, *Sarracenia* | 2 | |
| Bug Clear | | *Nepenthes* | 1 | |

## Discussion

Arthropod pests. While the arthropod pests that feed on carnivorous plants are well known in general, only a few specifics are known as there has been no effort to systematically document the pests found on cultivated carnivorous plants and very few pests have been identified to species. Because so little is known, growers have an opportunity to contribute to scientific knowledge. The best way to do this in the United States is to submit pests for identification to local entomologists at state departments of agriculture, local Extension services, or arthropod identification and plant disease laboratories associated with state universities (e.g., the Penn State Insect Identification Lab). Other countries will have different institutions, but often have agencies to identify insect pests. If submitting specimens to experts for identification is not possible, then posting high-quality photographs online is helpful as it preserves the interaction and some pests can be identified to species or another useful taxonomic level based on photographs. The best place to post photos is iNaturalist (inaturalist.org) as it is global in reach, covers all life, can be searched taxonomically, which makes screening photographs of plants for pests much easier, and is used by scientists to conduct research – more than 500 scientific publications have been based on iNaturalist data so far (Skvarla & Fisher 2023).

Aphids are the best studied group of pests, but most species are only reported from one or a few hosts from one or a few areas. In North America, three specialist species have been reported from wild plants, but none have been reported from cultivated plants. This lack of clarity can complicate pest control as a number of polyphagous species that are pests in agricultural crops are resistant to pesticides (Georghiou & Lagunes-Tejada 1991; Silva *et al*. 2012), but it's not clear if pesticide resistance species feed on carnivorous plants. Similarly, the presence of a few aphid-vectored plant viruses in carnivorous plants shows that such viruses can infect cultivated carnivorous plants, but it's not clear how widespread the phenomenon is or which aphids are vectoring the viruses.

In areas where native carnivorous plant-feeding arthropods exist, there is an opportunity to test the host range of those species. For example, will sundew plume moths (*Buckleria parvulus*) in eastern North America feed on cultivated non-native sundews such as *Drosera capensis*? Do *Buckleria negotiosus* in South Africa feed on *Drosera* at all? If growers observe these specialist caterpillars on their sundews, it's likely that any observation they make is new and has never been reported before. Similarly, grass-carrying wasps occur worldwide, but have only been reported from *Sarracenia* in the Southeastern United States. Will species outside of the native range of *Sarracenia* utilize pitchers as nesting areas?

Knowing which arthropod species native to an area can help with conservation as well. For example, growers in North Carolina, especially those that live near wild Venus flytrap colonies, should be aware of Venus flytrap cutworm moths and report potential caterpillars to the appropriate entities, such as the North Carolina Natural Heritage Program and U.S. Fish and Wildlife Service, as any observations of these endangered moths could be critically important to saving the species from extinction.

Pesticides. While a country-level review of the legality of various pesticides is beyond the scope of this article, many of the products suggested in books and other media (Table 4) have been banned by various countries and states around the world. For example, all of the systemic products except bifenthrin have been banned in the European Union, acephate is banned in China and India, and various U.S. states have banned imidacloprid and other neonictinoids. Some of the contact pesticides, particularly malathion, have also been banned and are generally unavailable. This can make it difficult for home growers to decide what product to use if a specifically recommended active ingredient is unavailable where they live.

Another issue is that some published works recommend specific brand products without specifying the active ingredient. This can create issues when the active ingredient is changed but the product label remains largely unchanged. For example, some sources suggested using Sevin, which historically used carbaryl as the active ingredient. However, in recent years Sevin brand products have changed the active ingredient to any of three different chemicals, none of which are carbaryl. This can create problems if newer chemicals have different phytotoxic effects in plants or if they have different efficacy against pests.

Insecticidal soaps are the only group of pesticides that have multiple recommendations not to use them. The active ingredient in insecticidal soaps are potassium salts of fatty acids and it is variously reported that they harm plants because they are alkaline (D'Amato 1998) or that they break down into potassium in the growing medium (Sarracenia Northwest 2010). Otherwise, it appears that many pesticides are safe to use on carnivorous plants. Commercial growers reported that they use a variety of products without issue on many different plant taxa (California Carnivores 2022a, b; ICPS 2022 a, b; CPN 2023; Table 4) and only two of the twenty-five survey respondents reported possible phytotoxicity issues after applying pesticides. Both products that were reported to harm plants were combination products that include two pesticides (deltamethrin and abamectin or imidacloprid and tau-fluvalinate, respectively) and the fungicide tebuconazole. It may be that tebuconazole, the only active ingredient shared between the two products, has phytotoxic effects when applied to certain plants or in certain situations. Rice (2005) reported that Bayer Rose and Flower Insect Killer, which contains imidacloprid and cyfluthrin, had phytotoxic effects (leaf curling and browning) in some *Dionaea* but not other genera including *Byblis*, *Drosera*, *Genlisea*, *Pinguicula*, or *Sarracenia*, so different effects within and between plant groups is not unknown.

Imidacloprid was recommended by multiple published sources and was the most popular active ingredient amongst respondents, likely owing to its ease of use, broad range of pests killed, wide over-the-counter availability in the United States and high proportion of respondents from that country. Previous reports have indicated that it can be phytotoxic to *Dionaea* (Rice 2005) and one of the products reported to harm plants by survey respondents contained imidacloprid.

In conclusion, while many pesticides are apparently safe for carnivorous plants, some of them (i.e., at least imidacloprid and tebuconazole) should be evaluated for phytotoxicity issues as they may be toxic to some plants in some situations. Additionally, alternatives to imidacloprid should also be assessed due to the unavailability of the chemical in many countries and potential for it to be banned in the United States, either by the federal government or piecemeal by various state governments.

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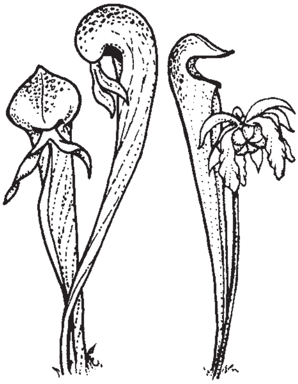


# CARNIVOROUS PLANT NEWSLETTER

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**Front Cover: *Exyra semicrocea* larva in *Sarracenia flava* pitcher, Liberty Co., Florida. Photo by Barry Rice. Article on page 75.**

**Back Cover: Typical *Exyra* larva-eaten *Sarracenia flava* pitcher. Photo by Djoni Crawford. Article on page 75.**

Carnivorous Plant Newsletter is dedicated to spreading knowledge and news related to carnivorous plants. Reader contributions are essential for this mission to be successful. Do not hesitate to contact the editors with information about your plants, conservation projects, field trips, or noteworthy events. Advertisers should contact the editors. Views expressed in this publication are those of the authors, not the editorial staff.

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