

Influence of Timing and Prey Availability on Fruit Damage to Apple by *Campylomma verbasci* (Hemiptera: Miridae)

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ABSTRACT *Campylomma verbasci* Meyer is a zoophytophagous mirid that feeds on small arthropods as well as apple (*Malus domestica* Borkhausen) fruits, causing economic damage to some cultivars. The influence of timing and prey availability on the amount of fruit damage was studied to determine whether either factor could be used to refine a management program. *C. verbasci* nymphs were caged on branches of fruiting 'Golden Delicious' apple trees during the period from bloom through early fruit set. The greatest amount of fruit damage occurred during the bloom period; little or no damage occurred after fruit reached ≈ 13 mm in diameter. The availability of prey did not reduce the incidence of fruit damage by *C. verbasci*, nor did it influence the survival of nymphs. Nymphal survival was higher, however, in cages where a blossom or fruitlet was present versus a vegetative spur. These data support the hypothesis that post petal fall insecticide applications (those made after the fruit is greater than ≈ 10 -13 mm in diameter) are not useful in preventing economic levels of fruit damage in Washington State, and that petal fall applications would only prevent a fraction of the total amount of damage by this pest. The data from this study do not support the hypothesis that manipulating arthropod prey species of *C. verbasci* will prevent fruit damage. There was evidence to support the hypothesis that nymphs can survive a relatively short period (7 d) without arthropod prey.

KEY WORDS *Malus domestica*, feeding behavior, economic injury

Campylomma verbasci MEYER is a sporadic fruit-feeding pest of apple (*Malus domestica* Borkhausen) in Washington (Beers et al. 1993). Damage was rarely a cause for concern until the late 1980s, when the reported incidence of damaging populations increased. Higher levels of damage first occurred in the northern fruit-growing areas of central Washington. This area is contiguous with the Okanagan valley fruit district of British Columbia, where *C. verbasci* has been a significant pest since the 1970s (Madsen et al. 1975). Fruit damage levels of up to 57% have been reported in Washington where populations were untreated (Reding et al. 1992, Reding 2000). This level of damage in a primarily fresh-fruit industry is economically unacceptable, where fruit damage thresholds are typically <1% (Beers et al. 1993).

Campylomma verbasci overwinters in woody perennial hosts, including apple and pear (*Pyrus communis* L.) (Thistlewood 1986). The first-generation nymphs are present from late March to mid-April through early June in central Washington (Reding 2000), and some proportion of the adults produced migrate to herbaceous hosts. Nymphs and adults can be found in orchards throughout the growing season, but generally in lower numbers than in spring (McMullen and Jong 1970, Reding 2000). The greatest proportion of succeeding generations occurs on herbaceous

weed hosts, especially mullein (*Verbascum thapsus* L.) (McMullen and Jong 1970, Thistlewood et al. 1990). Beginning in early fall, adults migrate back into orchards where females lay overwintering eggs (McBrien et al. 1994, Reding and Beers 1996c).

Campylomma verbasci feed on plant tissues, including vegetative and reproductive parts. On sensitive cultivars, feeding damage (usually referred to as stings) is characterized by a dark corky wart on the fruit surface, often surrounded by a depression. Multiple stings can severely deform the fruit, although single stings can sometimes go unnoticed during grading on deeply colored cultivars. Some cultivars are more susceptible to injury than others, with damage more apparent on light-colored cultivars.

Only the nymphs of the overwintering generation cause fruit injury (Boivin and Stewart 1982, Reding and Beers 1996a). Although they are present in the orchard for many weeks, control recommendations (Beers et al. 1993, BCMAFF 1996) have targeted the period encompassing bloom. Precautionary pesticide applications are sometimes made throughout the period when nymphs are present, based on the detection of nymphs and fruit damage, and the desire to prevent further injury. If injury occurs throughout the nymphal period, some proportion may be prevented by later applications. However, if injury occurs during a very narrow time frame in the development of either the fruit or the insect, applications made after this time are not economically justifiable.

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Table 1. Timing and description of treatments, 1994–1995

Time period	Bud developmental stage	Nymphal stage ^a	Date ^b
1994			
I	Bloom-petal fall	Young	20–27 April
II	Fruitlet (3–13 mm)	Intermediate	3–10 May
III	Fruitlet (13–25 mm)	Intermediate + mature	13–20 May
1995			
I	Bloom-petal fall	Young	26 April–3 May
II	Fruitlet (3–6 mm)	Young + intermediate	5–12 May
III	Fruitlet (6–19 mm)	Intermediate	17–24 May

^a Young, instars I and II; intermediate, instars III and IV; mature, instar V.

^b Deployment of vegetative tissue treatments was delayed by 24–48 h in 1995 at periods II and III.

Campylomma verbasci also is considered an important predator in some regions, feeding on several species of small arthropods, including mites, aphids, psyllids, and thrips (Collyer 1953, McMullen and Jong 1970, Niemczyk 1978, Thistlewood 1986, Smith 1989). The feeding behavior of *C. verbasci* has been studied in various regions of North America to better understand its preferences and dietary requirements, and to relate those to its tendency to behave as either a pest or a predator. Lord (1971) reported the observation that *C. verbasci* damage is rare in orchards with high mite populations, leading to the speculation that arthropod prey were preferred to phytophagy. Thistlewood and Smith (1996) suggested that manipulation of prey densities could be a novel management technique to effectively reduce or prevent fruit injury. In laboratory studies it has been shown that there is enhanced survival if consumption of animal prey occurs (McMullen and Jong 1970), and that in fact the latter is necessary for the completion of development of the early instars. However, Bartlett (1996) found in laboratory tests that *C. verbasci* continue to use plant food sources even in the presence of prey, and that pollen was sufficient for nymphs to complete development in the absence of prey.

Two hypotheses were examined in the current study: (1) there is a time in the seasonal phenology of the apple and *C. verbasci* after which fruit damage no longer occurs, and thus subsequent sprays will not affect fruit damage; and (2) the availability of arthropod prey will reduce the amount of fruit damage that occurs, providing an alternative management strategy. In addition, the experimental design allowed us to examine the effect of short periods of deprivation of arthropod prey on nymph survival. These hypotheses were examined with a single multifactor experimental design carried out during two field seasons.

Materials and Methods

The studies were conducted in 1994–1995 in a mature 'Golden Delicious' apple orchard at the Washington State University Tree Fruit Research and Extension Center, Wenatchee, WA. This cultivar is highly sensitive to *C. verbasci* feeding (Thistlewood et al. 1989), thus providing a sensitive indicator of fruit damage. The test arena was a sleeve cage over the

apical portion of a branch. Tests were conducted at ambient field temperature by using contemporaneous field-collected *C. verbasci* nymphs.

Three successive periods (7 d in duration) were tested to determine the timing of injury. The initial period was based on apple bud development (Chapman and Catlin 1976), specifically full bloom (Table 1), which was also the time at which sufficient numbers of *C. verbasci* had hatched from overwintering eggs. During each period, four treatments were tested in a 2 × 2 factorial design. The first factor was arthropod prey availability (with or without prey). The prey species used were early instar aphid nymphs [*Dysaphis plantaginea* (Passerini) and *Rhopalosiphum fitchii* (Sanderson); one or two per cage] in 1994, and twospotted spider mite (*Tetranychus urticae* Koch; 10 per cage) in 1995. Aphids were from populations taken from the same orchard as the *C. verbasci* nymphs, and were the most likely natural prey item. Early instar aphids were used in period I, whereas intermediate to late instars were used in periods II and III. Adult *T. urticae* from a laboratory colony were used in 1995 because of the lack of a field population of aphids. The second factor was plant tissue type (vegetative only or vegetative plus reproductive). Each treatment was replicated 30 times, with a replicate consisting of one caged branch containing one *C. verbasci* nymph.

Cages were constructed of polyester fabric with a weave sufficiently tight to prevent escape of the nymphs, but open enough to allow light penetration and air exchange. The cages were tubes (20 cm long by 5 cm diameter) tied around the tree branch at the proximal end, and closed with a binder clip at the distal end to allow examination without removal. The plant material in each potential cage site was first examined for presence of either *C. verbasci* nymphs, signs of *C. verbasci* injury, and other arthropods, and only those found free of all of these were used in the experiment. All nonwoody plant material in the cage except a single blossom or actively growing leaf (depending on the treatment) was removed to facilitate examination. Fruit diameters in the appropriate treatments were taken at the beginning of periods II and III (period I was bloom through petal fall) by using a linear caliper just before introduction of *C. verbasci* nymphs.

Tree branches were enclosed in cages at the beginning of the three periods. *C. verbasci* nymphs were

Table 2. Analysis of categorical data for the effects of time period and prey availability on fruit injury of Golden Delicious apples by *C. verbasci* nymphs

Factor ^a	df	χ^2	P
1994			
Time	2	44.91	0.0001
Prey	1	0.55	0.4587
Time \times prey	2	1.41	0.4937
1995			
Time	2	51.27	0.0001
Prey	1	0.14	0.7081
Time \times prey	2	0.25	0.8839

^a Time, 7-d interval beginning at full bloom; prey, presence or absence of prey (aphids 1994, *T. urticae* 1995).

collected with a beating tray from the block and transferred directly to the cages, and thus had experienced the same developmental conditions as the trees. The most abundant stages present in the orchard at the beginning of the period were used in the experiment. The five instars were categorized as young (instars I-II), intermediate (III-IV), or mature (V) (Table 1). Prey were introduced into the cages in the appropriate treatments immediately after the *C. verbasci* nymphs.

At the end of each period, cages were inspected to evaluate the survival of *C. verbasci*. The nymphs were removed, along with all vegetative (leaf) plant material. The leaf material removed from the cages was examined for arthropod prey. Fruit diameters were remeasured, and cages were resealed to prevent ingress of nonexperimental *C. verbasci* nymphs. The cages were examined after an additional 7 d when fruit had developed the characteristic damage.

Because the experimental conditions could not be reproduced exactly each year, the 2 yr were analyzed separately. The response frequencies of fruit injury and nymphal survival were tested by using a categorical data modeling procedure (PROC CATMOD, SAS

Institute 1988). The analysis of fruit injury data was a 2×3 factorial (prey \times time period) treatment design, and the analysis for percentage survival data was a 2×2 (tissue type \times prey) factorial design. In the latter case, periods were analyzed separately because of the missing cell in period I (1995). Percentages were declared different if the chi-square was significant at $P \leq 0.05$ and 95% CI did not overlap.

Results and Discussion

Fruit Damage. The effect of time period was highly significant in both years (Table 2). There was a clear trend for a decline in fruit injury throughout the three periods (Fig. 1) (percentages were pooled across prey treatments). Mean fruit injury in the earliest period (I, full bloom through petal fall) was significantly higher ($\approx 42\%$) than the last period (III, up to 25-mm fruitlets) in both years of the study. Fruit damage resulting from exposure to *C. verbasci* nymphs in the third time period was negligible ($<2\%$).

The results of this study support the hypothesis that the majority of fruit injury occurs during a relatively narrow time frame, from full bloom through ≈ 1 wk after petal fall. Nevertheless, they do not exclude the possibility that some injury occurs earlier or later than the periods studied. Before this study, damage was thought to occur only after petal fall (Thistlewood and Smith 1996). The experimental design does not provide the ability to distinguish between feeding habits of different instars and fruitlet susceptibility as primary regulators of fruit injury, because only naturally occurring populations were tested. For example, young nymphs were never exposed to fruit >10 mm, and mature nymphs were never caged with blossoms. However, the experimental conditions used in this study reflect typical plant and insect phenology in central Washington, where fourth and fifth instars do not occur until after petal fall (Reding 2000). The difference

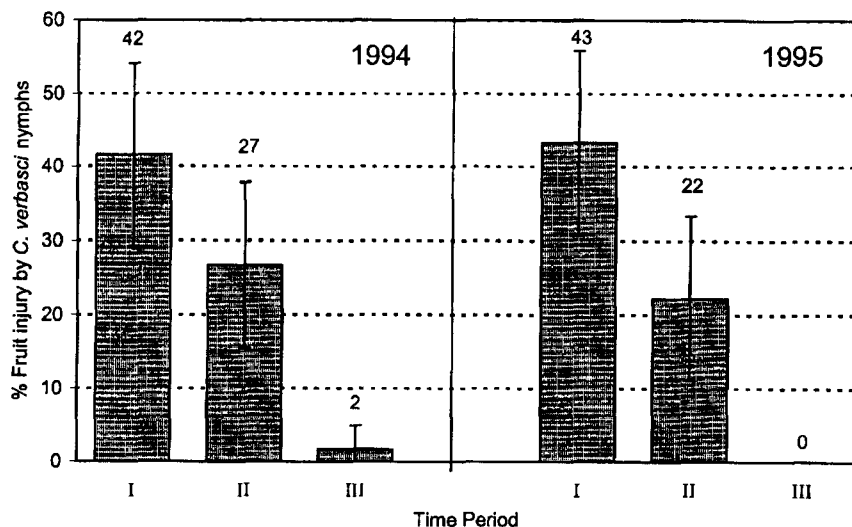


Fig. 1. Effect of time on the incidence of fruit injury to Golden Delicious apples by *C. verbasci* (mean percentages with standard errors).

Table 3. Analysis of categorical data for effects plant tissue type and prey availability on survival of *C. verbasci* nymphs in the field during three time periods, 1994–1995

Year	Time Period	Factor ^a	df	χ^2	P
1994	I	Tissue	1	4.13	0.0421
		Prey	1	0.00	0.9609
		Tissue × prey	1	0.01	0.9307
	II	Tissue	1	0.36	0.5489
		Prey	1	0.64	0.4234
		Tissue × prey	1	0.66	0.4171
	III	Tissue	1	8.02	0.0046
		Prey	1	2.58	0.1083
		Tissue × prey	1	0.43	0.5142
1995	I	Tissue	1	—	—
		Prey	1	0.52	0.4690
		Tissue × prey	1	—	—
	II	Tissue	1	3.65	0.0560
		Prey	1	0.22	0.6393
		Tissue × prey	1	0.22	0.6393
	III	Tissue	1	6.57	0.0103
		Prey	1	1.17	0.2790
		Tissue × prey	1	0.03	0.8594

^a Tissue refers to fruiting cluster or vegetative spur; prey, presence or absence of prey.

in threshold developmental temperatures between the host plant (6.6°C; Anstey 1966) and *C. verbasci* (9.2°C; Judd and McBrien 1994) may be responsible, in some climatic regions, for an asynchrony between the two whereby the appropriate nymph stage is not present at the same time as the susceptible fruit stages.

Based on data and observations from various geographic and climatic areas, the fruit susceptibility hypothesis appears to be the more likely of the two. In general, there is no concern about *C. verbasci* feeding on fruit in the second and third generations, when fruit is typically >40 mm in diameter (MacPhee 1976). This hypothesis was tested explicitly by Reding and Beers (1996a), who found no damage occurred to 'Delicious' after exposure to either adults or nymphs in July. Boivin and Stewart (1982) also found that no damage resulted from either early or late instar *C. verbasci* nymphs caged with fruit in a region (southwestern Québec) where *C. verbasci* hatches after fruit set. These authors further speculated that small nymphs are unable to mechanically damage more advanced fruit and, for this reason, *C. verbasci* is not a pest in that region. Similarly, Ross and Caesar (1920) report that the adults, which under normal conditions are not exposed to blossoms or <10-mm fruitlets, do not injure fruit.

More evidence for the fruit susceptibility hypothesis comes from differential susceptibility of the two major commercial pome fruit species. *C. verbasci* damage to pear fruit is rare (McMullen and Jong 1970, Beers et al. 1993). Thus, it is generally considered an important predator of pear psylla (*Cacopsylla pyricola* Foerster) on this crop, whereas on sensitive apple cultivars, it is generally considered a pest. Pickett (1938) and Thistlewood (1986) discuss differential susceptibility among apple cultivars. Although lower attack rates may be due to simple lack of attractiveness to this facultative zoophytophage, there is correlative evidence that fruits that are

physically more difficult to penetrate are the least attacked.

There is further inferential evidence for a narrow time frame for *C. verbasci* damage to apple. Insecticide trials where applications are made at petal fall are wholly or partly unsuccessful in preventing fruit damage, even when nymphs are nearly eliminated. J.F.B. and R. F. Smith (unpublished data) achieved only a 66% reduction in fruit damage with the most effective material tested when applications were made at petal fall. Reding and Beers (1996b) found no reduction in damage when a very effective material (formetanate hydrochloride) was used at petal fall. In the same test, another short-lived but effective material (imidacloprid) applied just before bloom had the lowest level of fruit damage, even though later hatching nymphs survived the residues.

The effect of prey availability was not significant in either year, indicating that the presence of arthropod prey did not diminish the propensity to feed on fruit (Table 2). These data do not support the hypothesis that manipulating populations of *C. verbasci* prey species during the critical period around bloom would be of any value in pest management programs. In practical terms, such manipulations could not be readily or consistently achieved, and could just as easily result in problematic populations of prey species, many of which are indirect pests.

Nymphal Survival. The plant tissue type with which the nymphs were caged had a fairly consistent effect on nymphal survival (Table 3), with generally higher survival in cages with a blossom or fruitlet present (Fig. 2). This lack of effect of prey availability on nymphal survival was contrary to expectations. Nymphs in all periods were able to survive at least 7 d without arthropods. This study was not designed to study the need for prey for completion of the life

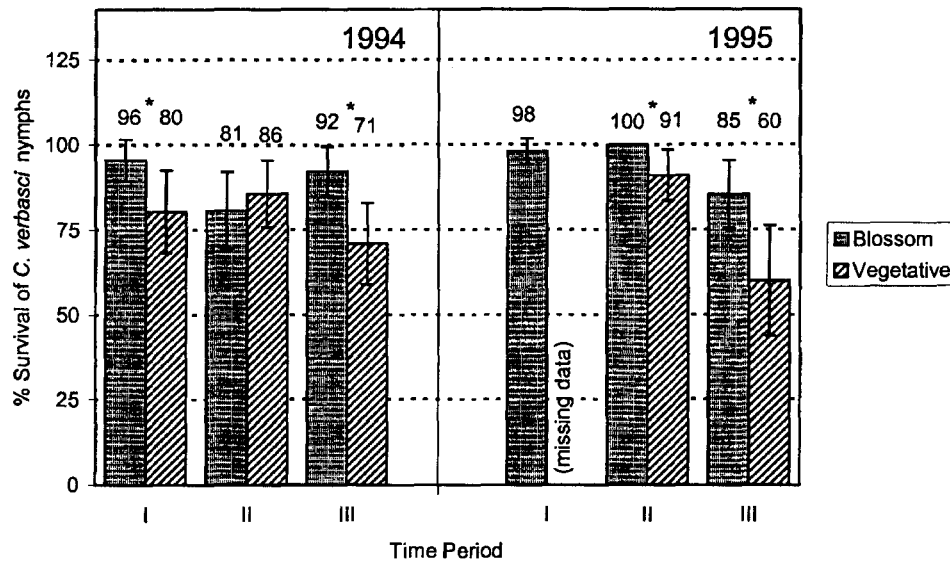


Fig. 2. Effect of plant tissue type on the survival of *C. verbasci* nymphs on Golden Delicious apples. Asterisks over pairs of means indicate a significant chi-square ($df = 1$) at that time for the plant tissue effect (mean percentages with standard errors).

cycle; it is possible that nymphs, especially intermediate and mature stages, had already taken some arthropod prey before introduction into the cages. The effect of plant tissue type on survival in period I is consistent with the findings of Bartlett (1996), who indicated that pollen was an adequate source of nutrition for nymphs in the absence of arthropod prey. Blossoms are sources of pollen and nectar, and may also provide refugia for *C. verbasci* nymphs.

There is evidence in our study that nymphs survived short periods (7 d) without pollen or prey. We found from 56 to 93% survival in treatments with no prey and only vegetative plant tissue available to the nymphs. Although 23% of the no-prey replications (time periods I and II, 1994 only) had some naturally occurring arthropod prey species [apple rust mite, *Aculus schlechtendali* (Nalepa) or western flower thrips, *Frankliniella occidentalis* (Pergande)], these prey do not appear to be favored items for *C. verbasci* (Bartlett 1996). When these replications were dropped from the calculations, survival in these treatments was still high (80–95%).

This study provides several indications for management of *C. verbasci* under Washington conditions that were previously lacking. Applications made before bloom may be effective both in terms of nymphal control and fruit damage prevention, but often the hatch of *C. verbasci* nymphs is not sufficiently progressed to make an adequate assessment of the population, and thus the need for control measures. Applications made during bloom are effective in fruit damage prevention, and allow time for accurate population assessment, although they carry with them the risk of toxicity to or repellency of pollinators. Delaying the application until after bloom will only prevent some fraction of the potential damage, thus reducing the economic benefit.

Although this study was conducted for only 2 yr on a single cultivar, we feel the results apply reasonably

well to central Washington conditions. Insecticide timing tests conducted from 1991 to 1995 (Reding 2000) support the efficacy of prebloom or bloom timing against *C. verbasci*, and the inability of later timings to prevent damage. In this region, the full bloom dates of the two major cultivars, Delicious and Golden Delicious, are only a few days apart, thus only minor adjustment are necessary to accurately time applications on Delicious. The economic injury levels on other cultivars, however, requires further study.

The problems associated with insecticide applications made during bloom form the impetus for seeking other management strategies. *C. verbasci* has no known natural enemies that are useful in commercial orchards (Beers et al. 1993). Even if natural enemies were discovered, the narrow time frame in which damage occurs would limit the potential for biological control of this direct pest. Mitigating the fruit damage potential while conserving *C. verbasci* as a predator for the rest of the season would be an ideal solution. Altering *C. verbasci*'s feeding habits in favor of zoophagy versus phytophagy by providing arthropod prey at the appropriate time is a strategy that addresses these two needs. Unfortunately, this study provides no evidence that *C. verbasci*'s feeding behavior can be successfully altered.

Managing *C. verbasci* populations in orchards will continue to be challenging, given the increasing restrictions on broad-spectrum pesticide use and the trend toward more selective programs. In some cases, even a single application of a broad-spectrum material may seriously compromise the success of the program. Integrated pest management tactics such as risk prediction with pheromone trapping (McBrien et al. 1994, Reding and Beers 1996c), more precise sampling, and damage threshold schemes (Thistlewood and McMullen 1989, Thistlewood et al. 1989, Reding and Beers 1996c) will help reduce insecticide applications

to noneconomic populations. Although mating disruption of *C. verbasci* appears to have promise (McBrien et al. 1997), this highly selective tactic has yet to be implemented on a commercial scale. Manipulation of herbaceous host plants in or near the orchard appears to have limited potential (Thistlewood 1986, Reding and Beers 1996c). Currently, sampling and the use of effective but nondisruptive materials as needed appear to be the most appropriate approach.

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