Visual Cues and Capture Mechanisms Associated with Traps for Plum Curculio (Coleoptera: Curculiondae)[1]

Tracy C. Leskey[2]

USDA-ARS Appalachian Fruit Research Station, 2217 Wiltshire Road,
Kearneysville, West Virginia 25430-2771 USA

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Abstract The plum curculio, *Conotrachelus nenuphar* (Herbst), is a serious pest of stone and pome fruit in eastern North America, but an effective trap-based approach for monitoring this pest has not yet been developed. Therefore, the effectiveness of visual cues provided by pyramid and branch-mimicking cylinder traps and capture mechanisms of standard and enhanced pyramid traps (black pyramid traps with white borders and two collection devices), screen traps, standard and enhanced branch-mimicking cylinder traps (capture mechanism located at the base of the trap), Lindgren funnel and Vernon beetle traps were evaluated in 2003-2004. Pyramid traps captured more adults than branch-mimicking cylinder traps, and the greatest captures were in black and green pyramid traps. Enhanced pyramid traps did not capture more plum curculios than standard black pyramid traps. Capture mechanisms of standard masonite pyramid and screen traps were the most effective with significantly greater captures than other trap types.

Key Words *Conotrachelus nenuphar*, plum curculio, weevil, trapping, monitoring, IPM

The plum curculio, *Conotrachelus nenuphar* (Herbst), is a serious pest of stone and pome fruit in eastern North America (Racette et al. 1992, Vincent et al. 1999), and there has been a great deal of effort toward development of a trap-based monitoring system (Tedders and Wood 1994, Mulder et al. 1997, Prokopy and Wright 1998, Prokopy et al. 2000, Piñero et al. 2001, Leskey and Prokopy 2002) for use against plum curculio in commercial orchards (Johnson et al. 2002, Prokopy et al. 2003, Leskey and Wright 2004a) as chemically-based pest management progresses toward narrow-spectrum, reduced-spray environments due to restrictions placed on broad-spectrum materials. The only proven approach to monitoring plum curculio in apples is that of inspecting developing apple fruit for evidence of fresh oviposition scars on fruit in trees. This technique has been enhanced by creating 'trap trees'. Apple trees are baited with synthetic volatile dispensers of plum curculio aggregation pheromone and benzaldehyde which result in an aggregation of oviposition injury in baited tree canopies (Prokopy et al. 2003, 2004).

However, the approach appears to have potential for apple orchards and not for peach orchards. Leskey and Wright (2004a) found that plum curculio were only attracted to traps baited with the aggregation pheromone and benzaldehyde in apples

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[2] Email: tleskey@afrs.ars.usda.gov

and not in peach. Also, oviposition scars made by plum curculio are more easily discernable from other forms of insect injury on apples than on stone fruit (Johnson et al. 2002, Leskey and Wright 2004a). Furthermore, as with a trap-based system, this approach also must reliably overcome competition from and/or obstruction by unbaited, attractive host trees (Leskey and Wright 2004b). Therefore, attempts to find a competitive, trap-based approach for plum curculio in these systems are warranted.

Development of monitoring systems for plum curculio has been based on the behavioral understanding that most adults overwinter outside of commercial orchards and immigrate into orchards at or near petal fall. Several trap types have been tested including: (1) the pyramid trap, believed to provide an attractive visual stimulus by mimicking a tree trunk (Tedders and Wood 1994, Mulder et al. 1997) and has been reported to capture more crawling than flying individuals (Prokopy and Wright 1998); (2) the Plexiglas™ panel trap covered with Tangletrap™ and attached to wooden posts, designed to capture flying adult plum curculios (Prokopy et al. 2000); (3) the screen trap, made of folded screen, wrapped around an orchard tree and designed to intercept crawling individuals on the tree trunk (Mulder et al. 1997), and; (4) the black cylinder trap, constructed of ABS (acrylonitritrile butadiene styrene) pipe, providing the visual stimulus of an upright vertical tree branch and designed to capture crawling adults in the orchard tree canopy (Leskey and Prokopy 2002).

In studies in which these traps and baits have been evaluated for their ability to be used as monitoring tools in West Virginia and Massachusetts, amount and timing of trap captures have failed to reflect amount or timing of oviposition injury observed in fruit trees (Prokopy et al. 2002, Prokopy et al. 2003, Leskey and Wright 2004a) and have, thus far, failed to serve as a reliable tool to determine need for and timing of insecticide application. However, aside from the fact that plum curculio captures decrease significantly after petal fall (Prokopy et al. 2002, Leskey and Wright 2004a) and synthetic olfactory baits deployed in association with traps seem to be outcompeted by natural host stimuli (Leskey and Wright 2004b), little is known regarding the relative strengths and weaknesses of particular trapping systems.

To identify these strengths and weaknesses, each component of the trapping system must be evaluated independently of the others. These components include: (1) attractiveness of synthetic baits; (2) visual cues provided by particular traps; (3) capture mechanism of particular trap styles, and; (4) deployment strategy, i.e., where and when the trap is installed. In 2003-2004, we designed a series of experiments to evaluate the following components: (1) visual stimuli associated with pyramid and cylinder traps, and (2) capture mechanisms of six different trap styles.

Materials and Methods

Visual cues, 2003. Standard-sized (1.22 m tall × 0.56 m base width) pyramid traps were constructed of black coroplast (corrugated polypropylene), of white coroplast painted with flat latex exterior green paint, and of clear acrylic to represent the following visual stimuli: standard black trunk mimic, foliage mimic, or no stimulus (clear acrylic), respectively. Standard-sized pyramid traps consisting of black coroplast trimmed in white tape along peripheral margins were purchased from IPM Technologies (Portland, OR) to represent an enhanced trunk mimic [by use of increasing contrast between black and white (Whalon and Coombs 2003)]. These same stimuli were applied to cylinder traps as well. Cylinder traps were constructed of ABS pipe (with the exception of the 'no stimulus' trap constructed from clear acrylic pipe), 25 cm tall, and painted with green or black flat latex exterior paint. The black cylinder trap representing an enhanced stimulus was fitted with a white coroplast trim to increase contrast. Three replicates of each trap type were deployed in a mixed fruit orchard with a resident plum curculio population. Within each replicate, trap location was randomly assigned. Pyramid traps were deployed on the ground between tree trunks [as proximity to host trees reduces pyramid trap effectiveness (Leskey and Wright 2004b)], and cylinder traps were deployed in the canopy on horizontal branches of plum trees. Traps were deployed on 17 April and baited with a combination of benzaldehyde with an average daily release of ~10 mg/day (determined gravimetrically and described in Leskey and Wright 2004a) and grandisoic acid (IPM Technologies, Portland, OR) with a reported release rate of ~0.6 mg/day (as reported by the manufacturer). Benzaldehyde dispensers were replaced weekly. On 5 May, all baits were removed to isolate the effects of visual stimuli in the absence of attractive olfactory stimuli and traps remained unbaited for the remainder of the experiment ending on 3 July 2003. Traps were checked weekly and the number of plum curculios captured was counted.

Visual cues, 2004. Standard-sized pyramid traps (Leskey and Wright 2004a) were constructed of white Sintra (partially extruded PVC) sheets (Laird Plastics, Pittsburgh, PA) and painted with flat latex exterior paint. Traps were painted in the following colors: black, black with 2.5 cm white border along trap edges, green, yellow, or white. Traps also were constructed of clear polycarbonate. These traps represented the following visual stimuli: standard black trunk mimic, enhanced trunk mimic (black with white border), foliar mimics (green and yellow), and no visual stimulus (white and clear polycarbonate). Spectral reflectances of black, green, yellow, and white flat exterior latex paint and of clear Plexiglas were determined using a StellarNet EPP 2000C fiberoptic spectrometer (StellarNet, Tampa FL) fitted with an IC2-UV/visible light integrating sphere, and spectral reflectance curves were generated using SpectraWiz (Fig. 1). Cylinder traps were constructed of PVC pipe (with the exception of the no stimulus trap constructed from clear polycarbonate pipe), 25 cm tall, and painted with black, black with four 1-cm white stripes spaced 3.5 cm apart, green, yellow, or white flat latex exterior paint. Pyramid and cylinder traps were either unbaited or baited with a combination of benzaldehyde dispensers (as described above) and grandisoic acid dispensers (ChemTica International, S.A., San Jose, Costa Rica) with a release rate (25 mg) of ~1 mg/day (as reported by the manufacturer). Four replicates of each trap type with or without bait were deployed in an unsprayed peach orchard. The orchard consisted of 7 rows with 18 trees per row (4.9 m between rows × 3.7 m between trees) of 'Loring' on Lovell rootstock planted in 1990. There was a large overwintering population of plum curculios within the orchard. The orchard was divided into four replicates of equal dimensions, and each trap type was deployed within a replicate. Pyramid traps were deployed on the ground between tree trunks, and cylinder traps were deployed in the canopy on horizontal branches of plum trees. Trap location was randomly assigned within each replicate. Traps were deployed on 12 April and checked weekly until 27 May.

Capture mechanism. In 2003, traps were deployed within a block of an unsprayed peach orchard as described above. Within each replicate, trap location was randomly assigned. All traps were baited with a combination of benzaldehyde and grandisoic acid dispensers identical to those used for Visual cues, 2003 experiment. Benzaldehyde dispensers were replaced weekly. Trap types included: (1) standard black pyramid traps constructed of masonite, placed between trees; (2) standard 25

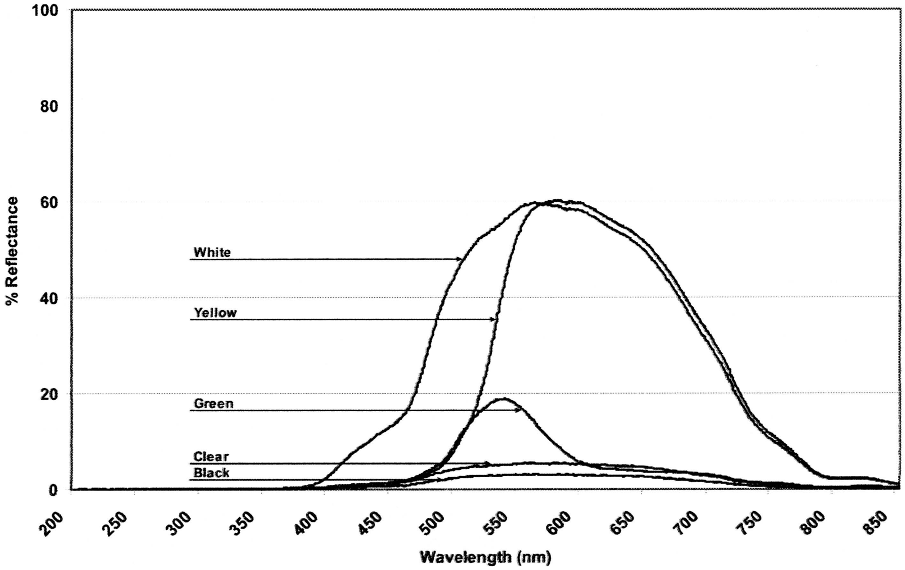

Fig. 1. Spectral reflectance curves obtained from flat exterior latex black, green, yellow, and white paint and from Plexiglas.

cm tall black branch-mimicking cylinder traps topped by boll weevil funnel trap tops and attached to horizontal limbs within tree canopies (Leskey and Prokopy 2002); (3) standard screen traps consisting of folded vinyl screen attached at the base of tree trunks (Leskey and Wright 2004a); (4) Intercept™ black pyramid traps constructed of coroplast, with white trim and with a boll weevil trap top located at the top of the trap and a second boll weevil collection device inserted 30 cm from the base (IPM Technologies, Portland, OR) placed between trees; (5) 1.22 m tall Lindgren funnel traps (Pherotech, Delta, B.C., Canada) hung from 1.32 m tall metal frames placed between trees; (6) 25 cm tall black cylinder traps of equal dimension, but with the boll weevil collection device attached to the bottom of the cylinder rather than the top (to exploit the visual stimulus, but decrease the distance traveled for capture), attached to horizontal limbs within tree canopies and; (7) Vernon beetle traps (Pherotech, Delta, B.C., Canada) deployed on the ground between trees (Fig. 2).

Traps were deployed on 17 April and checked weekly until 19 June. The number of plum curculios captured in each trap was recorded.

Statistical analysis. Nontransformed data, as the homogeneity-of-variances assumption was met in all cases, were analyzed using the GLM procedure (SAS Institute 2001) to construct analysis of variance (ANOVA) tables for cumulative trap captures recorded over the two trapping periods (2003) and for cumulative trap captures for each trap type recorded over the entire trapping period (2004). The model included the class variables trap color and bait in 2004. The dependent variable data on capture mechanism for 2003 were log (y + 1) transformed as homogeneity-of-variance assumptions were violated according to the Brown and Forsythe Test. Transformed data were analyzed using the GLM procedure (SAS Institute 2001) to

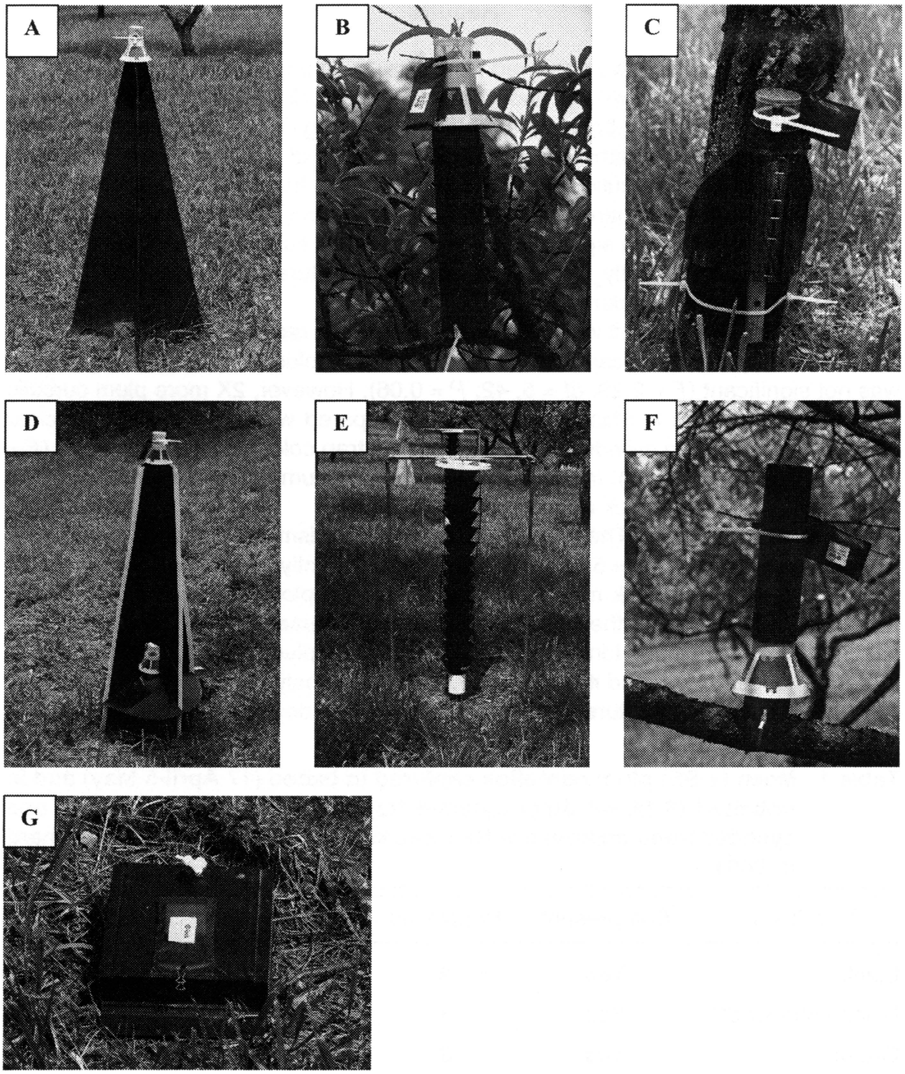

Fig. 2. Traps types used in the capture mechanism studies: (A) standard black masonite pyramid, (B) standard cylinder, (C) standard screen, (D) enhanced coroplast pyramid, (E) Lindgren funnel, (F) enhanced cylinder and (G) Vernon beetle.

construct analysis of variance (ANOVA) tables for cumulative trap captures recorded over the entire season. As the GLM indicated significant differences, multiple comparisons were calculated using Tukey's HSD ($P < 0.05$). The mean number of plum curculio adults captured in the upper and lower collection devices of the enhanced pyramid traps was compared using a paired t-test.

Results

Visual cues. In 2003, we observed no difference in captures among baited pyramid ($F = 0.66$; df = 3, 8; $P = 0.60$) and cylinder ($F = 0.18$; df = 3, 8; $P = 0.91$) traps with different visual cues. After baits were removed, there again was no significant difference among unbaited pyramid trap captures ($F = 1.05$; df = 3, 8; $P = 0.42$) although 5X to 6X more plum curculio adults were captured in black, enhanced black, and green pyramid traps compared with clear pyramid traps (Table 1). Among unbaited cylinder traps, there was a significant difference among captures ($F = 4.85$, df = 3, 8; $P = 0.03$) with significantly more plum curculios captured in black cylinder traps compared with clear cylinder traps (Table 1).

In 2004, the effect of bait was not significant and was removed from the models for pyramid and cylinder trap captures. The effect of trap color on pyramid trap captures was not significant ($F = 2.29$; df = 5, 42; $P = 0.06$). However, 2X more plum curculio adults were captured in black pyramid traps compared with white, yellow, or clear pyramid traps. Among cylinder traps, the effect of trap color was not significant ($F = 2.03$; df = 5, 42; $P = 0.09$). In this case, the greatest number of plum curculios was captured in enhanced black cylinder traps (Table 2).

Capture mechanism. The effect of trapping mechanism had a significant effect on trap captures ($F = 17.7$; df = 5, 18; $P < 0.0001$). Significantly more plum curculios were captured in standard black masonite pyramid traps deployed between trees and in screen traps attached to the base of tree trunks compared with standard and enhanced cylinder traps and Lindgren traps (Table 3). No plum curculios were captured in Vernon beetle traps, and it was removed from the analysis. The mean number of plum curculios (±SE) captured in the upper collection device of enhanced pyramid

Table 1. Mean (± SE) plum curculios captured in baited (17 April-5 May) and in unbaited (6 May-3 July) pyramid traps deployed between trees and cylinder traps deployed within tree canopies in a mixed fruit orchard in 2003

Trap color	Bait present	Replicates	Pyramid traps*	Cylinder traps
Black	Yes	3	7.0 ± 1.2a	3.0 ± 1.0a
Black enhanced**	Yes	3	11.0 ± 2.0a	3.3 ± 0.9a
Green	Yes	3	18.0 ± 11.0a	4.0 ± 1.5a
Clear	Yes	3	9.0 ± 3.6a	2.7 ± 1.8a
Black	No	3	22.3 ± 10.2a	11.3 ± 2.0a
Black enhanced†	No	3	19.7 ± 8.0a	10.0 ± 2.1ab
Green	No	3	21.7 ± 11.3a	6.7 ± 1.8ab
Clear	No	3	3.7 ± 2.0a	2.7 ± 0.9b

* Means in the same column followed by a different letter are significantly different according to one-way ANOVA followed by Tukey's HSD ($P < 0.05$).

** Indicates that a 2.5-cm white border on trap edges.

† Indicates presence of four 1-cm white stripes on trap cylinder.

Table 2. Mean (± SE) plum curculios captured in pyramid traps deployed between trees and cylinder traps deployed within tree canopies in an unmanaged peach orchard from 12 April-27 May, 2004

Trap color	Replicates	Pyramid traps*	Cylinder traps
Black	8	64.8 ± 17.6	15.9 ± 3.4
Green	8	54.2 ± 9.6	12.6 ± 4.2
Enhanced	8	41.5 ± 8.0	24.5 ± 4.1
White	8	32.0 ± 4.9	12.8 ± 4.3
Yellow	8	30.5 ± 7.2	8.6 ± 1.1
Clear	8	27.7 ± 6.3	17.3 ± 4.7

* Means in the same column were not significantly different according to one-way ANOVA (*P* < 0.05).

Table 3. Mean (± SE) plum curculios captured in traps deployed on the ground between trees, at the base of tree trunks, or within tree canopies in an unmanaged peach orchard from 17 April-19 June, 2003

Trap type	Deployment location	Replicates	Mean ± SE*
Standard pyramid	Between trees	4	115.0 ± 36.1a
Standard screen	Tree trunk	4	113.8 ± 11.9a
Enhanced pyramid**	Between trees	4	58.3 ± 11.8ab
Standard cylinder	Tree canopy	4	21.8 ± 9.2bc
Enhanced cylinder**	Tree canopy	4	11.8 ± 3.1c
Lindgren funnel	Between trees	4	5.3 ± 1.6c

* Means in the same column followed by a different letter are significantly different according to one-way ANOVA folowed by Tukey's HSD (*P* < 0.05).

** Indicates a base collection device incorporated into standard trap design.

traps (50.75 ± 10.93) was significantly greater ($t = 4.18$, df = 3, $P = 0.025$) than the number captured in the lower collection device (7.50 ± 2.02).

Discussion

Combined results revealed that pyramid traps captured more plum curculios than cylinder traps. Furthermore, black and green pyramid traps appeared to provide the most attractive visual stimuli, as more plum curculios were captured in traps of these colors (Tables 1, 2). However, our results were not significant and indicate that plum curculio may be somewhat of a visual generalist (Prokopy and Owens 1978) in terms of response to color (Leskey and Prokopy 2002). The plum curculio feeds on plants in two families, Rosaceae and Ericaceae, and thus is a polyphagous herbivore that may respond to more generalized visual cues associated with host shrubs and trees.

Instead of a preference for specific colors, at least at a distance, plum curculio may approach darkly colored pyramid traps based on their appearance as dark silhouette similar in shape to that of a tree trunk and in visual contrast with the surrounding background (Prokopy and Owens 1983). This is believed to be the case for the pecan weevil, *Curculio caryae* (Horn), as higher numbers of weevils were captured in darkly-colored pyramid traps (Tedders et al. 1996). Similarly, captures of pales weevil, *Hylobius pales* (Herbst), and the pitch-eating weevil, *Pachylobius picivorus* (Germar), were higher in black and brown pyramid traps than in white or yellow pyramid traps in mixed pine-hardwood environments (Mizell and Tedders 1999).

We did not, however, observe an increase in trap captures in enhanced pyramid traps compared with standard black pyramid traps in three separate trials (Tables 1 to 3). Although these traps are intended to increase contrast between the trap and the surrounding background by adding a white border, we did not observe this trend in the border row or within orchards. However, Whalon and Coombs (2003) concluded that this trap design is most effective in the woods, so perhaps, in or near orchards (as tested here) competing visual stimuli of host trees themselves negate any sort of contrasting effect.

Among trap types with different capture mechanisms, standard masonite pyramid and screen traps were significantly better than other trap types. These results likely reflect the fact that these traps exploit major points of entry of plum curculios into host fruit trees prior to arrival in the canopy. Once in the canopy, plum curculios can forage for food and oviposition resources found throughout the canopy, generally by traversing the upper and lower surfaces of limbs by crawling (Leskey and Prokopy 2002), and easily bypass a trap located at a particular point within the canopy as was the case with cylinder traps. Captures in these traps were significantly lower than those in standard masonite pyramid or screen traps. Conversely, standard masonite pyramid traps positioned between trees and screen traps attached to the base of tree trunks have less chance than those in the tree canopy of being avoided by a plum curculio once it has arrived. Each trap type exploits the natural tendency of plum curculio to crawl up surfaces, and uses capture mechanisms that guide and funnel adults present over a large surface area upward into a single collection point. Lindgren funnel traps, used primarily for flying scolytids in forested environments (Miller et al. 2003, Lindgren and Miller 2002), also have successfully captured curculionid species (Cook 2002). Vernon beetle type-traps (ramp traps) have been used to monitor crawling curculionids in subtropical and tropical habitats including the West Indian sugarcane weevil, *Metamasius hemipterus* (Oliver) (Oehlschlager et al. 2002). Both trap types failed to provide effective capture mechanisms for plum curculios.

Enhanced pyramid traps used in the capture mechanism studies were equipped with two collection devices. The upper collection device is intended to capture adults that fly directly to the pyramid trap and then proceed to the top collection device, whereas the lower collection device located at the base of the trap is designed to capture adults that crawl directly to traps. We found that significantly more adults, over 6X more, were captured in the upper collection device than the lower collection device. Our results indicate that more plum curculios were flying rather than crawling to pyramid traps. This finding is in direct contrast with those previously described in which plum curculios arrived at pyramid traps principally by crawling rather than by flight (Prokopy and Wright 1998, Prokopy et al. 1999). However, these results were based on populations in Massachusetts where daily temperatures are lower than those experienced in the mid-Atlantic (Prokopy and Wright 1998) and on observations of plum curculio movement toward a pyramid trap placed next to a tree trunk (Prokopy et al. 1999). Plum curculios will fly at temperatures above 20°C, but crawl at temperatures below 20°C (Prokopy et al. 1999). Our experiment was conducted in West Virginia where the average daytime temperature throughout the trapping period was 22°C (Leskey, unpubl. data) and our pyramid traps were located between trees, rather than next to host tree trunks. Thus, it is not surprising that most of the plum curculios captured likely flew rather than crawled to pyramid traps. Direct observations of plum curculio movement toward pyramid traps may elucidate differences in behavior between populations found in New England and the mid-Atlantic and further explain the variation in results reported here from those of previous studies.

In conclusion, visual cues associated with pyramid traps are not very specific in terms of color, but likely create a silhouette that is in contrast with the surrounding visual background that is perceivable to a plum curculio at a distance. Standard black masonite pyramid traps positioned between trees and screen traps attached to the base of tree trunks were the most effective traps in terms of total captures. Capture mechanisms of these two trap types exploited major points of entry into host fruit trees and the natural tendency of plum curculio to crawl up. However, for an effective monitoring system to be developed for plum curculio, it is likely that synthetic baits that are more competitive with odors of developing fruit also will be necessary (Leskey and Wright 2004b, Leskey et al. 2005), similar to what has been developed for other economically important weevil species including *Rhyncophorus palmarum* (L.) (Oehlschlager et al. 1993) and *M. hemipterus* (Giblin-Davis et al. 1996).

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