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Plant architecture, prey distribution and predator release strategy interact to affect foraging efficiency of the predatory mite *Phytoseiulus persimilis* (Acari: Phytoseiidae) on cucumber

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ABSTRACT

We examined the ability of adult predatory mites, *Phytoseiulus persimilis* Athias-Henriot, to search for and consume twospotted spider mites, *Tetranychus urticae* Koch, on cucumber plants that were manipulated to exhibit different architectures and prey distributions among leaves. Plants were manipulated to have either six small leaves or two large leaves; however, both plants types had similar total surface areas. Prey were located either all on one basal leaf or evenly distributed among all leaves. In one experiment, we measured prey-finding time when predators were released at the top or bottom of plants. Regardless of release point, *P. persimilis* found prey more rapidly when prey were on all leaves. On such plants, *P. persimilis* found prey patches first on leaves closest to the release point. Predator release point only affected prey-finding time when prey were located on the basal leaf of 6-leafed plants; it was longer when predators were released at the top. In a second experiment, we measured consumption and oviposition rates of predatory mites. *Phytoseiulus persimilis* consumed more prey on six-leafed than two-leaved plants regardless of prey distribution. Prey consumption and predator oviposition was highest on prey patches nearest the release point. We conclude that releasing *P. persimilis* over the plant canopy may not be effective during early stages of spider mite infestations on plants with a complex architecture. Both prey distribution and plant architecture should be considered when making decisions concerning release of *P. persimilis* in augmentative biological control programs.

1. Introduction

Biological control programs require practitioners to have a broad knowledge of biology because many variables may affect the efficacy of a biological control agent. One such variable is the physical structure, or architecture, of the crop plant on which arthropod pests are feeding. Plant architecture is the spatial arrangement and dimensions of leaves, stems and branches at a point in time (Cloyd and Sadof, 2000). Architectural traits that can affect natural enemies include leaf and plant connectedness (Andow and Prokrym, 1990; Skirvin and Fenlon, 2003), plant size (Thorpe, 1985; Cloyd and Sadof, 2000), leaf number (Stamp and Browers, 1993; Cloyd and Sadof, 2000) and plant surface area (Burbutis and Koepke, 1981; Kanour and Burbutis, 1984; Maini and Burgio, 1990). The architecture of a plant may either positively or negatively affect the foraging efficiency of predators and parasitoids (Barbosa and Letourneau, 1988; Dicke and Sabelis, 1989; Kareiva and Sahakian, 1990; Grevstad and Klepetka, 1992; Peitsch et al., 1992; Coll and Bottrell, 1994). Plant architecture can affect natural enemies directly by mediating their host plant choice (Romero and Vasconcellos-Neto, 2005), altering their movement and survival on a plant (Obrycki and Tauber, 1984; Grevstad and Klepetka, 1992; Clark and Messina, 1998) or otherwise modifying their behavior (Kareiva and Sahakian, 1990; Legrand and Barbosa, 2003). Plant architecture can also influence natural enemies indirectly, for instance by influencing herbivore spatial refuges (Freese, 1995), distribution (Clark and Messina, 1998) and abundance (Lawton, 1983). The spatial distribution of prey may interact with plant architecture as well (Ryoo, 1996; Stavrinides and Skirvin, 2003; Gontijo, 2008).

We have been studying the effects of plant architecture and prey distribution on foraging by the predatory mite *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) on cucumber plants (*Cucumis sativus* L.). *Phytoseiulus persimilis* is a small (<0.5 mm) predator often used for biological control of the twospotted spider mite (*Tetranychus urticae* Koch, Acari: Tetranychidae) in greenhouses and conservatories. In commercial greenhouse operations that use biological control, *P. persimilis* is commonly released in one of two ways: by placing open shipping containers around

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plants in a greenhouse, which releases them near the base of plants; or by dispersing them over the canopy, which releases them closer to the top of plants. Because this predator is minute and must walk along a plant surface to reach its prey, we expected that differences in plant architecture would have a significant impact on its foraging efficiency depending on where it is released. We previously observed that on cucumber plants with different architectures under different prey distributions, *P. persimilis* allocated its time differently among moving, resting, and feeding behaviors and among the plant parts on which it searches (Gontijo, 2008). However, we had not assessed whether differences in time allocation affected foraging efficiency, which is a critical component of biological control. One way of assessing the effect of plant architecture on predator foraging efficiency of predators is to measure the time it takes a predator to find and consume their prey. Prey-finding time can be defined as the amount of time it takes for the predator to encounter its first prey after being released, and prey consumption rate is the number of prey consumed during a defined time period. Predators with rapid prey-finding time and high prey consumption rate are expected to be more effective biological control agents, while the opposite holds for predators with longer prey-finding time and low prey consumption rates. Our specific objectives were to quantify the prey-finding time and consumption and oviposition rate of *P. persimilis* when foraging on cucumber plants with different numbers and size of leaves and different prey distributions, and to assess the possible interaction between plant architecture and prey distribution.

2. Materials and methods

2.1. Plants and arthropods

We obtained seeds of the cucumber cultivar 'Cumlaude' from Hydrogarden Company, Inc. (Colorado Springs, CO, USA). Seeds were sown individually into 6.25-cm^2 square pots containing FAFARD® Super-Fine Germinating Mix (Conrad Fafard, Inc., Agawam, MA, USA). Seedlings were later transplanted into pots containing FAFARD® Growing Mix. To avoid competition for light, seedlings were spaced (stem center to stem center) 30 cm apart on a greenhouse bench when the first true leaf was completely expanded. Seedlings were watered daily and a 20–10–20 N–P–K fertilizer (Scotts Peters General Fertilizer, Scotts Company, Marysville, OH, USA) was applied through the irrigation system by dissolving 1048 g of fertilizer into a 75.7 L (20-gal) container of water and delivering it through a Hozon siphon mixer at a ratio of 1:16 (fertilizer solution:tap water). Thereafter, plants were fertilized during the watering process as needed.

To produce plants with the same total surface area but different architectures (i.e., different leaf size and number), we took cucumber seedlings sown at the same time and varied transplanting dates and the size of pots into which they were transplanted. Seedlings that were intended to be 2-leafed plants were transplanted into 15-cm diameter pots when four leaves were completely expanded (fifth leaf starting to appear), whereas seedlings that were intended to be 6-leafed plants were transplanted into 10-cm diameter pots when six leaves were completely expanded (seventh leaf starting to appear). Four days after transplanting seedlings intended to have six leaves, we measured the surface areas of all plants and trimmed leaves from those designated as 2-leafed to achieve approximately the same total plant surface area on all plants; we trimmed a newly emerged seventh leaf on the six-leafed plants to make sure that all plants received the same treatment. This procedure resulted in two-leaved and six-leaved plants with similar total surface areas; 551.91 ± 9.90 cm^2 for two-leaved plants and 554.80 ± 10.05 cm^2 for six-leafed plants (Gontijo, 2008). Although the total plant surface area was the same, the surface areas for component plant parts were significantly different between the two plant architectures (Gontijo, 2008); two-leafed plants had longer stems and petioles, and individual leaves had a larger surface area (240.60 ± 4.11 cm^2 each) compared to individual leaves of six-leafed plants (82.98 ± 1.87 cm^2 each). Two-leafed plants also had longer internodes, thicker stems, and were taller than six-leafed plants (Fig. 1).

Fig. 1. Illustration of two cucumber plant architectures used in the experiments. Two-leafed plant on left and six-leafed plant on right.

Twospotted spider mites were obtained from colonies maintained in greenhouses at Kansas State University, Manhattan, KS, under a photoperiod of 16:8 L:D, relative humidity of 60 ± 10% and temperature of 25 ± 2 °C. Twospotted spider mites were reared on lima bean (*Phaseolus lunatus*) plants growing inside 0.3 × 0.6 m plastic flats. New flats of lima bean plants were added every other day. *Phytoseiulus persimilis* were obtained from Koppert Inc. (Romulus, MI) and maintained on lima bean plants infested with *T. urticae* under similar environmental conditions. Voucher specimens of *P. persimilis* used in these experiments were deposited in the Kansas State University Museum of Entomological and Prairie Arthropod Research as Lot No. 200. All experiments were conducted in a greenhouse under similar environmental conditions as the ones under which predators and prey were maintained.

2.2. Prey-finding

This experiment was set up as a completely randomized design. The structure was a 2 × 2 factorial, with two plant architectures and two prey distributions resulting in four treatment combinations. The plant architectures were two-leafed (plants with two large leaves) and six-leafed (plants with six small leaves) as described above. Twospotted spider mites were distributed either on a single basal leaf or in equal numbers on every leaf, depending on the treatment. Leaves designated to receive prey were infested by placing a 1-cm^2 bean-leaf disk containing 10 adult female *T. urticae* on the abaxial surface of the leaf. The spider mite-infested disk was kept on the designated leaf for 24 h, which allowed spider mite females to migrate off the disk onto the cucumber plant. The spider mites stayed on the leaves on which they were released, resulting in a mixture of adult spider mites, webbing and spider mite eggs on infested leaves at the time of predator release. The spider mites formed 1–3 small patches between leaf veins, occupying 1–3 cm^2. On six-leafed plants, prey patches covered ~3–4% of the area of an individual leaf, and on two-leafed plants a little more than 1% of the area of a leaf.

After prey were established as described above, a single adult female *P. persimilis* that had been starved for 2 h was placed either at the base of the stem (1–2 cm above the media) or at the top of the main stem (1–2 cm above the insertion of the uppermost leaf)