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Relative Effects of Plant (*Solenostemon scutellarioides*) Size and Variegation on the Searching Efficiency and Life History Characteristics of *Cryptolaemus montrouzieri* (COLEOPTERA: COCCINELLIDAE).

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RELATIVE EFFECTS OF PLANT (*Solenostemon scutellarioides*) SIZE AND VARIEGATION ON THE SEARCHING EFFICIENCY AND LIFE HISTORY CHARACTERISTICS OF *Cryptolaemus montrouzieri* (COLEOPTERA: COCCINELLIDAE)

A Thesis
Submitted to the Faculty
of
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Juliana Ferreira Garcia

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TO MY PARENTS

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ABSTRACT

Garcia, Juliana Ferreira. Ph.D., Purdue University, December 1998. Relative Effects of Plant (*Solenostemon scutellarioides*) Size and Variegation on the Searching Efficiency and Life History Characteristics of *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae). Major Professor: Robert J. O'Neil.

Attack rates, search strategy and search behavior were measured for third instar *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) attacking third instar citrus mealybug, *Planococcus citri* Risso (Homoptera: Pseudococcidae), on green and yellow-variegated *Solenostemon scutellarioides* (L.) Codd (= *Coleus blumei* L.) plants of different sizes. Selected life history characteristics of *C. montrouzieri* from third instar to adulthood fed different amounts of *P. citri* as prey were also examined. Treatments included plants of different leaf color (green and yellow-variegated), morphology (such as, height, leaf area and leaf number) and numbers of mealybugs per plant (1, 8 and 16 mealybugs per plant). Five experiments were conducted. In the first experiment, "small" (ca. 2-week old) green and yellow plants of similar plant height, leaf number, and leaf area were used. The second and third experiments, consisted of "large" green and "large" yellow plants, with leaf area of 8-10 times that of the plants used in experiment 1. The fourth experiment used green and yellow plants similar in plant height and leaf area, but differing in leaf number. The fifth experiment used plants of similar leaf numbers, but different plant heights and leaf area. Attack rates were measured for a 24h period and searching behaviors were observed for 4h. On average predators attacked between 1 to 4 mealybugs depending on the number of mealybugs and plant size. There was no effect of plant color on attack rates and searching behavior. Attack rates were positively related to prey density, whereas the area searched by predators was inversely related to prey density. Analyses suggested that leaf area was the plant characteristic that most affected attack rates. Behavioral observations indicated that most attacks occurred on the same or nearby leaf were predators were initially placed. Predators that did not attack prey spent more time stationary. Predators changed their behavior after encountering and feeding on prey, to an area-restricted search movement. Predators fed few prey had a decrease in body weight and survival. The implications for these studies suggests that *C. montrouzieri* experiencing low attack rates under low prey densities, which if common in field situations, might result in a decline of predators survival and reproduction.

CHAPTER ONE

INTRODUCTION AND REVIEW OF LITERATURE

Introduction

Procuring food is important to all insects. For insect predators, active searching, stalking and trapping are the main strategies used to find and capture prey. Visual, tactile, chemical and mechanical stimuli are used to locate them. Diverse mechanisms and behavior patterns are also involved in capturing prey, such as rapid flying or running, modified legs for grasping, mouthparts modified for piercing the exoskeleton of arthropod prey, etc. In many cases, digestive fluids are injected into the prey, rendering it immobile and flaccid after the body fluids are extracted (Evans 1984). Insect predators capture prey in the air (e.g., dragonflies), on the ground (e.g., ground beetles), or on vegetation (e.g., lady beetles) (Atkins 1980; Evans 1984).

Many factors can influence the searching efficiency of natural enemies, including host density (Hassell 1982), host size (Luck et al. 1982) and age class (Murdoch et al. 1987), natural enemy reproductive state (Waage 1990) and age (Vet 1983), the presence of other natural enemies (Hassell and Varley 1969), abiotic conditions such as temperature (Mack et al. 1981; Wollkind et al. 1988), and biotic conditions such as plant size (O'Neil 1988a) and architecture (Kareiva and Odell 1987; Kareiva and Sahakian. 1990; Hare et al. 1990; Grevstad and Klepetka. 1992). Host density and spatial dispersion are considered some of the most influential aspects of host-natural enemy dynamics (Hassell 1978, Price 1984, Price 1991; Edwards et al. 1980). Responses of natural enemies to host density and spatial dispersion are varied and include changes in attack rates (Murdoch 1977), search behaviors (Waage 1983), and aggregative responses (Reeve and Murdoch 1985). Search strategies may not be constant over all prey levels or time. Natural enemies may modify their search behavior after gaining information on prey availability, spatial dispersion, potential rates of energetic returns, or risks (Stephens and Krebs 1986; Hassel and Southwood 1978; Wiedenmann and O'Neil 1992).

An organism's life history is its lifetime pattern of growth, differentiation, storage of nutrients and reproduction (Begon et al. 1990). Principle life history traits for animals include fecundity, size of young, age at first reproduction, interactions between adult mortality and reproduction and variation in these traits among an individual's progeny (Denno and Dingle 1981). Life history strategies may include patterns of fecundity, mortality and parental care. The environment and interactions with other organisms affect manifestations of life history strategies (May 1976). Life history strategies reflect the genotype, the environment and the interaction between them.

Changes in life history characteristics such as reproductive rates or survival schedules usually have an effect on the organism's fitness. According to Calow (1979), attempts to increase fitness by modifying one trait may conflict with other traits that tend to decrease fitness. Tradeoffs between traits are commonly observed, particularly when resources become limited or the environment degrades (Tallamy and Denno 1981; Ricklefs 1990; Herms and Mattson 1992).

Natural enemies use captured host biomass to fuel their own population growth. The rate of population growth and the population size attained depend significantly on the life history strategy employed by the natural enemy. For natural enemies, the ability to establish populations in a given environment and control pests depends on how effectively they find prey and how they apportion captured prey energy among competing physiological demands (Gutierrez et al. 1990, Legaspi and O'Neil 1993). Plants can affect natural enemy performance at every step in this process by influencing the searching success of natural enemies, the quality of host and prey resources and consequently, the natural enemy's life history traits.

Tritrophic interactions between plants, herbivores, and predators, occur when there is a significant interaction between attacks by natural enemies on prey, and the plant's physical or chemical characteristics. Plant characteristics may effect the third trophic level directly, by providing nutrients, or indirectly, by modifying prey quality and quantity (Vinson 1987; Boethel and Eikenbary 1986; Price et al.1980). For example, plant morphology may influence how predatory insects pursue prey over the surface that they search (Andow and Prokrym 1990; Carter et al. 1984; Kauffman and Kennedy 1989; Boethel and Eikenbary 1986.). Differences in plant size may affect the prey distribution and density on the host plant, affecting the natural enemy's searching behavior and efficiency (Evans 1976; Hassell 1966; Wallin and Ekbom 1994; Chiverton 1988; Hassell and May 1974, 1986). O'Neil (1988b) showed that search strategy of the predator *Podisus maculiventris* Say was related to changes in plant size. As plants grew in size (measured as leaf area), prey density (number/unit leaf area) declined. Predators responded to this plant-induced change in density by increasing the plant area they searched as prey density declined.

Plant variegation is one factor which can induce changes in plant growth rates and morphology and affect herbivores (Sadof and Raupp 1991, 1992; Yang and Sadof 1995). For example, Yang and Sadof (1995) observed that yellow-variegated *Solenostemon scutellarioides* was more susceptible to attack by *Planococcus citri* Risso (Homoptera: Pseudococcidae), compared with green Coleus. The intrinsic rate of increase and successful establishment of *P. citri* was higher on yellow-variegated plants when compared to green plants.

Plant growth and variegation may differentially affect parasitoids and predators both quantitatively and qualitatively. For example, *P. citri* show difference in size when fed on variegated and non-variegated plants. Since host size influences whether parasitoids choose to oviposit female or male eggs (larger hosts are typically chosen for oviposition of female eggs), there can be a shift in parasitoid sex ratio dependent upon plant variegation (Yang and Sadof 1997). In contrast, since host-size effects on the predator's sex ratio are not common, it is not expected that hosts reared on variegated plants will affect a predator's sex ratio. Further, since parasitoids are highly mobile and often use chemical cues to find hosts, plant size (within limits) most likely will not affect parasitoid-host encounter rates. However, because predators commonly encounter hosts by walking over plants leaf surfaces, it is expected that plant size will have a significant effect on predator's searching success.

Knowledge of how plant size and variegation affect the ability of a predator to find prey and how such traits affect the life history characteristics of the predator can be utilized to predict its potential effectiveness in biological control programs. To determine how plant size and variegation affect tritrophic interactions, I will use the predatory beetle *Cryptolaemus montrouzieri*[1] attacking *P. citri* on Coleus as a model system. Specifically, I will measure the attack rate, searching strategy and life history characteristics of *C. montrouzieri* attacking *P. citri*, at different densities, on variegated and non-variegated Coleus plants of different sizes.

Literature Review of *Cryptolaemus montrouzieri*

Cryptolaemus montrouzieri Mulsant, is native to eastern Australia, and has been reported to occur also in Fiji, Ceylon and South China (Clausen 1978). This predaceous coccinellid was among the first species to be used to control an agricultural insect pest, and as such, it has assumed great importance in the biological control literature (Booth and Pope 1986). Since its first introduction in California in 1891 from Australia by Albert Koebele, *C. montrouzieri* has been the one of the most-widely distributed of all natural enemies of mealybugs (Clausen 1978). *Cryptolaemus montrouzieri* has been imported into more than 40 countries, primarily in warm temperate or tropical regions (Clausen 1978).

Both adults and larvae have a wide host range, feeding extensively on all stages of mealybugs (Clausen 1978). Adults are similar in shape and size (5 mm long) to other coccinellids. Adults are mainly black with a brown head, wing tips and abdomen (Cooper 1985). Adults show sexual dimorphism, with the males having the ventral part of the last abdominal segment deformed and the first pair of femora yellow. Females are not so deformed and have dark-colored femora (Fisher 1963). Adults mate one to two days following emergence, and begin ovipositing six days later. Eggs are placed in or near host egg masses. (Clausen 1978). Depending on how they have fed as larvae, females will lay up to 400 small yellow eggs over a two month period (Cooper 1985). Eggs hatch in 4 to 8 days depending on temperature (Clausen 1978). Young larvae burrow into clumps of mealybugs eggs to feed. As larvae grow, they emerge to feed on mealybug nymphs and become more active and conspicuous. While similar morphologically to other coccinellids, *C. montrouzieri* larvae are covered by long white waxy threads. Larvae require ca. 12-20 days to complete development through four instars. The entire egg to egg life cycle may be completed in slightly less than a month (Clausen 1978; Cooper 1985). Larvae settle in crevices, curled-up leaves or other hidden locations to pupate. Adults then emerge in about 5-11 days (Fisher 1963).

The optimal temperature for *C. montrouzieri* development is about 20-25°C (Cooper 1985). Development is arrested at temperatures below 10°C; adults and larvae do not survive sub-freezing temperatures. Outside of greenhouses, there are usually no more than 4 generations per year (Hussey and Scopes 1985). There is some evidence that hot dry climates are more tolerable than hot humid climates (Clausen 1978).

According to Hussey and Scopes (1985), at 21°C, larvae may consume over 250 second-third instar mealybugs during its life cycle. Adults are most active under sunny conditions. Adult searching behavior is unproductive above 33°C and they become torpid below 16°C (Hussey and Scopes 1985). Larvae present similar behaviors over this temperature range, with peak activity at around 28°C (Hussey and Scopes 1985). Adult *C. montrouzieri* detect their prey using visual and chemical cues. Fourth instar are not able to perceive prey except by physical contact (Heidari and Copland 1992). This may be caused by the presence of the waxy coat that covers *C. montrouzieri* larvae.

The presence of honeydew, honey or mealybugs significantly increase egg production and viability, and reduce the pre-ovipositional period (Heidari and Copland 1993). Hussey and Scopes (1985) and Cooper (1985), state that the total number of eggs produced by this coccinellid is strongly influenced by the adult and larval diet.

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[1] Voucher specimens of both predator and prey insects were deposited in the Robert W. Meyer Insect Collection at the Department of Entomology at Purdue University.

Aside from the apparent effective "classical" biological control of citrus mealybug in Western Australia, most successful efforts in using *C. montrouzieri* have been through periodic releases, especially in California and Spain (Bartlett 1978). At one point in time (1963), insectaries in the USA were producing 30 million beetles per year, primarily for release in citrus, which resulted in a successful control of citrus mealybug (Fisher 1963). *Cryptolaemus montrouzieri* has been used to control pests in other crops such as coffee, tea, grapes, figs, pomegranates and apples (Cooper 1985). *Cryptolaemus montrouzieri* has also been shown to exert some control over other scale insects such as Californian red scale in Cyprus (Cooper 1985). Neither the functional response nor the searching efficiency of *C. montrouzieri* attacking *P. citri* have been measured.

Literature Review of *Planococcus citri*

Planococcus citri Risso is a small, soft-bodied insect with sucking mouthparts. Female are wingless, ovoid and flattened, and reach a length of 1.6-3.5 mm. Males are short-lived, small, winged insects (Hussey and Scopes 1985; Cox 1981). Mating occurs soon after the female's last molt and a male can mate with as many as 20 females (James 1937). About two weeks after fertilization, females produce 300-500 amber-colored eggs, which accumulate over a month into a posterior ovisac (Bartlett 1978). Eggs are small (ca. 0.3 mm long) and are laid within a protective mass of waxy threads. Eggs hatch into a dispersive "crawler" stage, that searches for feeding sites on which it will settle. The third instar males spin an elongate white waxy cocoon, undergo metamorphosis, and after the third molt, become a small, winged insect. Immature females have three molts and are mobile throughout their lives (Hussey and Scopes 1985). Egg to adult development takes about 30 days at 30°C and ca. 90 days at 18°C (Hussey and Scopes 1985). Annually, 2-3 generations can be observed outdoors in California and 5-6 generations in greenhouses (Bartlett 1978).

The citrus mealybug is probably the most cosmopolitan and generally destructive species of the pseudococcids (Bartlett 1978). While believed native to China (Bartlett 1978), *P. citri* is commonly encountered outdoors in all warm climates and in greenhouses and sheltered places in all temperate areas (Bartlett 1978). Citrus mealybug is an extremely polyphagous species found on more than 25 families of host plants, including grapes, coffee, mangos, bananas, beans, pomegranates and tobacco (Bartlett 1978; McKenzie 1967). *Planococcus citri* attacks mainly aerial parts with a preference for tender stems, flower buds and young fruit clusters. Mealybug feeding reduces plant vigor and causes a yellowing of the foliage, which sometimes leads to distortion and frequently defoliation of the host plant. While feeding, mealybugs produce large quantities of honeydew, and secondary damage can be caused by the growth of sooty molds (Hussey and Scopes 1985).

When fed green versus variegated Coleus, *P. citri* showed differences in their life history characteristics (Yang 1995; Yang and Sadof 1995). On variegated plants, citrus mealybug had much higher colonization rates and lower mortality. In contrast, the percentage of females was slightly higher on green plants than on variegated plants.

Literature Review of *Solenostemon scutellarioides*

Solenostemon scutellarioides (L.) Codd (= *Coleus blumei* L.) belongs to the mint family, Lamiaceae, which contains more than 300 species (Toogood 1971; Codd 1975). Although native to tropical or subtropical areas (Bailey 1976), it is easily cultivated in North American gardens (Seymour 1970). *S. scutellarioides*, commonly known as Coleus, is a popular bedding plant throughout the world due to its brightly colored and variegated foliage. Voigt (1982) listed Coleus as the tenth most important ornamental bedding plant in the United States. Coleus are distinguished by richly colored, toothed, often deeply cut leaves in shades of red, yellow and purple. Plants may reach 1 m when growing in strong indirect light, and their leaves may measure 0.15 m. across. Plants receiving full sun are smaller, with less brilliantly colored foliage; leaves tend to wilt on hot days (Toogood 1971).

Commercialization of more than 200 commercial varieties of ornamental Coleus plants has been facilitated by their ability to produce large number of seeds and an impressive range of stable color variation (Boye and Ripe 1938). Plants can be propagated either sexually or asexually. For the seeds to germinate, light is required. Humid conditions and air temperature between 21°C and 27°C improve rooting (Bubel 1989; Lebowitz 1985).

Foliar color variegation in Coleus is caused by differences in the distribution and levels of chlorophyll and/or anthocyanins (Marcotrigiano et al. 1990). Boye (1941) suggested that the control of Coleus variegation is nuclear and can be inherited. Yang and Sadof (1995) showed that variegation in Coleus can reduce photosynthesis and plant growth. Green leafed plants had a higher photosynthetic rate than those of red- or yellow-variegated plants, and yellow-variegated plants produced more new leaves per unit of biomass than either red-variegated or green plants (Yang and Sadof 1995). The general morphology of yellow-variegated Coleus is quite different from green Coleus. Yellow-variegated plants appear more dense than same-aged green plants, being 63% shorter and having 50% more leaves than green plants. Leaves of yellow-variegated plants are 21% smaller than green plants and the total leaf area per yellow-variegated plants is 55% greater than green plants (Yang 1995).

Objectives

Cryptolaemus montrouzieri searches actively on vegetation for prey. The searching behavior of predators is affected by many factors including plant variegation and plant size. Plant variegation influences plant growth rates and morphology, which affects prey distribution, density, and intrinsic rates of increase. These plant characteristics, in turn, can effect the searching ability and behavior of predators. Also, because plant size affects the total area a predator must search to find prey, it may also influence predator searching efficiency and rate of attack. Finally, plant-induced changes in predator attack rates could affect a predator's life history characteristics. Therefore, the objectives of this study were to determine the relative effect of Coleus size and variegation on the attack rate, searching efficiency and life history characteristics of *C. montrouzieri*, attacking *P. citri* as a prey.

The following chapters present the experiments and their results discussed according to the objectives of this study. Chapter two contains the attack rates and searching strategy of *C. montrouzieri* searching for *P. citri* at different densities on Coleus of different size and variegation and compares it with Petri dish studies. Chapter three presents the searching behavior of *C. montrouzieri* searching for *P. citri* at different densities on Coleus of different size and variegation. Finally, Chapter four contains the development and weight of *C. montrouzieri* from third instar to adult emergence fed different amounts of *P. citri* as prey.

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