KEYS TO MANAGEMENT OF THE GLASSY-WINGED SHARPSHOOTER: INTERACTIONS BETWEEN HOST PLANTS, MALNUTRITION, AND NATURAL ENEMIES

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ABSTRACT
Our previous work has shown that glassy-winged sharpshooter (GWSS) eggs and nymphs face two primary mortality agents: egg parasitism and malnutrition. Female GWSS chose the host plants for oviposition and consequently the habitat that exposes the eggs to parasitism and also the potential host plant nutrition immediately available to the nymphs. We have developed a conceptual model of these behaviors, choices and tradeoffs facing female GWSS and are interested in the behaviors and cues used by GWSS in making these choices. The effects of host plant assemblages and host plant chemistry on the distribution, performance and behavior of GWSS and its natural enemies are keys to understanding the system. Categorizing host species as to their importance to GWSS life stages is necessary to direct any plant manipulations aimed at population suppression or manipulation. Research in this proposal addressed several aspects of these interactions

INTRODUCTION
Our research in North Florida has documented that different host species are utilized by GWSS for different purposes. Within our region, adult GWSS are most conspicuous on adult feeding hosts (i.e. Prunus in early summer, crape myrtle in mid-summer). Confining GWSS on specific hosts has shown that these same hosts may be poor ovipositional hosts or inadequate for the development of immature GWSS. Larger numbers of egg masses are often found on hosts where GWSS adults are only occasionally observed. We have also quantified the nutritional basis for adequacies as adult feeding hosts versus developmental hosts; our understanding of ovipositional preference is much less complete. Conflicting nutritional needs throughout the GWSS life cycle suggest that multiple host usage is required for optimal population growth of GWSS. Quantifying how the life stages of GWSS utilize each host species and elucidating the behaviors and important behavioral cues provides the background data necessary for formulating strategies to disrupt the life cycle of GWSS.

OBJECTIVES
1. Determine the relationship of host plant xylem chemistry on host selection, feeding and ovipositional behavior of GWSS and its parasites.
2. Assess host plant acceptance and subsequent feeding rate, host plant selection and acceptance for oviposition and the survival and performance of early and late instar nymphs as a function of host plant species.
3. Quantify the impact of these plant variables on the behavior and parasitism rate of eggs by *Gonatocerus ashmeadi.*

RESULTS
The survival and movement behavior under field and laboratory conditions of nymphs of GWSS and two other leafhopper species was determined. We investigated the visual acuity of the nymphal stages of three leafhopper species: *Homalodisca coagulata*, *H. insolita*, and *Oncometopia nigricans*. Under laboratory conditions, the nymphs of *H. coagulata* and *O. nigricans* could discriminate spectra and were highly attracted to hues of yellow with safety yellow being the most attractive. The nymphs of *H. insolita* were also attracted to yellow hues, but were more attracted to cream yellow. In the laboratory, maximum jumping distance of third instar *H. coagulata*, *H. insolita*, and *O. nigricans* was 68.0, 49.7, and 39.2 cm respectively, when provided with a target. The fifth instars of *H. coagulata*, *H. insolita*, and *O. nigricans* had a maximum jumping distance of 78.8, 29.2, and 45.5 cm, respectively. GWSS nymphs were able to walk at least 30 m in less than two hours indoors using a tile floor as a substrate,. Additionally, all nymphal stages of *H. coagulata* dispersed up to 10 meters after three days under field conditions when released into an outdoor grass-covered arena. The neonates of *H. coagulata*, *H. insolita*, and *O. nigricans* survived on average, 83.5, 70.5, and 83.0 hours without plant feeding, respectively.
We investigated the effects of soybean genotype on GWSS development, and if nutritional changes of xylem fluid affected developmental success. Three glabrous isolines (D90-9216, D88-5320 and D88-5328) and one pubescent genotype (Hagood) were examined. All three glabrous genotypes proved suitable developmental hosts, yielding sixty to two hundred successfully matured adults in cages originally loaded with 8 mating pairs of leafhoppers. Minor variations in life history characteristics (growth rates, success and time of development) suggest that the genotype D88-5328 was marginally superior as a developmental host. Chemical analyses of xylem fluid showed that this genotype provided higher dietary nitrogen in the form of amides and ureides as leafhoppers approached maturation. The pubescent genotype Hagood was a much less suitable host. Chemical analyses of xylem fluid showed that Hagood was not nutritionally deficient; thus, we conclude that trichomes of pubescent soybean were a deterrent to leafhopper feeding and development.

While all three glabrous isolines consistently produced matured GWSS, developmental times were extended in several instances. Chemical analyses of xylem fluid showed that under conditions of heavy leafhopper feeding, nutrients in xylem fluid began to decline over time which may have further contributed to slow leafhopper development. In these experiments only pre-plant slow release fertilizer was applied. Our results suggest that supplemental nitrogen may be necessary to consistently develop GWSS with minimal developmental periods.

We quantified the relationship between host selection, consumption rates, ovipositional preference and developmental suitability for several of the host species most utilized in California (Navel oranges, Spanish Pink Lemon and Chardonnay grapes). Experiments were repeated with several of the hosts most important in Florida (crape myrtle, oak leaf holly and the native yaupon holly) to determine if utilization patterns were the same for both sets of hosts. No-choice tests were run simultaneously on each host species (4 plants of only one host species per cage as opposed to one plant from each host species combined in each cage) to determine performance on individual hosts. Since GWSS is in a non-reproductive state the majority of the year, tests were run on both non-reproducing (autumn) and producing (summer) cohorts of insects. In the initial experiment of non-reproducing GWSS we also compared the response of field collected GWSS to those reared and maintained on soybean to examine if feeding history impacted insect behavior or performance.

Choice tests were conducted by releasing 12 male and 12 female GWSS into cages containing the three host species and glabrous soybean. Soybean was included for comparative purposes as it is one of the few hosts that we have found that is a consistent developmental host. Host selection was visually assessed 1 to 2 times daily for 10-22 days. At the termination of the experiment, surviving leafhoppers were counted and weighed. All leaves in each cage were examined and eggs were counted. Individual GWSS were then confined on each host plant in feeding assemblies for determination of consumption rates. Xylem fluid was collected from half of the plants of each species for subsequent chemical analyses. Thirty to forty neonates were placed on each of the remaining hosts and checked daily to determine developmental suitability of each host.

In the first choice test (Navel, Spanish Pink Lemon, Chardonnay and Soy), abundances of both reproducing and non-reproducing adults were highest on Navel. Subsequent tests of consumption rates and immature development showed Navel to be a very poor feeding and developmental host. It was, however, the preferred host for oviposition. One of the most surprising results was that GWSS remained on Navel when not reproductively active (experiments run in autumn), even though consumption rates were low. Tests for non-reproducing GWSS were run for over three weeks; those of reproducing GWSS had to be terminated after ten days so that eggs could be quantified. During the latter portion of the three week period of selection, abundances of GWSS eventually began to decline on Navel with very gradual shifts to the superior feeding hosts.

Trends in the second choice test (crape myrtle, yaupon holly, oak-leaf holly and soy were very different. For field collected GWSS in autumn (non-reproducing) crape myrtle and yaupon holly had the highest abundances. For reproducing adults, the vast majority of GWSS remained on crape myrtle, which was also the superior feeding host during this time period. Oviposition and development on crape myrtle were not significantly different than the two holly species.

Two other trends in the data are noteworthy. Soy reared GWSS were significantly different than field collected GWSS in terms of host selection and consumption rates. The data suggest that it is important to be aware of feeding history when assessing GWSS behavior. Secondly, soy was a very poorly selected host (both abundance and oviposition) despite being the superior rearing host in both sets of experiments, and an adequate feeding host. Our previous research has documented that GWSS does very well when confined on glabrous soybean. The inability of GWSS to recognize soybean (and perhaps other legumes) as a suitable host merits further investigation.

Chemical analysis of xylem fluid of all plants used in the experiments has recently been completed. Statistical analyses of how nutrients relate to GWSS utilization are currently being performed. Some trends are already obvious. In our selection experiments, Spanish Pink Lemon was rarely selected by GWSS. Chemical analyses showed that xylem of lemon used in these experiments was extremely deficient in nutrients, containing ca. 30% of the organic nitrogen of Navel. These results contrast xylem fluid of Navel and lemon that we have analyzed from California (in collaboration with Carlos Coviella), in which field grown lemon have organic nitrogen 30-50% higher than Navel and nearly ten-fold higher than our potted plant material. Both the chemical data from the field in California and data from our greenhouse show consistent relationships between xylem nutrients and host selection (higher amino acids resulting in higher selection). The failure of Spanish Pink Lemon to remain vigorous under greenhouse conditions highlights the need to assess GWSS host utilization in conjunction with chemical data and available field data.

CONCLUSIONS

Leafhopper nymphs are capable of surviving without a plant food source for in excess of three days and also are able to move relatively long distances from plant to plant and on the ground. This information is highly relative to the determination of potential female ovipositional strategies. If nymphs are highly mobile and capable of finding suitable host plants on their own, then female choice of host plants for oviposition may be less critical. This in turn may indicate that oviposition is affected by factors other than host plant chemistry relative to the special requirements of nymphs.