HOST EFFECTS ON OVIPOSITION, DEVELOPMENT, AND FEEDING BEHAVIOR OF THE SQUASH BUG, ANASA TRISTIS (DEGEER)

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HOST EFFECTS ON OVIPOSITION, DEVELOPMENT,

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BUG, ANASA TRISTIS (DEGEER)

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PREFACE

Each chapter of this thesis is a separate and complete manuscript to be submitted for publication in journals of scientific literature. Presentation of each chapter adheres to the guidelines for manuscript preparation according to the Entomological Society of America.

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CHAPTER I

OVIPOSITIONAL PREFERENCE OF THE SQUASH BUG, *ANASA TRISTIS* (DEGEER), AMONG SIX SQUASH CULTIVARS

Abstract

Three summer and three winter squash cultivars were field evaluated over a two year period for ovipositional preference by the squash bug, *Anasa tristis* (DeGeer). Two cultivars of summer squash, yellow straightneck 'Hyrific' and crookneck, were most preferred. As a group, summer squash was more preferred for oviposition than winter squash. Preference for summer squash may be useful in implementing a trap cropping system. Leaves were the favored oviposition site on all cultivars with over two-thirds of the egg masses located on the abaxial leaf surface. Egg mass location was unaffected by squash cultivar.

Introduction

The squash bug, _Anasa tristis_ (DeGeer), is an important insect pest of plants in the family Cucurbitaceae (Britton 1919, Beard 1940, Gould 1943, Davidson & Lyon 1979). This insect begins attacking cucurbits in the spring following adult emergence from overwintering sites. Feeding may continue until the crop is completely destroyed by the bugs or by a heavy frost. Large populations have caused significant economic losses to commercial growers throughout many parts of the United States.

Squash cultivars are commonly separated into two groups: summer squash and winter squash. The clearest usage of the term summer squash refers to plants which have fruits that are eaten when immature, from as early as the day of flowering to the stage when the rind is starting to harden. Winter squash refers to plants in which the fruits are eaten when mature or stored for winter use (L. H. Bailey Hortorium 1976).

Hoerner (1938) in Colorado and Knowlton (1952) in Utah, reported that the squash bug preferred winter squashes as food plants over summer squashes and that they migrated to summer squashes only when the preferred hosts were dead. This feeding preference was not observed in Kansas (Novero et al. 1962). In New York, this insect favored _Cucurbita_ maxima (winter squashes) for both feeding and oviposition over C. pepo (summer squashes) and C. moschata (winter squashes) (Howe 1949). A four year study of phytophagous insect associations with five cultivated and 14 mesophytic and xerophytic wild Cucurbita spp. was conducted in Illinois (Howe & Rhodes 1976). In this study, Anasa tristis showed a high ovipositional preference for the Maxima and Mixta groups (winter squash) and a low preference for all other groups.

Squash bug ovipositional preference research in the southern part of the United States has not been reported. Therefore, the primary objective of this study was to determine the ovipositional preference of A. tristis for six commercially grown squash cultivars in Oklahoma. A secondary objective was to examine egg mass size and location as affected by squash cultivar.

Materials and Methods

Ovipositional preference of the squash bug was studied during the summers of 1983 and 1984 at the Oklahoma State University Horticultural Research Station near Perkins, Payne County, Okla. The cultivars evaluated included three summer (yellow straightneck 'Hyrific', crookneck, and zucchini) and three winter (acorn, spaghetti, and butternut) squashes. These squash cultivars are all Cucurbita pepo L. except butternut which is C. moschata (Duch.) Poir. These squash were chosen for evaluation because they are all grown commercially and are subject to attack by the squash bug. The six cultivars were planted in a completely randomized design in both years. Hills were seeded with four seeds during the third week of May each year with a spacing of 1.8 m in all directions. Ethalfluralin, a preemergence herbicide, was applied to the plots according to label directions. No other pesticides were used during the study. Following emergence and complete expansion of cotyledons, seedlings were thinned to one plant per hill. The plot was irrigated and cultivated as required.

Random samples of four plants per cultivar were taken on 29 July and 17 August, and three plants per cultivar were sampled on 30 August 1983. In 1984, two plants per cultivar were sampled on 8 August and 13 August for a total of 15 plants per cultivar during the two years. For each sampled plant the following information was recorded: 1) number of leaves, 2) number of egg masses, 3) number of eggs per mass, and 4) egg mass location. Five egg mass locations were identified: abaxial leaf surface, adaxial leaf surface, petiole, vine, and flower.

Data were analyzed using a general linear models procedure (SAS Institute Inc. 1985, 433-506). Two additional variables, eggs/leaf (total eggs divided by total number of leaves per plant) and percent of leaves on which oviposition occurred, were included in the analysis. These two variables were calculated to enable comparisons between cultivars with variable growth patterns. Each variable was subjected to analysis of variance for each sample date. Where significant differences in the variables occurred between cultivars, means were separated using Duncan's multiple range test ($P \leq 0.05$ [SAS Institute Inc. 1985, 448]).

Results

There were no significant differences between squash cultivars for mean total egg masses and total eggs on any sampling date. Also, no significant differences were detected in total egg masses or total eggs between years although more eggs were found on all hosts, except zucchini, in 1984.

On 29 July 1983, zucchini had significantly more leaves ($F = 4.23$; $df = 23$; $P \leq 0.05$) than the other squash cultivars. On all other sampling dates, there was no significant differences in the mean number of leaves among squash plants. No significant differences in the mean number of leaves per cultivar between years occurred, except for zucchini. Zucchini had significantly more leaves in 1983 than in 1984 ($F = 8.46$; $df = 15$; $P \leq 0.05$).

Significant differences between cultivars were found in eggs/leaf on all sampling dates (Table 1). On 29 July 1983 and 13 August 1984, straightneck and crookneck had significantly more eggs/leaf ($F = 4.64$; $df = 23$; $P \leq 0.05$ and $F = 22.18$; $df = 11$; $P \leq 0.05$, respectively) than the other cultivars. Straightneck alone had significantly more eggs/leaf than the other five squash on 17 August 1983 ($F = 10.09$; df = 23; $P \leq 0.05$). Data combined for both years showed that straightneck and crookneck had significantly more eggs/leaf ($F = 10.70$; df = 89; $P \leq 0.05$) when compared to the other four cultivars. Comparing summer and winter squash, summer squash had significantly more eggs/leaf on each sample date, and over the two year average, than winter squash.

In Table 2, all sample dates show that straightneck and crookneck had a higher percent of leaves with eggs than the other four squash cultivars. In 1984, eggs were recorded on over 60% of the leaves of these two hosts. Combining both seasons, straightneck and crookneck had a significantly higher percent of leaves with eggs ($F = 9.24$; df = 89; $P \leq 0.05$) than the other four cultivars. In grouping the hosts into summer and winter squashes, a significantly higher percent of leaves with eggs was found on summer squash for all sample dates except 13 August 1984.

Nearly all egg masses were found on the leaves. Host type did not affect the site of oviposition. A total of 2987 egg masses were deposited on the plants sampled with 72.28% located on the abaxial leaf surface and 25.54% located on the adaxial leaf surface (Table 3). Butternut was the only host that varied greatly from the others. Straightneck had the largest total number of egg masses; 874 or 29.26%.

In addition, host type did not affect the number of eggs per mass except on 17 August 1983 when spaghetti had significantly fewer eggs per mass (10.86) than the other hosts ($F = 5.01$; $df = 22$; $P \leq 0.05$). Throughout both seasons an average of 18.90 ± 0.64 ($\pm$SEM) eggs were deposited in each egg mass with a range of 6 - 39 eggs per mass.

Discussion

The mean number of egg masses, mean number of eggs, and mean number of leaves did not differ significantly between cultivars. However, eggs/leaf is a valid variable to use in making comparisons regarding ovipositional preference. These results show that straightneck and crookneck squash are preferred for squash bug oviposition. The percent of leaves with eggs shows the same results.

In both analyses of eggs/leaf and percent of leaves with eggs, winter squash was not preferred for oviposition on any sample date. In a study in New York where the 10 center leaves of each of 10 hills were sampled once, Howe (1949) found that five cultivars of *C. moschata* (winter squash) were the least preferred when compared to three cultivars of *C. maxima* (winter squash) and five cultivars of *C. pepo* (summer squash). Squash bug associations with nine *Cucurbita* groups in Illinois showed that four times as many eggs were deposited on plants in the Pepo group when compared to the Moschata group (Howe & Rhodes 1976). These studies corroborate our results in Oklahoma.

Knowing that leaves are the favored oviposition site, with over two-thirds of the egg masses located on the abaxial leaf surface, and that egg mass location is unaffected by host species is important for two reasons. First, this information can be used in the development of sampling strategies to predict probable insect populations from egg counts. Second, any insecticide applications should be directed toward the underside of the leaves where nymphs aggregate following eclosion.

The number of eggs per mass was not affected by squash cultivar. Beard (1935 [2 values] and 1940), Elliot (1935), and Wadley (1920) reported average eggs per mass as 15.4, 14.4, 14.2, 16.9, and 15, respectively. Although the average egg mass size in the present study was slightly larger (18.9) than previous studies, all values are similar. Knowledge of the distribution of egg mass sizes is important in predicting squash bug populations in pest management programs.

Results of this study show that straightneck and crookneck are the preferred hosts for oviposition by the squash bug. As a group, summer squash is preferred for oviposition over winter squash. Therefore, summer squash, such as straightneck or crookneck, may be useful as a trap crop in a system where select cucurbits would escape substantial damage by squash bugs. Physical and chemical aspects of antixenosis need to be investigated to determine specific factors which cause squash bugs to avoid certain host cultivars. These factors may then be selectively bred into squash plants to deter attack by the squash bug.

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Table 1. Eggs/leaf (±SEM) of *A. tristis* on six squash hosts, Perkins, Okla.

	1983			1984		
Host	29 July[a] (4)[b]	17 Aug. (4)	30 Aug. (3)	8 Aug. (2)	13 Aug. (2)	All (15)
Straightneck (S)[c]	4.04 a	29.34 a	17.06 ab	28.35 a	39.11 a	21.30 a
	(±1.26)	(±5.46)	(±5.74)	(±8.35)	(±2.11)	(±3.75)
Crookneck (S)	3.56 a	15.91 b	21.60 a	20.65 ab	32.70 a	16.64 a
	(±0.80)	(±3.29)	(±1.66)	(±0.98)	(±4.35)	(±2.67)
Zucchini (S)	0.46 b	12.72 bc	14.61 ab	6.80 c	9.44 b	8.60 b
	(±0.20)	(±2.39)	(±5.57)	(±0.68)	(±3.52)	(±1.86)

Table 1. Continued

Acorn (W)	1.30 b	7.26 bc	5.82 b	9.96 bc	17.26 b	7.07 b
	(±0.84)	(±2.60)	(±0.61)	(±2.84)	(±1.38)	(±1.50)
Spaghetti (W)	0.70 b	3.52 c	4.90 b	6.52 c	9.68 b	4.26 b
	(±0.61)	(±2.12)	(±3.30)	(±1.04)	(±1.86)	(±1.10)
Butternut (W)	0.53 b	3.12 c	5.47 b	4.03 c	7.40 b	3.59 b
	(±0.16)	(±0.80)	(±0.43)	(±0.33)	(±2.86)	(±0.70)
Summer Squash	2.69 A	19.32 A	17.75 A	18.60 A	27.08 A	15.51 A
	(±0.66)	(±2.99)	(±2.57)	(±4.54)	(±5.91)	(±1.80)
Winter Squash	0.84 B	4.63 B	5.40 B	6.84 B	11.44 B	4.98 B
	(±0.33)	(±1.18)	(±0.99)	(±1.34)	(±2.11)	(±0.69)

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

[b]Plants sampled per cultivar.

[c]S = summer squash; W = winter squash.

Table 2. Percent of leaves with eggs (±SEM) of *A. tristis* on six squash hosts, Perkins, Okla.

Host	1983			1984		
	29 July[a] (4)[b]	17 Aug. (4)	30 Aug. (3)	8 Aug. (2)	13 Aug. (2)	All (15)
Straightneck (S)[c]	19.26 a (±5.91)	62.28 a (±4.62)	50.48 ab (±17.33)	62.66 ab (±7.34)	67.89 a (±12.11)	49.25 a (±6.25)
Crookneck (S)	12.70 ab (±3.51)	45.47 ab (±6.01)	55.31 a (±3.85)	65.09 a (±11.83)	68.22 a (±10.73)	44.35 a (±6.00)
Zucchini (S)	2.72 b (±1.15)	30.67 bc (±5.77)	35.51 abc (±8.96)	24.89 c (±5.67)	34.22 a (±10.22)	23.89 b (±4.24)

Table 2. Continued

Acorn (W)	5.76 b	24.77 c	23.61 bc	37.53 bc	47.84 a	24.25 b
	(±3.62)	(±8.38)	(±1.75)	(±5.65)	(±5.38)	(±4.35)
Spaghetti (W)	4.11 b	18.56 c	15.53 c	21.33 c	39.59 a	17.28 b
	(±2.83)	(±6.24)	(±4.73)	(±8.30)	(±7.78)	(±3.58)
Butternut (W)	2.45 b	12.62 c	22.17 c	19.58 c	31.53 a	15.27 b
	(±0.68)	(±2.37)	(±1.55)	(±2.60)	(±7.54)	(±2.78)
Summer Squash	11.56 A	46.14 A	47.10 A	50.88 A	56.78 A	39.16 A
	(±2.94)	(±4.84)	(±6.47)	(±9.10)	(±8.68)	(±3.55)
Winter Squash	4.11 B	18.65 B	20.44 B	26.15 B	39.67 B	18.93 B
	(±1.46)	(±3.56)	(±1.97)	(±4.55)	(±4.31)	(±2.13)

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

[b]Plants sampled per cultivar.

[c]S = summer squash; W = winter squash.

Table 3. Location of *A. tristis* egg masses on six squash hosts, Perkins, Okla., 1983-1984

Location	% of total egg masses found per cultivar						
	Host						
	Straight-neck	Crookneck	Zucchini	Acorn	Spaghetti	Butternut	All
Abaxial leaf surface	69.17	71.48	68.79	71.34	69.17	91.55	72.28
Adaxial leaf surface	29.18	25.34	29.36	25.73	27.50	7.77	25.54
Petiole	0.34	0.34	0.62	0.16	0	0.34	0.33
Vine	1.14	1.85	1.23	2.77	3.33	0.34	1.64
Flower	0	1.01	0	0	0	0	0.20
Total Egg Masses	874	596	487	614	120	296	2987

CHAPTER II

OVIPOSITIONAL PREFERENCE OF THE SQUASH BUG, *ANASA TRISTIS* (DEGEER), AMONG FIVE CUCURBIT HOSTS

Abstract

Five cucurbit hosts were field evaluated for ovipositional preference by the squash bug, *Anasa tristis* (DeGeer). Two cultivars of *Cucurbita pepo* were found to be most preferred with 'Yellow Straight Neck Hyrific' squash being more preferred than 'Jack O' Lantern' pumpkin. Relatively few eggs were found on *Cucumis melo* 'Hales Best #36' muskmelon, *C. sativus* 'Poinsett' cucumber, and *Citrullus lanatus* 'Crimson Sweet' watermelon. It may be possible to utilize the preferred *C. pepo* cultivars in trap cropping practices. The abaxial leaf surface was the favored oviposition site on all hosts with over two-thirds of the egg masses found on this surface. This phenomenon is important in developing squash bug sampling strategies and in insecticide applications.

Introduction

The squash bug, *Anasa tristis* (DeGeer), is an important insect pest of cucurbits (Davidson and Lyon 1979). Although hosts of the squash bug include both native and cultivated cucurbit species, this insect has a low ovipositional preference for wild species (Howe and Rhodes 1976). Adult populations are consistently higher among cultivated species and have caused significant economic loss in commercial fields throughout the United States.

Feeding preference for squash and pumpkin has been reported by Wadley (1920), Elliot (1935), Hoerner (1938), and Beard (1940). It is hypothesized that the ovipositional preference of the squash bug would be similar to the feeding preference, but no detailed studies have been reported. Therefore, the primary objective of this study was to determine the ovipositional preference of *A. tristis* for certain commercially grown cucurbit hosts in Oklahoma. A second objective was to quantitatively define the preferred ovipositional site and egg mass size on the host plants.

Materials and Methods

Ovipositional preference was studied during the summer of 1985 at the Oklahoma State University Horticultural Research Station near Perkins, Payne County, Okla. The five cucurbits evaluated were squash (Cucurbita pepo L. var.melopepo 'Yellow Straight Neck Hyrific'), pumpkin (Cucurbita pepo L. var. pepo 'Jack O' Lantern'), muskmelon (Cucumis melo L., Reticulatus Group, 'Hales Best #36'), cucumber (Cucumis sativus L. 'Poinsett'), and watermelon (Citrullus lanatus (Thunb.) Matsum. and Nakai 'Crimson Sweet'). These members of the family Cucurbitaceae were chosen for evaluation because they are all subject to attack by the squash bug and they are all grown commercially. Forty-five hills of each host were planted in a completely randomized design. Hills were seeded with four seeds on 20 May with a spacing of 1.5 m in all directions. A preemergence herbicide, ethalfluralin, was applied to the plot according to label directions. No other pesticides were used during the study. On 11 June, seedlings were thinned to one plant per hill. The plot was irrigated and cultivated as required.

Plants were allowed to become infested with the natural population of squash bugs in the area. This population developed from cucurbits grown in surrounding fields in previous years. These cucurbits included watermelon, cucumber, muskmelon, and seven cultivars of squash. Therefore, the squash bugs were not preconditioned to a particular cucurbit host.

Random samples of three plants per host were taken on 25 June, 10 July, and 31 July, and two plants per host were sampled on 15 August and 21 August for a total of 13 plants per host. For each sampled plant the following information was recorded: 1) number of leaves, 2) number of egg masses, 3) number of eggs per mass, and 4) egg mass location. Seven egg mass locations were identified: abaxial leaf surface, adaxial leaf surface, petiole, vine, flower, fruit, and peduncle (fruit stalk).

Data were analyzed with a general linear models procedure (SAS Institute Inc. 1985, 433-506). The following variables were included in the analysis on a per plant basis: eggs/leaf (total eggs divided by total number of leaves per plant) and percent of leaves on which oviposition occurred. Although there is a leaf area model for squash (Fargo & Bonjour 1986), no models are available for the other four cucurbits. Plant size could not be directly compared between hosts. Therefore, eggs/leaf and percent of leaves with eggs were calculated in order to make comparisons between hosts. Each variable was subjected to analysis of variance for each sample date. Where significant differences in the variables occurred between hosts, means were separated using Duncan's multiple range test ($P \leq 0.05$ [SAS Institute Inc. 1985, 448]).

Results

A total of 2580 egg masses with 51,587 eggs were deposited on all plants sampled between 25 June and 21 August. Eggs were found exclusively on pumpkin on 25 June. Approximately two weeks later, eggs were also observed on squash. Eggs were first sampled on watermelon and cucumber plants on 31 July. No eggs were found on muskmelon plants until the 15 August sampling period.

The mean number of egg masses and eggs are summarized in Tables 1 and 2, respectively. Pumpkin had significantly more egg masses and eggs on 25 June ($F = 3.57$; $df = 14$; $P \leq 0.05$) than the other four hosts. No significant differences were seen in the second and last samples. On 31 July, pumpkin had significantly more egg masses and eggs than the other four hosts and squash had significantly more than watermelon, cucumber, and muskmelon. For a seasonal average, pumpkin and squash had significantly more egg masses ($F = 3.58$; $df = 64$; $P \leq 0.05$) and significantly more eggs ($F = 3.88$; $df = 64$; $P \leq 0.05$) than the other three hosts.

Total number of leaves varied throughout the sampling periods although no significant differences were seen in the two August samples (Table 3). Initially, significantly more leaves were found on pumpkin ($F = 5.22$; $df = 14$; $P \leq 0.05$) than the other cucurbits. In subsequent samples, watermelon had the most leaves while pumpkin had the second highest number of leaves. Cucumber always had the fewest leaves.

The number of eggs/leaf did not differ significantly between hosts on 25 June ($F = 2.59$; $df = 14$; $P > 0.05$) but significant differences did occur on all other sampling dates (Table 4). Squash plants had significantly more eggs/leaf on 10 July ($F = 7.61$; $df = 14$; $P \leq 0.05$), 15

August ($F = 99.71$; df = 9; $P \leq 0.05$) and 21 August ($F = 44.82$; df = 9; $P \leq 0.05$) than the other four host plants. On 31 July, there were significantly more eggs/leaf on squash and pumpkin than on the other three hosts ($F = 8.11$; df = 14; $P \leq 0.05$). Table 4 also shows that throughout the season the number of eggs/leaf increased for both squash and pumpkin (both C. pepo cultivars). There was an average of less than one egg/leaf for watermelon, muskmelon, and cucumber throughout the study.

Percent of leaves with eggs was not significantly different between hosts on the 25 June sampling date ($F = 3.23$; df = 14; $P > 0.05$) (Table 5). However, squash and pumpkin had a significantly higher percent of leaves with eggs on 31 July than the other hosts ($F = 8.11$; df = 14; $P \leq 0.05$). There was a significantly higher percent of squash leaves with eggs on 10 July ($F = 12.84$; df = 14; $P \leq 0.05$), 15 August ($F = 79.65$; df = 9; $P \leq 0.05$) and 21 August ($F = 61.89$; df = 9; $P \leq 0.05$) than on the other cucurbits. The percent increased for squash and pumpkin throughout the season. In both August samples, the percent of pumpkin leaves with eggs was significantly higher than the percents for watermelon, muskmelon, and cucumber. Each of these latter three cucurbits had less than 4% of leaves with eggs at any one time.

The largest percent of egg masses was located on leaves. Squash and pumpkin had 68.29 and 68.36% of the egg masses located on the abaxial leaf surface and 29.27 and

21.95% on the adaxial leaf surface, respectively (Table 6). Pumpkin and squash plants had 1362 (52.79%) and 1107 (42.91%) egg masses, respectively, whereas muskmelon, cucumber, and watermelon had a total off 111 egg masses (4.30%). There was an average of 19.5 ± 0.67 (±SEM) eggs per egg mass. No significant difference was seen in the number of eggs per mass between hosts ($F = 0.75$; $df = 34$; $P > 0.05$).

Discussion

Squash bugs oviposited more eggs on squash and pumpkin (both _C_. _pepo_) than on watermelon, muskmelon, and cucumber. Wadley (1920) stated that if normal host plants are overcrowded or dead, the squash bug may attack other nearby cucurbits, but it is usually only a serious pest of squash and pumpkin. In Connecticut, it was found that feeding and oviposition occurred on summer squash, Hubbard squash, and pumpkin in the field while cucumber, watermelon, muskmelon, and citron (_Citrullus_ _lanatus_ (Thunb.) Matsum. and Nakai var. _citroides_ (L. H. Bailey) Mansf.) were not attacked by the squash bug (Elliot 1935). Elliot (1935) also made unsuccessful attempts to rear young nymphs on these latter four cucurbits. In the present study, few nymphs were observed on watermelon, muskmelon, or cucumber until late in the season, following the conclusion of the sampling period, when squash and pumpkin plants had died. After the foliage and vines of all plants died, nymphs and adults shifted their feeding to the remaining fruits of the five hosts.

Squash ranked highest in the number of eggs/leaf. Additionally, the percent of squash leaves with eggs was about twice that of pumpkin. The data for both eggs/leaf and percent of leaves with eggs show high ovipositional preference for squash by this pest. This information is also indirect evidence of greater squash bug numbers on these plants. Damage caused by the greater density of *A. tristis* on squash may be one of the factors causing squash plants to succumb first.

There was no difference between hosts in egg mass location. Leaves were the favored oviposition site on all hosts with over two-thirds of the egg masses located on the abaxial leaf surface. In addition, there was no difference between hosts in the number of eggs per mass. Wadley (1920), Beard (1935 [2 values] and 1940), and Elliot (1935) reported average egg mass sizes of 15.4, 14.4, 14.2, 16.9, and 15 eggs, respectively. The average egg mass size in the present study was 19.5 eggs. Although the average egg mass size in the present study was slightly larger than previous work, all values are similar. Knowledge of ovipositional sites and the distribution of egg mass sizes provides valuable pest management information in the development of sampling strategies, insecticide application techniques, and predicting squash bug populations.

The data confirm that squash and pumpkin are preferred by the squash bug for oviposition, and may therefore be valuable as trap crops. However, since this experiment was conducted as a choice test with hosts planted together within the same field, it is unknown whether squash bugs would concentrate in an adjacent field or border of the preferred host over a less preferred host. Further tests are needed with larger adjacent plots to determine the potential of squash and pumpkin as a trap crop.

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Table 1. Total egg masses (±SEM) of *A. tristis* deposited on five cucurbit hosts, Perkins, Okla.

	Sampling Date - 1985					
Host	25 June[a] (3)[b]	10 July (3)	31 July (3)	15 Aug. (2)	21 Aug. (2)	All (13)
Squash	0 a	4.33 a (±0.67)	42.33 b (±13.28)	253.50 a (±7.50)	230.00 a (±58.00)	85.15 a (±31.36)
Pumpkin	1.67 a (±0.88)	5.00 a (±3.51)	83.33 a (±22.88)	172.00 a (±111.00)	374.00 a (±288.00)	104.77 a (±51.32)

Table 1. Continued

Watermelon	0 a	0 a	2.67 c	28.00 a	5.00 a	5.69 b
			(±1.33)	(±16.00)	(±3.00)	(±3.36)
Muskmelon	0 a	0 a	0 c	5.50 a	5.50 a	1.69 b
				(±3.50)	(±5.50)	(±1.04)
Cucumber	0 a	0 a	0.33 c	1.50 a	5.50 a	1.15 b
			(±0.33)	(±1.50)	(±1.50)	(±0.61)

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

[b]Plants sampled per host.

Table 2. Total eggs (±SEM) of *A. tristis* deposited on five cucurbit hosts, Perkins, Okla.

Host	Sampling Date - 1985					
	25 June[a] (3)[b]	10 July (3)	31 July (3)	15 Aug. (2)	21 Aug. (2)	All (13)
Squash	0 b	91.67 a	842.33 b	5174.00 a	4500.50 a	1703.92 a
		(±26.19)	(±233.58)	(±349.00)	(±1068.50)	(±626.95)
Pumpkin	25.00 a	113.33 a	1886.33 a	3594.50 ab	7116.50 a	2115.08 a
	(±13.23)	(±86.40)	(±454.87)	(±2269.50)	(±5474.50)	(±984.55)

Table 2. Continued

Watermelon	0	b	0	a	58.67 c	445.00 b	77.00 a	93.85 b
					(±29.34)	(±255.00)	(±44.00)	(±53.24)
Muskmelon	0	b	0	a	0 c	118.00 b	87.50 a	31.62 b
						(±94.00)	(±87.00)	(±20.12)
Cucumber	0	b	0	a	5.33 c	24.50 b	122.00 a	23.77 b
					(±5.33)	(±24.50)	(±60.00)	(±14.38)

[a]Means within a column followed by the same letter are not significantly different (P > 0.05; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

[b]Plants sampled per host.

Table 3. Total leaves (±SEM) of five cucurbit hosts, Perkins, Okla.

Host	Sampling Date - 1985					
	25 June[a] (3)[b]	10 July (3)	31 July (3)	15 Aug. (2)	21 Aug. (2)	All (13)
Squash	32.67 b (±5.55)	103.00 bc (±9.00)	248.33 b (±47.56)	335.50 a (±31.50)	203.00 a (±25.00)	171.46 bc (±32.31)
Pumpkin	56.00 a (±9.17)	299.00 ab (±40.43)	672.67 a (±235.48)	383.00 a (±199.00)	615.50 a (±422.50)	390.77 ab (±97.41)

Table 3. Continued

Watermelon	30.67 b	415.33 a	701.00 a	1312.50 a	717.00 a	576.92 a
	(±6.69)	(±53.49)	(±93.94)	(±380.50)	(±22.00)	(±126.64)
Muskmelon	21.67 b	232.00 abc	294.00 ab	329.50 a	533.50 a	259.15 bc
	(±4.63)	(±126.50)	(±97.73)	(±50.50)	(±261.50)	(±63.59)
Cucumber	18.67 b	62.00 c	163.67 b	278.50 a	157.50 a	123.46 c
	(±5.04)	(±14.15)	(±76.21)	(±29.50)	(±18.50)	(±29.76)

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

[b]Plants sampled per host.

Table 4. Eggs/leaf (±SEM) of *A. tristis* on five cucurbit hosts, Perkins, Okla.

Host	Sampling Date - 1985					
	25 June[a] (3)[b]	10 July (3)	31 July (3)	15 Aug. (2)	21 Aug. (2)	All (13)
Squash	0 a	0.89 a	3.86 a	15.46 a	21.86 a	6.84 a
		(±0.22)	(±1.32)	(±0.41)	(±2.58)	(±2.40)
Pumpkin	0.48 a	0.33 b	3.25 a	8.64 b	10.32 b	3.85 a
	(±0.30)	(±0.22)	(±0.75)	(±1.44)	(±1.81)	(±1.18)

Table 4. Continued

Watermelon	0 a	0 b	0.08 b	0.31 c	0.11 c	0.08 b
			(±0.04)	(±0.11)	(±0.06)	(±0.03)
Muskmelon	0 a	0 b	0 b	0.41 c	0.11 c	0.08 b
				(±0.35)	(±0.11)	(±0.06)
Cucumber	0 a	0 b	0.03 b	0.08 c	0.83 c	0.15 b
			(±0.03)	(±0.08)	(±0.48)	(±0.10)

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

[b]Plants sampled per host.

Table 5. Percent of leaves with eggs (±SEM) of *A. tristis* on five cucurbit hosts, Perkins, Okla.

Host	Sampling Date - 1985					
	25 June[a] (3)[b]	10 July (3)	31 July (3)	15 Aug. (2)	21 Aug. (2)	All (13)
Squash	0 a	3.65 a (±0.59)	16.11 a (±5.37)	45.15 a (±0.08)	58.77 a (±4.83)	20.55 a (±6.47)
Pumpkin	2.11 a (±1.17)	1.39 b (±0.80)	10.54 a (±2.31)	24.30 b (±4.74)	30.11 b (±5.24)	11.61 a (±3.34)

Table 5. Continued

Watermelon	0	a	0	b	0.38 b	1.80 c	0.64 c	0.46 b
					(±0.20)	(±0.62)	(±0.37)	(±0.20)
Muskmelon	0	a	0	b	0 b	1.70 c	0.69 c	0.37 b
						(±1.17)	(±0.69)	(±0.24)
Cucumber	0	a	0	b	0.20 b	0.49 c	3.01 c	0.58 b
					(±0.20)	(±0.49)	(±1.31)	(±0.34)

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

[b]Plants sampled per host.

Table 6. Location of A. tristis egg masses on five cucurbit hosts, Perkins, Okla., 1985

	% of total egg masses found per host					
	Host					
Location	Squash	Pumpkin	Watermelon	Muskmelon	Cucumber	ALL
Abaxial leaf surface	68.29	68.36	91.89	90.91	86.67	69.30
Adaxial leaf surface	29.27	21.95	4.05	4.55	0	24.30
Petiole	1.54	0.22	0	0	0	0.78
Vine	0.81	8.88	4.05	4.55	13.33	5.27
Flower	0.09	0.07	0	0	0	0.08
Fruit	0	0.29	0	0	0	0.16
Peduncle	0	0.22	0	0	0	0.12
Total Egg Masses	1107	1362	74	22	15	2580

CHAPTER III

HOST EFFECTS ON THE SURVIVAL AND DEVELOPMENT OF THE SQUASH BUG, *ANASA TRISTIS*, (DEGEER)

Abstract

The influence of five cucurbit hosts on survival, developmental time, and adult weight of the squash bug, Anasa tristis (DeGeer), was examined. Percent survival from egg to adult was significantly affected by host. Survival to the adult stage on the five hosts was highest on pumpkin (70.0%), followed by squash (49.0%), watermelon (14.4%), cucumber (0.3%), and muskmelon (0%). Host type had a significant effect on developmental time to third and fifth instar, and to adult, with a longer developmental time on watermelon. The adult sex ratio was 1:1. Adult females were significantly heavier than males and the effect of host on adult weight was significant only for males. Greater adult weights for both males and females resulted when insects developed on squash.

Introduction

The squash bug, *Anasa tristis* (DeGeer), is an important native insect pest of cucurbits in the United States (Wadley 1920, Elliot 1935, Beard 1940). Squash bug numbers have been shown to increase dramatically throughout the plant growing season (Fargo et al. 1988). Large populations have caused commercial growers significant economic loss.

Insect development is a key factor in understanding insect ecology. Development of the squash bug as a function of temperature has been investigated by Fargo & Bonjour (1988) and Fielding & Ruesink (1988). Results from these studies can be used to develop effective pest management strategies for use by commercial producers.

Many studies have investigated the interactions between insects and their host plants. The relationship between squash bug development and host type, however, has not been reported. The purpose of this study was to evaluate the impact of five cucurbit hosts on the biology of the squash bug. The specific objectives were to quantify the influence of host type on egg to adult survival, developmental times, and adult weight.

Materials and Methods

Rearing cages were made using 3.8 liter (21.7 cm tall) clear plastic round containers (15 cm diameter) with snap-onlids. Holes were cut on opposite sides (7.6 cm diameter) and in the lids (10.7 cm diameter) of the containers and covered with cloth for ventilation. Filter paper was placed in the bottoms of the cages to provide a surface on which dislodged insects could walk to return to the plant and to aid in the recovery of exuviae.

Cucurbit hosts included squash (Cucurbita pepo L. var. melopepo 'Yellow Straight Neck Hyrific'), pumpkin (Cucurbita pepo L. var. pepo 'Jack O' Lantern'), watermelon (Citrullus lanatus (Thunb.) Matsum. and Nakai 'Crimson Sweet'), cucumber (Cucumis sativus L. 'Poinsett'), and muskmelon (Cucumis melo L., Reticulatus Group, 'Hales Best #36'). These members of the family Cucurbitaceae were selected because they are all grown commercially and are subject to attack by the squash bug. Plants were grown in a greenhouse in 6.3 cm square plastic pots containing a soilless growing medium. Seedlings at the two- to four-leaf stage were placed in individual cages as a food source for the insects and were replaced as necessary.

A total of four experiments were conducted at a constant temperature of 26.7°C under a 16:8 (L:D) photoperiod from 1987 to 1988. This temperature was chosen due to optimal egg hatch and nymphal survival for the squash bug (Fargo & Bonjour 1988). In all experiments, 15 eggs from the same mass were placed in each cage. For experiment 1, field-collected eggs of undetermined ages were placed in each of four cages per host. In experiment 2, eggs of undetermined ages were obtained from a laboratory colony of adult squash bugs. These eggs were placed in each of five cages per host. Eggs for experiments 3 and 4 were field-collected within 24 h of oviposition and placed in each of six cages per host. Therefore, a total of 21 cages per host were observed over the two year period.

Mean egg developmental time in experiments 3 and 4 were included in the data for experiments 1 and 2 so that mean times to adult could be compared for all cages. Development was monitored daily by recording the number of live and dead squash bugs in each nymphal instar per cage. Insects reaching the adult stage were sexed and removed from the rearing cages. Adults in experiments 3 and 4 were weighed on a Mettler AE 160 balance following removal.

Developmental time in each life stage was estimated using the technique developed by Fargo (1986) for cohort data. Data were analyzed with a general linear models procedure (SAS Institute Inc. 1985, 433-506). Developmental times, percent of insects becoming adults, and weight of adult insects were subjected to analysis of variance for host effect. Where significant differences in the variables occurred, means were separated using Duncan's multiple range test ($P \leq 0.05$ [SAS Institute Inc. 1985, 448]). The pooled sex ratio was tested for conformation to a 1:1 ratio using the chi-square statistic.

Results and Discussion

There were no significant differences between years for any of the variables. In general, no differences were seen between experiments except in mean weights of adult insects. Therefore, the data, except mean weights, were pooled to examine host effect.

Survival to adult was significantly affected by host ($F = 48.74$; $df = 104$; $P \leq 0.05$) (Table 1). Squash bugs reared on pumpkin had the highest percent survival. Only one insect survived to the adult stage on cucumber and no insects survived on muskmelon. Nearly all nymphal mortality occurred in the second stadium. Death in this early stadium would indicate that cucumber and muskmelon exhibit an antibiotic effect on squash bug development. Previous studies by this author have shown that first instar nymphs were able to ingest fluid equally well on all five cucurbits (unpublished data). Therefore, antixenosis apparently does not play a role in nymphal mortality.

Mean developmental times to first through fifth instars and to adult are given for pumpkin, squash, and watermelon in Table 2. Developmental times for cucumber and muskmelon are not included because only one insect survived to the adult stage on cucumber and no insects developed to the adult stage on muskmelon. Developmental times in the field have been reported by other researchers (Weed & Conradi 1902, Chittenden 1908, Wadley 1920) but no information was presented relative to temperature or host type. There was no significant difference in developmental time among the three hosts to first, second, or fourth instar. Beginning with developmental time to third instar, a trend was established in which insect development on pumpkin required the least amount of time and insects on watermelon required the most time. Insects on watermelon had significantly longer developmental times to fifth instar ($F = 6.92$; df = 55; $P \leq 0.05$) and to adult ($F = 16.33$; df = 55; $P \leq 0.05$) than on pumpkin and squash.

The total number of adult males (209) and females (206) conformed to a 1:1 ratio. Therefore, neither male nor female squash bugs have a selected survival advantage under laboratory conditions. Beard (1940) and Fargo et al. (1988) have shown that the 1:1 sex ratio also exists in the field.

Mean weights of both male and female squash bugs were significantly greater in experiment 3 than experiment 4. Eggs collected for experiment 3 were oviposited earlier in the season by overwintering females whereas eggs for experiment 4 were oviposited later in the season by a combination of overwintering and first generation females. Whether this difference accounted for the decrease in adult weights in experiment 4 or whether some other factors were involved is unknown.

Adult male and female weights as affected by host are shown in Table 3. Significant differences in weight were seen for males ($F = 4.22$; df = 136; $P \leq 0.05$). Males reared on squash were the heaviest, followed by those that developed on pumpkin and watermelon. While there were no significant differences in female weight ($F = 1.88$, df = 130; $P > 0.05$), the trend was the same as that observed for males, with the heaviest females developing on squash, followed by pumpkin and watermelon. Males and females weighed 11.91 and 10.40% more, respectively, on squash than on watermelon. Combining host types, adult males weighed an average of 72.74% as much as adult females. Similar results were seen for males and females reared on Cucurbita moschata Duchesne var. Libbey's Select (Fielding & Ruesink 1988).

Whether physical or chemical factors of these five cucurbit hosts affect squash bug survival and development is unknown. Benepal & Hall (1966) have shown that mineral nutrition of host plants does influence the feeding response of the squash bug. Differences in nutritional composition of host plants may influence development. Detailed nutritional and physical studies are needed to determine the critical factors affecting squash bug development. Incorporation of these factors into host plants may deter the squash bug from attacking cucurbit crops.

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Table 1. Mean percent nymphal survivorship of A. tristis as affected by cucurbit host

Host	n	% survival (±SEM)[a]
Pumpkin	21	70.00 (±7.02) a
Squash	21	49.02 (±6.45) b
Watermelon	21	14.44 (±3.13) c
Cucumber	21	0.32 (±0.32) d
Muskmelon	21	0 d

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

Table 2. Mean developmental time (days) at 26.7°C from oviposition to first, second, third, fourth, and fifth instar, and to adult for *A. tristis* as affected by cucurbit host

Host (n)	Mean no. days (±SEM) to develop to					
	1st Instar[a]	2nd Instar	3rd Instar	4th Instar	5th Instar	Adult
Pumpkin (21)	7.46 a (±0.10)	10.12 a (±0.06)	17.10 a (±0.38)	22.21 a (±0.58)	27.24 a (±0.70)	37.03 a (±0.68)
Squash (21)	7.20 a (±0.11)	10.06 a (±0.10)	18.46 ab (±0.55)	23.96 a (±0.89)	28.90 a (±0.94)	37.27 a (±0.96)
Watermelon (14)	7.40 a (±0.15)	9.96 a (±0.09)	19.67 b (±0.82)	25.22 a (±1.08)	32.39 b (±1.24)	44.91 b (±1.56)

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

Table 3. Mean weights (mg) of adult A. tristis according to sex and cucurbit host

Host	(n)	Weight in mg (±SEM) Males[a]	(n)	Females
Pumpkin	(67)	94.99 ab (±2.44)	(64)	135.09 a (±3.13)
Squash	(51)	103.25 a (±2.16)	(49)	138.69 a (±3.41)
Watermelon	(19)	92.26 b (±3.20)	(18)	125.62 a (±5.64)

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

CHAPTER IV

HOST EFFECTS ON THE FEEDING BEHAVIOR OF THE SQUASH BUG, *ANASA TRISTIS* (DEGEER)

Abstract

Feeding behavior of first instar squash bugs, *Anasa tristis* (DeGeer), was electronically monitored and fluid ingestion was determined on several cucurbit hosts. Force required to puncture cucurbit host leaves was also examined. Squash bugs monitored for 8 h produced five recognizable behaviors on analog plotters: stylets withdrawn from the plant (baseline), probing, total stylet contact with the plant, committed ingestion (CI, an ingestion event >15 min in duration) and stylet withdrawal (exit). Significant host effects on these variables were only seen for cumulative CI. Squash bugs were able to ingest plant fluid equally well on all hosts as evidenced by no significant differences being found in the weights of fluid ingested. Leaf toughness was significantly different between hosts but when compared with feeding behavior, leaf toughness did not appear to be a factor affecting squash bug feeding.

Introduction

The squash bug, *Anasa tristis* (DeGeer) is a common insect pest of cucurbits throughout the United States (Wadley 1920, Elliot 1935, Beard 1940, Davidson & Lyon 1979). In Oklahoma, the squash bug completes two to three generations per year (Fargo et al. 1988). Feeding damage caused by large populations have resulted in significant economic losses in commercial cucurbit crops grown in many parts of the nation.

The electronic measurement system developed by McLean & Kinsey (1964) for measuring insect probing behavior has greatly facilitated the study of probing and feeding behavior of insects with piercing-sucking mouthparts. Electronic monitors have been used to study the probing behavior of various insects (Kennedy et al. 1978, Kawabe & McLean 1980), to correlate aspects of feeding behavior with virus transmission to plants (Scheller & Shukle 1986), and to study differences in the probing behavior of insects fed on various host plants (Campbell et al. 1982).

Previous studies by this author have shown that host type greatly affects development and survival of the squash bug (unpublished data). The purpose of the present study was to investigate possible reasons for these differences in development and survival. The specific objectives were 1) to correlate electronically recorded waveforms with squash bug feeding events, 2) to determine the influence of host type on electronically monitored feeding behavior and weight of fluid ingested, and 3) to examine leaf toughness of host plants.

Materials and Methods

Insects used in the feeding experiments were obtained from field-collected squash bug eggs. Individual egg masses were placed in separate petri dishes in an environmental growth chamber maintained at 26.7°C. Following eclosion, first instar nymphs remained in the petri dish, without food, for 12-24 h. Six nymphs from the same mass were then placed on six separate seedling plants for monitoring.

Electronic feeding monitors, modified several times from the first equipment used to record insect feeding (McLean & Kinsey 1964, 1967), were used to evaluate squash bug feeding. The equipment used in the present study involved six 9-V battery-powered feeding monitors (25 Hz) adapted from the system used by Brown & Holbrook (1976), and built by Kendow Technologies (Perry, Okla.). Successful recordings of the feeding behavior of first instar squash bug nymphs on seedling plants were obtained using this system. A squash bug nymph was attached by its dorsum to a 4 cm length of 10 μm diameter gold wire with colloidal silver paint. The nymph was placed on the abaxial surface of the second fully expanded leaf of a two- to three-leaf stage seedling. If the nymph continually walked off the plant or if the gold wire broke, a different nymph was used. An alternating current of 200 millivolts was passed into the plant through the growing medium. Monitoring began and feeding behaviors were recorded on three dual-pen strip-chart recorders at a chart speed of 0.5 cm per min.

Definition of Feeding Behavior

An initial study was conducted to correlate distinctive waveforms recorded by the electronic feeding monitors with the location of squash bug stylets within a leaf. Of special interest was the waveform which indicated feeding. To determine this waveform, 12 first instar nymphs were allowed to feed for at least 20 min on 12 squash seedlings, Cucurbita pepo L. var. melopepo 'Yellow Straight Neck Hyrific.' The feeding site was marked on the adaxial leaf surface. A 3 mm square section of leaf tissue was excised from the plant and placed in a vial of formalin-proprionic acid-alcohol fixative. After 24 h in the fixative, the leaf tissue was dehydrated by passing it through a tertiary butyl alcohol series. Leaf tissue was embedded in Paraplast and sectioned with a rotary microtome at a thickness of 12 μ. Sections were stained with a quadruple stain for microscopic examination.

Host Effect on Feeding Behavior

Electronically Monitored Feeding. The feeding behavior of first instar squash bugs was electronically monitored on the following six cucurbit cultivars: squash (*Cucurbita pepo* L. var. *melopepo* 'Yellow Straight Neck Hyrific'), pumpkin (*Cucurbita pepo* 'Jack O' Lantern'), watermelon (*Citrullus lanatus* (Thunb.) Matsum. and Nakai 'Crimson Sweet'), cucumber (*Cucumis sativus* L. 'Poinsett'), muskmelon (*Cucumis melo* L., Reticulatus Group, 'Hales Best #36'), and buffalo gourd (*Cucurbita foetidissima* HBK). The first five cucurbits are cultivated species and were chosen because they are all grown commercially and are subject to attack by the squash bug. Plants were grown in the greenhouse in 6.3 cm square plastic pots containing a soilless growing medium. Seedlings at the two- to three-leaf stage were used for monitoring. Buffalo gourd is a wild cucurbit and was transplanted from the field into 15.2 cm diameter pots due to difficulties in growing this plant from seed.

Six feeding monitors were used simultaneously (blocks) in each monitoring session. One plant of each host type was randomly assigned to a monitor within a block. There was a total of ten blocks with six plants per block. Feeding was monitored for 8 h. Temperatures in the monitoring room ranged from 23-28°C and relative humidity ranged from 62-80%.

Weight of Fluid Ingested. To insure that first instar nymphs feed and to determine if host type affects the weight of fluid ingested, an independent experiment was conducted. In this experiment, eggs and nymphs were treated as in the feeding monitor experiment. Groups of ten first instar nymphs, each from the same egg mass, were weighed on a Mettler AE 160 balance before being allowed to feed. Individual groups were then placed on each of the six cucurbit cultivars in separate rearing cages. Nymphs were reweighed at 24 and 48 h. Mean weight per insect was computed along with percent weight increase for 24 and 48 h. There was a total of three blocks of six cucurbit hosts.

Leaf Toughness. Leaf toughness was examined using a Universal Testing Machine (Canton, Mass.). Due to difficulties in rearing buffalo gourd from seed, only the five cultivated species were tested. A device was built to hold a leaf during the test. The device consisted of a 12.7 cm square piece of 6.4 mm thick clear acrylic sheet bolted to a 12.7 cm square piece of 12.7 mm aluminum plate. A series of holes, 2.4 mm in diameter, were drilled in the acrylic sheet with a 12.7 mm spacing in all directions. Plants in the two-leaf seedling stage were used to test leaf toughness. An in situ, fully expanded second leaf was carefully bolted between the acrylic sheet and aluminum plate. A probe of 1.2 mm diameter was allowed to puncture the leaf at a speed of 0.5 cm per min and the force (g) required to puncture the leaf was recorded. Five punctures were made per leaf in a linear series 1-1.5 cm above the base of the leaf, perpendicular to the midrib. Two replications of four plants per host were tested for leaf toughness giving a total of 40 punctures per host.

Data Analysis. Data were analyzed with a general linear models procedure (SAS Institute Inc. 1985, 433-506). Where significant differences in the variables occurred, means were separated using Duncan's multiple range test ($P \leq 0.05$ [SAS Institute Inc. 1985, 448]).

Results and Discussion

Definition of Feeding Behavior

A typical sequence of waveforms from the electronic feeding monitor tracings of first instar *A. tristis* is illustrated in Fig. 1. This type of waveform was seen on all hosts. There is a probe or series of probes, followed by an ingestion period which ends with an exit peak. Examinations of histological preparations showed that the stylet sheath tips were located in the vascular bundles during ingestion. Stylet penetration appeared to go directly through the cells causing localized injury to the epidermal and palisade cells. Similar observations have been reported by Beard (1940).

Waveforms were identified as baseline (stylets withdrawn from the plant) (Fig. 1, A), probe (Fig. 1, B), total stylet contact (Fig. 1, C), committed ingestion (CI, an ingestion event >15 min in duration) (Fig. 1, D), and exit peak (Fig. 1, E). No discernible waveform, such as the X-wave observed in aphid feeding patterns (McLean & Kinsey 1967), was found to precede ingestion by the squash bug.

Host Effect on Feeding Behavior

Electronically Monitored Feeding. No significant difference was seen in the frequency of baseline activity ($F = 0.70$; df = 58; $P > 0.05$) or in total baseline time ($F = 0.75$; df = 58; $P > 0.05$) between cucurbit hosts. Mean total baseline time was 377.5 $\pm$ 7.8 min. Squash bugs spent a majority (78.6%) of time with their stylets withdrawn from the plant.

The mean number of insect probes was not significantly different between hosts ($F = 0.70$; df = 58; $P > 0.05$). No significant difference was seen in the mean time of total stylet contact between hosts ($F = 2.35$; df = 58; $P > 0.05$). Mean time of total stylet contact with the host leaf was 86.4 $\pm$ 9.2 min or 18.0% of the monitoring time.

Time required for a squash bug nymph to penetrate the vascular bundle for the first CI varied between 8.4 and 50.8 min but was not significantly different between the hosts ($F = 0.79$; df = 50; $P > 0.05$) (Table 1.). No significant difference ($F = 1.83$; df = 50; $P > 0.05$) was seen in the amount of time spent in the first CI between hosts. However, in comparing cumulative CI times between hosts, significant differences were seen ($F = 2.45$; df = 58; $P \leq$

0.05). Although it took the squash bugs longer to reach the first CI on buffalo gourd, more time was spent in CI on this host during the monitoring period than for any of the cultivated cucurbit hosts.

Weight of Fluid Ingested. The weight of fluid ingested by squash bug nymphs showed no significant differences between hosts. Mean weights (±SEM), pooled across hosts, of individual nymphs at 0, 24, and 48 h were 0.671 ± 0.007, 0.929 ± 0.018, and 1.154 ± 0.012 mg, respectively. The percent increase in body weight for 24 and 48 h showed no significant differences between hosts. Therefore, the nymphs were able to ingest fluid equally well on all hosts in this confined situation.

Leaf Toughness. In the analysis of leaf toughness, no significant differences in the force required to penetrate host leaves was found between replications, plant number, or puncture location. Therefore, data were pooled to analyze leaf toughness between hosts. Significantly less force was required to puncture leaves of cucumber plants than leaves of the other four cucurbits ($F = 33.96$; $df = 199$; $P \leq 0.05$) (Table 2.). Thus, it would appear that the squash bug should be able to feed more easily on cucumber. In fact, the feeding monitor data did show that the squash bug was able to reach the first CI the fastest (8.4 min) on cucumber. However, the time to reach the first CI on squash was only 0.1 min longer than that for cucumber, yet the force required to puncture squash leaves is 1.6 times the force required to puncture cucumber leaves. Therefore, it appears that leaf toughness is not a factor influencing squash bug feeding.

<u>Conclusion.</u> The results of this study show that host type has little or no effect on the electronically monitored feeding behavior of first instar squash bug nymphs. Also, leaf toughness does not influence feeding behavior. The distinct differences in developmental time and survival of the squash bug on the five cultivated cucurbits must be attributed to other physical differences between the hosts or, more likely, differences in the chemical composition of these hosts.

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Table 1. Effect of cucurbit hosts on mean times (±SEM) related to committed ingestion (CI) of A. *tristis* over a period of 480 minutes.

Host	n	Time to 1st CI (min)[a]	n	Time in 1st CI (min)	n	Cumulative CI (min)
Buffalo gourd	10	50.8 a (±33.8)	10	85.5 a (±27.9)	10	105.4 a (±25.0)
Muskmelon	10	17.8 a (±8.8)	10	28.6 a (±5.8)	10	68.5 ab (±13.6)
Watermelon	7	31.5 a (±22.2)	7	58.2 a (±26.0)	10	66.8 ab (±22.9)
Squash	10	8.5 a (±1.9)	10	49.0 a (±17.0)	10	63.9 ab (±17.5)
Pumpkin	7	40.8 a (±34.9)	7	34.9 a (±7.6)	10	40.8 b (±10.2)
Cucumber	7	8.4 a (±1.5)	7	32.3 a (±4.4)	9	41.7 b (±12.1)

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

Table 2. Mean force (g) to puncture cucurbit leaves using a 1.2 mm diameter probe at a rate of 0.5 cm per minute.

Host	n	Force in g (±SEM)[a]
Muskmelon	40	43.3 (±1.5) a
Watermelon	40	45.6 (±1.4) a
Squash	40	43.5 (±1.5) a
Pumpkin	40	44.8 (±1.3) a
Cucumber	40	27.4 (±0.9) b

[a]Means within a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute Inc. 1985, 448]).

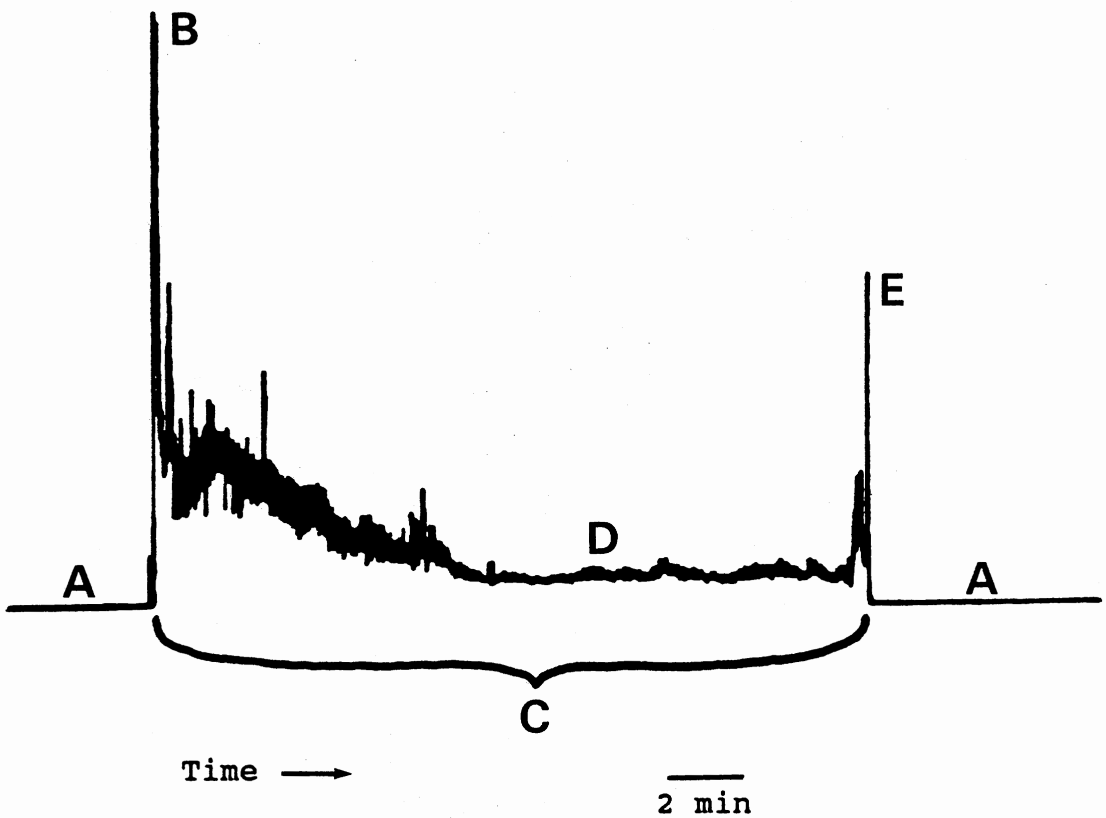

Fig. 1. Representative waveforms recorded during electronic feeding monitoring of first instar squash bugs, A. tristis, on cucurbit hosts. A = baseline, B = probe, C = total stylet contact, D = committed ingestion, E = exit peak. (Sequence of waveforms read from left to right; chart speed = 0.5 cm per minute).

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