A SURVEY OF SIZES AND WEIGHTS OF BEMISIA TABACI (HOMOPTERA: ALEYRODIDAE) B BIOTYPE LIFE STAGES FROM FIELD GROWN COTTON AND CANTALOUPES

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Abstract Size and weight measurements were made for all the life stages of *Bemisia tabaci* (Gennadius) B biotype from field grown cotton (*Gossypium hirsutum* L.) and cantaloupe (*Cucumis melo* L., var. *cantalupensis*) in Phoenix, AZ and Fargo, ND, USA in 2000 and 2001. Nymphal volumes were derived from the measurements. The average nymphal volume increase for settled 1st to the late 4th instar was exponential. The greatest increase in body volume occurred during development from the 3rd to early 4th instar. Nymphs on cotton leaves were wider, but not longer compared with those on cantaloupe. Ventral and dorsal depth ratios of nymphal bodies from 1st to late 4th instars from cantaloupe leaves were significantly greater compared with those from cotton leaves. During nymphal development from 1st to 4th instar, the average (from the two host species) ventral body half volume increased by nearly 51 times compared with an increase of 28 times for the dorsal body half volume. Adult female and male average lengths, from heads to wing tips, were 1 126 μm and 953 μm, respectively. Average adult female and male weights were 39 and 17 μg, respectively. Average widths, lengths, and weights of eggs from cotton and cantaloupe were, 99 μm, 197 μm, and 0.8 μg, respectively. Average widths, lengths, and weights for exuviae of non-parasitized nymphs from both cotton and cantaloupe were 492 μm, 673 μm, and 1.20 μg, respectively; and widths, lengths, and weights of parasitized nymph exuviae were 452 μm, 665 μm, and 3.62 μg, respectively. Both exuviae from non-parasitized and parasitized nymphs from cotton leaves were wider, longer, and heavier than those from cantaloupe leaves.

Key words *Bemisia tabaci* B biotype, *Bemisia argentifolii*, body size, body weight, body volume, parasitized exuviae

1 INTRODUCTION

Bemisia tabaci (Gennadius) B-biotype (= *B. argentifolii* Bellows and Perring), has been an economic pest of field and ornamental crop plants in the United States since 1991. Resulting agricultural losses of over one half billion dollars have occurred (Perring *et al*. 1993). Speculation is that the B biotype first occurred in Florida in 1986, and then spread to other parts of the United States with poinsettia (*Euphorbia pulcherrima* L.) shipments (Gill 1992). The B biotype (referred to hereafter as *B. tabaci*) is more cold tolerant, develops faster, and is five times more prolific than the A biotype (Gill 1992). Numerous factors, such as temperature and host species, influence the developmental rates of *B. tabaci* from eggs to adults (Butler *et al*. 1983, Coudriet *et al*. 1985, Wagner 1995, Darwish *et*

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al. 2000). Host plant effects on morphometrics of each developmental stage are poorly documented. However, Mound (1963) found in a field cage study that *B. tabaci* nymph exuvia on tobacco (*Nicotiana tabacum*) were longer and narrower than those from cassava (*Manihot esculenta*). Bethke *et al*. (1991) reported that in a leaf-cage study, *B. tabaci* nymphs were larger when reared on cotton than when reared on poinsettia. Liu and Oetting (1993) described and measured morphological characters of three species of whiteflies including *B. tabaci* from greenhouse grown plants. No information is available of host effects on size and weight of *B. tabaci* developing in the field. We reported earlier that cantaloupe (*Cucumi melo* L., var. *cantalupensis*) was a preferred host of *B. tabaci* compared with cotton (*Gossypium hirsutum* L.) and some other plant species (Chu *et al*. 1995). Different plant species have different leaf topographies as well as nutritional values that may influence *B. tabaci* development. The objectives of this survey were to examine size dimensions, weights, and body volumes of *B. tabaci* developmental stages and exuvia from non-parasitized and parasitized nymphs sampled from field grown cotton and cantaloupe.

2 MATERIALS AND METHODS

2.1 Field Plots

Cotton cv. Stoneville (ST) 474 (Stoneville Pedigreed Seed Co., Maricopa, AZ) and cantaloupe cv. Top Mark (Abbot & Cobb Inc., Brawley, CA) seeds were planted in April and July, respectively, in 2000 and 2001. The soil type was Avondale loam (Kimball *et al*. 1992).

2.2 Sampling and Measurement

Bemisia tabaci infested leaf samples from terminal seven leaf nodes on main stems of plants during August to October of each year were randomly selected, detached, and immediately placed in water filled floral tubes at approximately 0530 h. The floral tubes with leaf samples were placed in a Styrofoam cooler and shipped overnight to Fargo, ND for further processing. Forty groups of *B. tabaci* were randomly selected from the underleaf surfaces of the sampled leaves and removed with an anatomical needle. Each group consisted of three each of eggs, settled 1st and 2nd instar nymphs; one each of 3rd, early 4th, and late 4th instar nymphs; one each of male and female adults; and one each of exuviae from non-parasitized and parasitized nymphs.

2.2.1 Nymphs Nymphal instars were designated as settled 1st, 2nd, 3rd, early 4th, and late 4th instars when they measured 230–289, 290–379, 380–579, > 579 μm, and > 579 μm with distinctive red-eyes, respectively (James Buckner, unpublished data). The samples of each life stage were weighed with a Mettler Toledo MT/UMT Microbalance (CH-8606 Greitensee, Switzerland). Measurements of lengths and widths of the live nymphs, and exuvia were made using an image analysis program (OPTIMAS, Medina Cybernetics, Silver Spring, MD). Each individual life stage was placed at one edge of a microscope cover glass. The opposite edge of the cover glass was attached to a microscope slide with a piece of scotch tape. The lengths and widths of nymphs were measured from a dorsal view (Fig. 1A). The depths of nymphs were measured from the side at the nymph stylet base part of nymph body by raising the hinged cover glasses at 90° angles to the microscope slide surfaces. The depths of nymph bodies were further divided into the dorsal and ventral body halves by measuring the distance from the dorsal and ventral nymph surfaces to a horizontal reference line drawn in the submarginal cuticle area extending from anterior to posterior of the nymph bodies (Fig. 1B, lateral view). For settled 1st and 2nd instars, one individual was randomly selected form a set of three nymphs for measurement.

2.2.2 Calculation of nymph body volumes

Nymph body volumes were estimated using the ellipsoid model of Leithold (1972). The model describes a quadratic surface that appears to fit the nymphal body shape. The ellipsoid model is $4/3 \times \pi \times X \times Y \times Z$, where X, Y, and Z are the nymph lengths, widths, and depths for either the ventral or the dorsal half, respectively. Since the length and the width are twice the radius, the equation is reduced to:

$(4/3 \times \pi \times X/2 \times Y/2 \times Z/2$ (= dorsal height))/2 for the volume of dorsal body half,

$(4/3 \times \pi \times X/2 \times Y/2 \times Z/2$ (= ventral height))/2 for the volume of ventral body half, and

$1/6 \times \pi \times X \times Y \times Z$ (total height) for total body volume.

2.2.3 Adults, eggs, and exuvia For male or female adults, each individual was weighed and length from head tip to wing tip was measured. For live eggs, three eggs in each group were weighed and one egg was randomly selected for measurements of heights and widths (at the widest parts). For the exuvia, each individual was weighed and length and width (at the location adjacent to the adult exit holes) were measured using a scanning electron microscope (SEM).

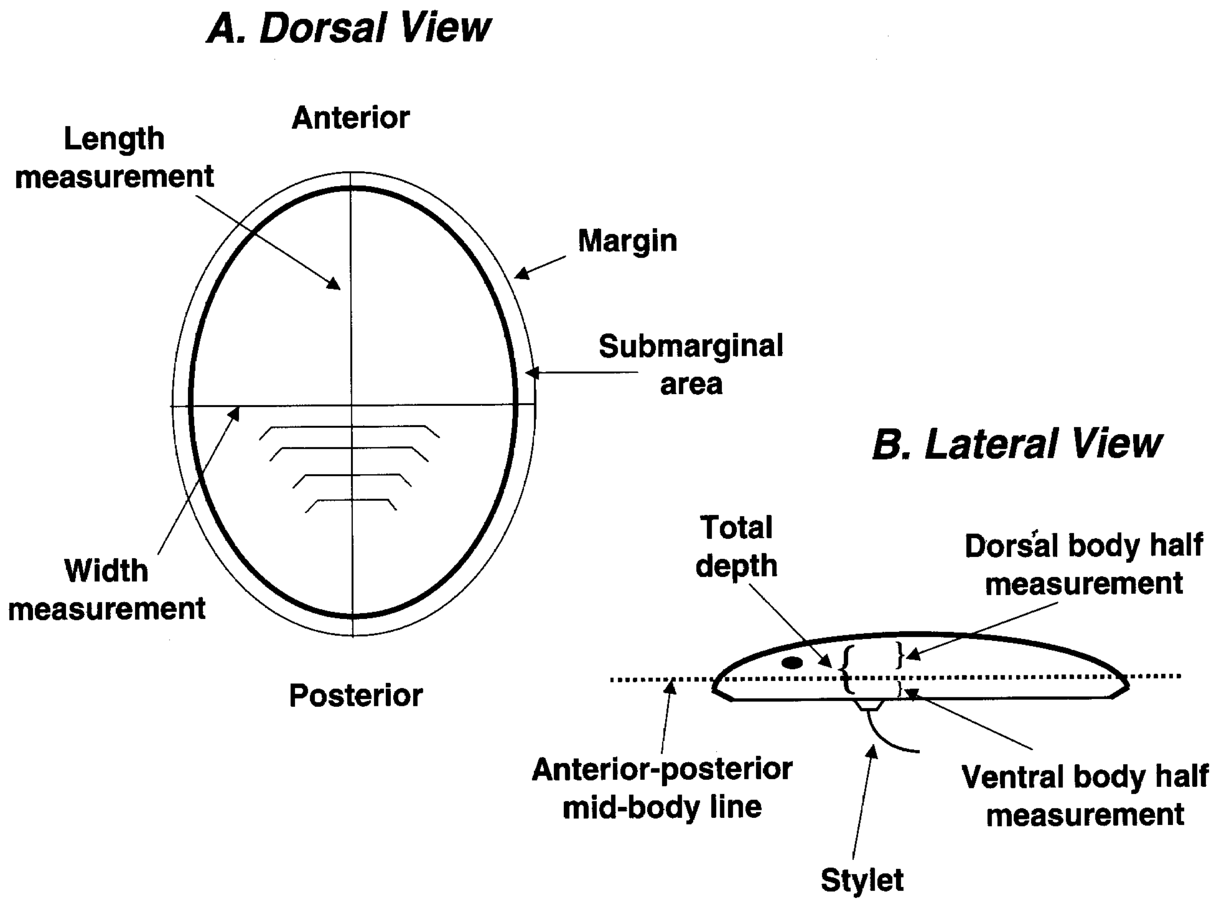

Fig. 1 Generalized *Bemisia tabaci* body structure diagram showing (A) dorsal view: width and length, and (B) side view: depth, dorsal and ventral half body measurement areas.

2.3 Data analyses

All measurements were square root transformed and analyzed with one-way ANOVA. The paired means from cotton and cantaloupe were separated using *t*-tests (MSTAT-C 1989). Mean weights of three eggs, and thee settled 1st or 2nd instars were used for the analyses. Means of untransformed measurements are presented. Mean nymph body volume values for cotton and cantaloupe for each life stage from the settled 1st to late 4th instars were analyzed using regression analysis and a generalized growth curve was constructed.

3 RESULTS

3.1 Nymphs

Mean total body volumes for nymphs from cotton and cantaloupe combined increased 3.4 times, 1.8 times, and 5.8 times during 1st to 2nd, 2nd to

3rd, and 3rd to early 4th instar development, respectively. Body volumes decreased 1.3 times during early 4th to late 4th instar development ($n = 80$ for each life stage, $F = 474.4$, $P < 0.001$, df = 4,395) (Fig. 2). The average body volume of early 4th instar nymphs was 35.6 × the average volume of 1st instar settled nymphs.

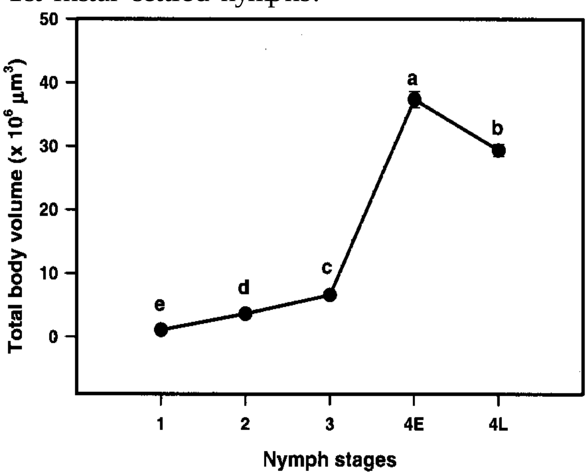

Fig. 2 Mean ± SE ($n = 80$) *Bemisia tabaci* volumes of nymph bodies in the 1st to early 4th (4E) and late 4th (4L) instars on field grown cotton and cantaloupes, ($F = 474.4$, $P < 0.0001$, df = 4,395).

The average total body volumes were not significantly different from the different hosts for 1st, 2nd, and late 4th instars ($F = 1.2$, 0.7, and 1.4; $P = 0.285$, none, and 0.248, respectively; df = 1, 78) (Table 1), but the average total body volumes of 3rd and early 4th instars from cotton were significantly less and significantly greater, respectively, than for nymphs from cantaloupe ($F = 10.1$ and 8.1, and $P = 0.002$ and 0.006, respectively; df = 1, 78). Theaverage volumes of dorsal body halves were not significantly different from the different hosts for 2nd, 3rd, and late 4th instars ($F = 1.1$, 2.7, and < 0.1; $P = 0.295$, 0.102, and none, respectively; df = 1, 78), but the average volume of dorsal body halves of the 1st and early 4th instars from cotton were significantly greater than nymphs from cantaloupe ($F = 9.1$ and 21.9; $P = 0.004$ and < 0.001, respectively; df = 1, 78). The average volumes of ventral body halves from cotton were significantly less for 1st, 2nd, and 3rd instars, not significantly different in early 4th instar, and significantly greater in late 4th instars than nymphs from cantaloupe ($F = 17.1$, 4.9, 14.2, 0.6, and 4.1; $P =$ < 0.001, 0.030, < 0.001, none, and 0.047, respectively; df = 1, 78). The ratios of ventral and dorsal body half volumes from 1st to early 4th instars from cotton were significantly less than from cantaloupe, but greater for the late 4th instar ($F = 24.9$, 9.2, 12.1, 16.6, and 5.7; $P < 0.001$, 0.003, < 0.001, < 0.001, and 0.020, respectively; df = 1, 78). As nymphs developed from 1st to early 4th instars, the overall averages of ventral body half volumes from cotton and cantaloupe increased about 48 times (71% more) compared with 28 times for the dorsal body half volumes.

Table 1 Mean ± SE lengths, widths, body volumes, and weights of *Bemisia tabaci* instars developing on field grown cotton and cantaloupe, Phoenix, AZ, USA 2000 and 2001.

Instar	Host	μm[a]			Volume (×10^5 μm^3)			V/D (×100)	
Weight (μg)		Width	Length	Depth	Total	Dorsal	Ventral		
1st	Cotton	135 ± 2[a]	250 ± 2[a]	57 ± 2[b]	10 ± 0[a]	7 ± 0[a]	3 ± 0[b]	50 ± 4[b]	0.9 ± 0.1[a]
	Cantaloupe	129 ± 3[b]	244 ± 4[a]	66 ± 2[a]	11 ± 0[a]	6 ± 0[b]	5 ± 0[a]	115 ± 14[a]	1.0 ± 0.1[a]
2nd	Cotton	214 ± 8[a]	355 ± 12[a]	76 ± 3[b]	34 ± 3[a]	21 ± 2[a]	13 ± 2[b]	70 ± 7[b]	3.1 ± 0.3[a]
	Cantaloupe	192 ± 6[b]	350 ± 10[a]	98 ± 4[a]	38 ± 4[a]	18 ± 2[a]	20 ± 2[a]	156 ± 39[a]	3.6 ± 0.3[a]
3rd	Cotton	270 ± 9[a]	434 ± 13[a]	71 ± 5[b]	51 ± 5[b]	29 ± 2[a]	23 ± 3[b]	82 ± 8[b]	4.9 ± 0.3[b]
	Cantaloupe	267 ± 10[a]	456 ± 14[a]	123 ± 8[a]	79 ± 8[a]	36 ± 3[a]	43 ± 5[a]	133 ± 12[a]	8.4 ± 1.0[a]
Early 4th	Cotton	498 ± 9[a]	724 ± 11[a]	214 ± 7[b]	409 ± 18[a]	215 ± 10[a]	195 ± 10[a]	92 ± 4[b]	32.5 ± 1.4[a]
	Cantaloupe	413 ± 10[b]	603 ± 12[b]	258 ± 9[a]	339 ± 16[b]	154 ± 9[b]	185 ± 10[a]	127 ± 7[a]	30.0 ± 1.2[a]
Late 4th	Cotton	445 ± 8[a]	664 ± 10[a]	193 ± 5[a]	305 ± 15[a]	173 ± 9[a]	132 ± 8[a]	79 ± 4[a]	28.0 ± 1.3[a]
	Cantaloupe	409 ± 6[b]	636 ± 8[b]	204 ± 6[a]	282 ± 13[a]	171 ± 8[a]	111 ± 7[b]	66 ± 4[b]	29.7 ± 1.3[a]

[a] Means ± SE (n = 40) within each instar in a column not followed by the same letters are significantly different (t-test, $P = 0.05$).

Regression analysis showed that for cotton, ventral body half volumes increased 4.3 times, 1.8 times, and 8.5 times and for cantaloupes 4.0 times, 2.2 times, and 4.3 times during development from 1st to 2nd, 2nd to 3rd, and 3rd to early 4th instars, respectively ($F = 308.1$ and 212.0; $P < 0.001$, respectively; df = 3, 156, Table 1). Dorsal body half volumes for nymphs on cotton increased 3.0 times, 1.4 times, and 7.4 times and on cantaloupe 3.0 times, 2.0 times, and 4.3 times, in each case for 1st to 2nd, 2nd to 3rd, and 3rd to early 4th instars development, respectively ($F = 348.6$ and 202.1; $P < 0.001$, respectively; df = 3, 156). The largest differences in increases of body volumes between cotton and cantaloupes occurred during development from 3rd to early 4th instars. For cotton, the ratios of ventral body half to dorsal body half volumes for nymphs on cantaloupes were 2.3 times, 2.2 times, 1.6 times, and 1.4 times for 1st, 2nd, 3rd, and early 4th instars, respectively. For cantaloupes, the ratios of ventral body half to dorsal body half growth rate increased only for settled 1st to 2nd instar nymphs and decreased during 3rd to early 4th and early 4th to late 4th instar development.

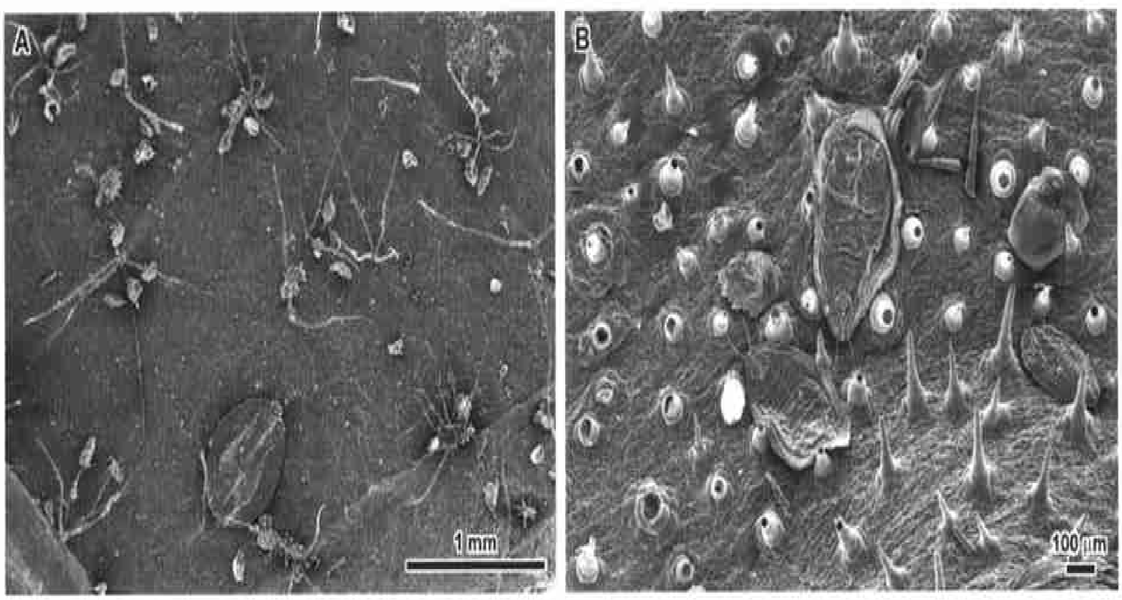

Fig. 3 Abaxial plant leaf surfaces and *Bemisia tabaci* nymphs. (A) cotton and (B) cantaloupe

Nymphs from cotton leaves were significantly longer in the early 4th and late 4th instar stages ($F = 51.7$ and 5.0; $P < 0.001$ and 0.028, respectively; df = 1, 78) and wider in each instar stage ($F = 4.3$ to 42.9; $P < 0.001$, respectively; df = 1, 78) except the 3rd instar compared with nymphs from cantaloupes (Table 1). However, nymphal dorso-ventral depths for 1st, 2nd, 3rd and early 4th instars from cantaloupe leaves were significantly greater compared with cotton (F = from 14.6 to 40.7; $P = 0.002$ to < 0.001, respectively; df = 1, 78).

Weights of each instar stage from cotton or cantaloupes were not significantly different, except for the 3rd instars that were heavier from cantaloupes compared with cotton ($F = 14.9$; $P < 0.001$; df = 1, 78) (Table 1).

3.2 Adults, eggs, and exuviae

The average adult length from head to tip of wing for female was 18 % longer compared with males ($F = 546.0$, $P < 0.001$, df = 1, 78) (Table 2). The average adult female weighed over 2 times more heavier than the average male, ($F = 697.9$, $P < 0.001$, df = 1, 78). The overall averages (cotton and cantaloupe) for widths, heights, and weights of eggs were 99 μm, 197 μm, and 0.8 μg, respectively. Differences between egg widths and weights from cotton and cantaloupe were not significantly different ($F = 3.2$ and 0.6; $P = 0.077$ and none, respectively; df = 1, 78). The average egg length from cantaloupe was longer than for cotton ($F = 4.2$, $P = 0.044$, df = 1, 78). The average weight of exuvia from parasitized nymphs was 3 times heavier than from non-parasitized nymphs ($F = 149.3$, $P < 0.001$, df = 1, 158). Exuviae of non-parasitized and parasitized nymphs from cotton leaves were significantly wider, longer, and heavier compared with cantaloupe (F = from 8.8 to 71.8, $P < 0.001$, df = 1, 158).

Table 2 Mean ±SE lengths, widths, and weights of *Bemisia tabaci* adults, eggs, and exuviae developed on field grown cotton and cantaloupes, Phoenix, AZ, 2000 and 2001.

Stage (μg)	Host	(μm) [a]		Weight
		Width	Length	
Adult				
Male	Cotton and cantaloupe	—	953 ±5[b]	17.0 ±0.3[b]
Female	Cotton and cantaloupe	—	1126 ±6[a]	39.0 ±0.8[a]
Egg	Cotton	84 ±1[a]	179 ±2[b]	0.81 ±0.04[a]
	Cantaloupe	113 ±18[a]	215 ±20[a]	0.84 ±0.02[a]
Exuviae				
Non-parasitized	Cotton	532 ±10[a]	697 ±10[a]	1.4 ±0.1[a]
	Cantaloupe	452 ±9[b]	648 ±9[b]	1.0 ±0.1b
Parasitized	Cotton	502 ±11[a]	714 ±12[a]	4.5 ±0.3[a]
	Cantaloupe	401 ±5[b]	616 ±12[b]	2.8 ±0.2[b]
Mean	Non-parasitized	492 ±8[a]	673 ±7[a]	1.2 ±0.1[b]
	Parasitized	452 ±8[b]	665 ±10[a]	3.6 ±0.2[a]

[a] Means ±SE ($n = 40$) of an insect stage within a column not followed by the same letters are significantly different, (t-test, $P = 0.05$).

4 DISCUSSION

Bemisia tabaci nymph growth has been reported to be influenced by the topography of abaxial leaf surfaces (Neal and Bentz 1999, Guershon and Gerling, 2001). As nymphs grow, more space is needed. Fig. 3 shows normal shaped nymphs on cotton compared with deformed nymphs on cantaloupes. Deformed 4th instar nymphs also found on a watermelon plants (Rosell *et al*. 1997). Although speculative, it appears that nymph deformities may occur because of the high trichome density on abaxial leaf surfaces of cantaloupe that interfere with the growth of nymphs. Results suggest nymph width growth on cantaloupe leaves may be compensated by depth growth but the weights of nymphs were similar on the two hosts. Further study under field conditions is needed to verify our observations. During growth from 1st to early 4th instar, nymph ventral body half volume increased 71% more than the dorsal body half volume even though settled (feeding) nymphs are sessile and the ventral body appressed to leaf surfaces (Freeman *et al*. 2001).

Lengths and widths of *Bemisia* nymphs have been reported to vary on different hosts under similar environmental conditions (Mound 1963, Bethke *et al*. 1991). Using greenhouse grown green bean plants, Gelman *et al*. (2002) showed that *T. vaporariorum* nymph body depth increased during substages 1 to 5 (corresponding to our early 4th instar) but remained the same during nymph sub-stages 6–9 (corresponding to our late 4th instar). The results differ from our field survey where nymph widths, lengths, and volumes decreased during the late 4th instar nymph development. The reasons for the difference are not known.

Gelman *et al*. (2002) suggested that the product of length × width, rather than mean lengths and widths gave more accurate identification of consecutive stages of *T. vaporariorum* instar development. The body volume measurements (length ×width ×depth) as shown in our studies may also

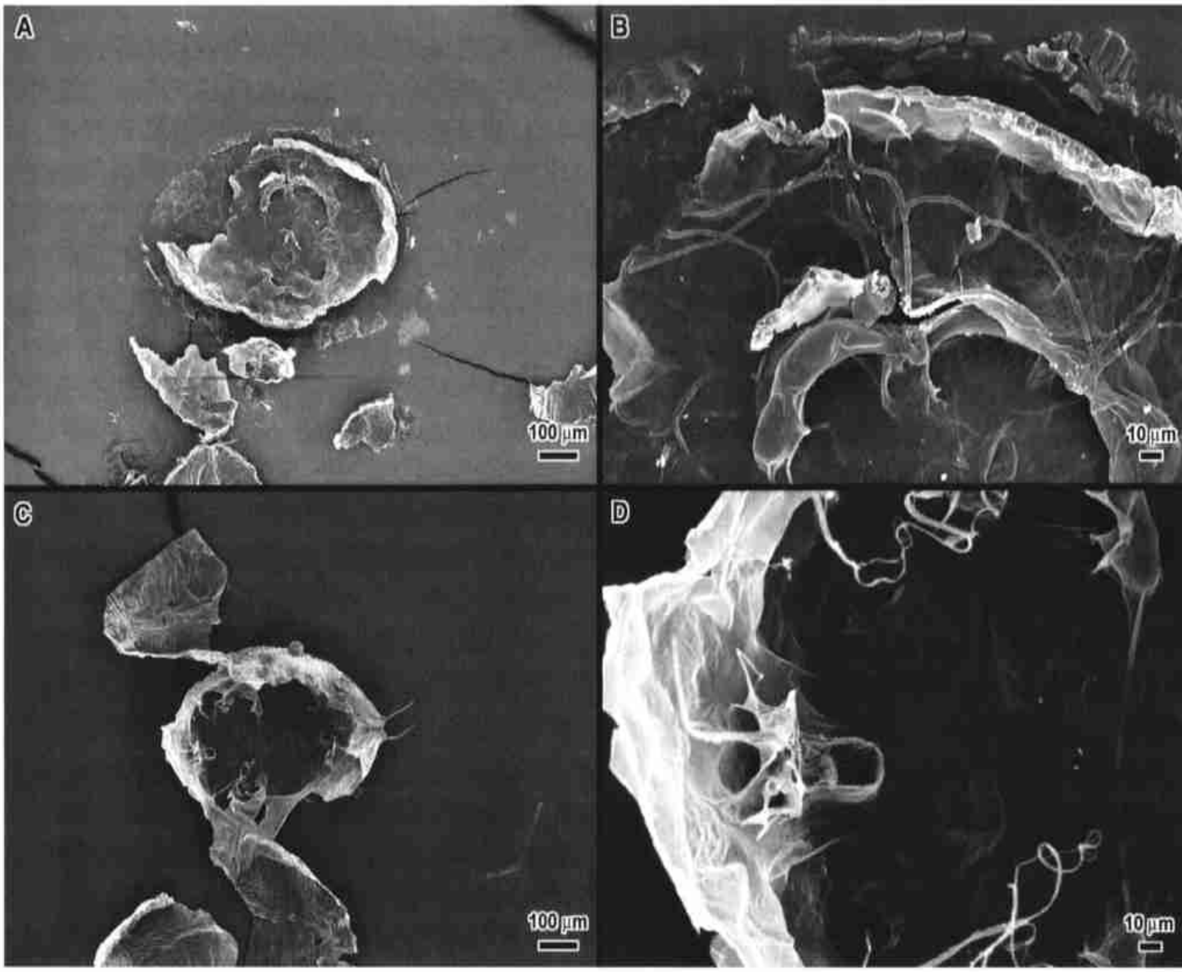

Fig. 4 Dissected *Bemisia tabaci* exuvia exposing the developing parasitized and non-parasitized nymphs : (A and B , parasitized nymphs) and (C and D , non-parasitized nymph) . Sectional tubes appear to be the parasitoid remains , are visible in exuvia from the parasitized nymph , but lacking in the exuvia from non-parasitized nymph.

be an alternative for identification of instars after verification of the accuracy and potential use of the method.

Adult females in our studies , similar to report of Bethke *et al*. (1991) were larger and heavier. The difference in size may be related to the reproductive function of females. Egg size measurements from cotton and cantaloupe hosts were not significantly different. The results may be due to dispersal between crops or simply that eggs are not effected by host association.

Exuviae from nymphs that developed on cotton were longer , wider , and heavier compared with cantaloupes. The results agree with those of Mound (1963) that sizes of exuviae from different host plant species varies. Exuviae from parasitized nymphs were significantly smaller compared with non-parasitized nymphs. This may occur because parasitism restricts nymph growth. However , exuviae from parasitized nymphs were 3 times more heavier than non-parasitized nymphs. Possibly because the exuviae from parasitized nymphs contain *Bemisia* remains and molting tissues and meconium from parasitoids (Fig. 4A - 4D) .

Mean nymph lengths from field grown cotton in our studies were smaller than those reported by Bethke *et al*. (1991) on greenhouse grown cotton. Limited nutritional supply and unfavorable environmental conditions in the field may account for the size differences.

5 CONCLUSION

A survey of *Bemisia tabaci* B biotype from field grown cotton and cantaloupe was conducted at the deserted southwest in the United Staes. Results showed that the increase of nymphal body volumes from the settled 1st to the late 4th instar followed an exponential growth curve. Ventral body half volume increased about 51 times compared with 28 times for the dorsal body half volume. The greatest increase in body volume was from the 3rd to early 4th instar. Ventral and dorsal depth ratios of nymphal bodies of all stages on cantaloupe were greater than those on cotton. On average for the two crops, the adult female was 20 % longer but more than twice heavier compared with the males. Average widths, lengths, and weights of eggs from cotton and cantaloupe were 99μm, 197μm, and 0.8μg, respectively. Average widths, lengths, and weights of exuviae for non-parasitized nymphs were 492μm, 673μm, and 1.20μg, respectively; and 452μm, 665μm, and 3.62μg, respectively, for parasitized nymph exuviae. Both exuviae from non-parasitized and parasitized nymphs from cotton were wider, longer, and heavier than those from cantaloupe. The differences of nymphal body growth and exuvia size between cantaloupe and cotton suggest that trichome density affected development of nymphal body shapes, but other plant functions e.g. nutritional levels may also be involved.

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棉花和香瓜的甘薯粉虱 *Bemisia tabaci* (同翅目, 粉虱科) B 生态型虫体大小和重量的田间调查

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2000 和 2001 年在美国凤凰城和北达科塔州法哥城田间,调查棉花和香瓜上甘薯粉虱 *Bemisia tabaci* B 生态型所有虫期虫体大小和重量。从若虫大小计算出若虫的体积。第一到第四龄晚期,若虫平均体积以指数方式增加。体积增加最快的是第三到第四龄早期。棉花上的若虫比香瓜上的宽,但是并不比较长。香瓜上第一到第四龄早期的若虫,最厚部位的腹部和背部厚度比例显著比棉花上的要高。两种寄主作物上的若虫从第一到第四龄发育期,腹部厚度平均增加将近 51 倍,而背部厚度只增加 28 倍。雌虫和雄虫从头顶到翅尖平均长度分别为 1126 和 953 微米,重量为 39 和 17 微克。棉花和香瓜上的虫卵平均长,宽,重分别为 197 微米,99 微米,和 0.8 微克。未被寄生的蛹壳长,宽,重分别为 673 微米,492 微米和 1.2 微克;被寄生的蛹壳为 665 微米,452 微米,和 3.6 微克。棉花上未被寄生和被寄生的蛹壳比香瓜上的长,宽,和更重。

关键词 *Bemisia tabaci* B 生态型, *Bemisia argentifolii*, 虫体大小, 虫体重量, 虫体体积, 被寄生的蛹壳