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Differences in Defoliation of Fruit Genotypes by Adult Japanese Beetle Feeding

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Abstract

Since Japanese beetles ((*Popillia japonica* Newman, Coleoptera: Scarabaeidae) were first reported in Northwest Arkansas in 1997, population and geographic distribution have increased significantly accompanied by damage to horticultural crops and other plants. The adult beetle trapping period in Northwest Arkansas counties begins in June and continues until mid-August with the greatest capture from 7 to 30 July. This paper reports observations of adult Japanese beetle (JB) damage during the period of 2003 through 2005 in fruit crops grown in Fayetteville, AR . Adult beetle trap catches increased annually from 1997 until 2004, decreased in 2005 and 2007 but rebounded in 2006 and 2008. The foliage of 262 apple, 27 apple rootstock, 17 crabapple, 21 blueberry, 20 blackberry and 17 grape genotypes was evaluated for adult JB feeding damage by multiple evaluators during two growing seasons (2003 and 2004). The majority of apple, crabapple, blackberry, blueberry, and grape genotypes had moderate to severe foliar feeding damage, but, several apple, blackberry, blueberry, and grape genotypes had minimal damage. When apples of the same cultivar ('Gala') on different rootstocks were evaluated, scion foliage damage varied significantly with rootstock. The findings and observations of this study may be useful in future research on the molecular or biochemical basis for variation in feeding preference, for breeding new genotypes with low adult foliar feeding susceptibility, and as a basis for developing recommendations and management strategies for Japanese beetle in fruit plantings in the upper mid-south region.

Japanese beetle (*Popillia japonica* Newman, Coleoptera: Scarabaeidae) (JB) was first reported in New Jersey in 1916 (3). By 1998, recently established populations of JB were noted in south and mid-west states including Alabama, Arkansas, Georgia, Iowa, Kansas, Maine, Michigan, Minnesota, Missouri, Nebraska, Oklahoma, Tennessee, Texas, and Wisconsin as well as southern Ontario and Quebec, Canada (29). In 1997, the earliest detection of JB in Arkansas occurred in Fayetteville (Washington County, +36° 4' N, -94° 11' W). By 2001, the Arkansas State Plant Board surveys indicated 11 Arkansas counties had established populations of JB with economic damage occurring in Benton and Washington Counties (13, 14, 37). Because it is a relatively new pest to this region, there are few reports on the feeding damage caused by adult JB on specific fruit crop cultivars grown in this region.

The beetle has reportedly damaged leaves and/or fruit of at least 300 plant species in over 80 families (5, 30, 31). Within its broad host range, beetles caused the greatest feeding damage on woody plants in the families Aceraceae, Betulaceae, Malvaceae, Rosaceae, Saliceae, Tiliaceae, and Ulmaceae (5, 16, 17, 27, 28, 30) as well as Vitaceae (14). Rosaceae is represented by several important economic and ornamental plants including apples, crabapples, and blackberries.

The damage to fruit crops by adult JB feeding may be both direct and indirect. The direct effect would be feeding upon the fruit while the indirect damage would be caused by leaf skeletonization and defoliation after foliar feeding which reduces the photosynthetic surface area of leaves needed to sustain fruit growth. However, neither of these effects has been well studied nor quantified. Previous research has demonstrated that

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damage by insect pests such as mites or leaf miners may reduce photosynthesis (4, 20, 32), fruit size, quality, and cropping (20, 21, 25). Therefore, in the absence of empirical evidence it is inferred that a level of defoliation by adult JB feeding during the growing season would be deleterious to the crop.

Adult JB tend to congregate and feed on plants, resulting in severe defoliation of more highly preferred hosts such as roses (*Rosa* spp.), lindens (*Tilia* spp.), and flowering crabapples (*Malus* spp.) (24, 31). Allelochemicals are important in attracting JB to a host. Japanese beetles are very attracted to rose flowers and to three of the odors they release, phenethyl alcohol, eugenol and geraniol (23). Ladd and McGovern (19) increased JB trap catch by baiting yellow funnel traps with two lures: 3:7:3 floral odor blend of phenylethyl propionate:eugenol:geraniol plus a sex pheromone lure R-japonilure (40). Metzger (26) reported that 85% of the plant species or varieties attacked by JB suffered sustained foliar and fruit feeding y if leaves or fruit contained >15 mg/g of soluble carbohydrate.

Japanese beetles have been deterred from feeding on host plants. Feeding damage was significantly reduced when foliage was coated with an extract of unripe holly fruits (*Ilex opaca* Aiton) that contain high levels of saponins (15). Fulcher et al. (6) identified phloridzin as the only endogenous phenolic that was significantly related to resistance to foliar feeding by JB. Kaolin clay (Surround®) particle film applied to foliage and fruit prevented peach fruit damage (22) and apple and grape foliar damage (DTJ, unpublished data). Known insect deterrents such as extracts of garlic, *Allium sativum* L., cayenne pepper, *Capsicum anuum* L., or neem, *Azadirachta indica* A Juss., applied to birch did not reduce JB feeding (41). Earlier, Ladd et al. (18) found that extracts of neem seeds containing azadirachtin were strongly deterrent. Japanese beetle feeding on susceptible roses was reported to increase when interplanted with companion plants, e.g., rue (*Ruta graveolens* L.), zonal geranium (*Pelargonium x hortorum* Bailey), garlic chives (*Allium scheonparum* L.), or surrounded with mesh bags of aromatic herbs of reputedly repellent nonhost volatiles, e.g., crushed red pepper (*Capsicum frutescens* L.), fennel seeds (*Foeniculm vulgare* Miller), crushed spearmint (*Mentha picata* L.), cedar shavings (*Juniperus* sp.), osage orange fruits (*Maclura pomifera* (Raif) Schneid.), and fleshy gingko seeds (*Gingko biloba* L.) (10, 11).

Most observations of host plant resistance to JB feeding damage were anecdotal descriptions making empirical and quantitative studies necessary (5, 9, 34). Fleming (5) noted discrepancies in the reported lists of plants that were either susceptible or resistant to JB. Ladd (16, 17) confirmed that plants classified by Fleming (5) to be moderately or highly preferred by JB included black cherry (*Prunus serotina* Ehrlich), 'Rome' apple (*Malus* x *domestica* Borkhold), European birch (*Betula pendula* Roth), and southern catalpa (*Catalpa bignonioides* Walt). Ranney and Walgenbach (33), reported significant differences in defoliation by JB among selected genotypes of birches (*Betula* spp.), flowering cherries (*Prunus* spp.), and flowering crabapples (*Malus* spp.). Gu et al. (8) found significant variation of beetle feeding damage among birch genotypes in Arkansas. Spicer et al. (39) reported consistent differences in defoliation damage to 42 different cultivars of flowering crabapples. Potter et al. (31) observed significant relative differences in susceptibility of flowering crabapples, lindens, and roses to defoliation by JB.

To date, a limited number of economic fruit genotypes have been evaluated for relative susceptibility to adult JB foliar feeding damage. In addition, no surveys have been conducted to determine how extensive the recently introduced JB population in Arkansas has become. As the JB population reached pest status in Fayetteville, AR, they began differentially attacking replicated blocks of breeding selections and cultivars of apple, blackberry, blueberry, crabapple and grapes. The objective of this work was to evaluate and document the levels of JB infestations in northwest Arkansas, and to determine the variation in susceptibility to JB foliar feeding in small fruit, grape and tree fruit genotypes.

Materials and Methods

Trapping. Trap monitoring for adult JB began in 1997 using TBC Japanese beetle yellow funnel traps (The Tanglefoot Company, Grand Rapids, MI) set at 0.5 m height and checked weekly throughout the flight season from early June until mid-August annually. Traps were initially placed in a residential neighborhood and at the University of Arkansas Research and Extension Center (UAREC) farm, Fayetteville, AR. In subsequent years as populations increased, trapping was expanded both in locations and in density of traps placed.

In order to determine the presence/absence, the date of emergence and relative population and distribution of the adult JB, trap catches were recorded in locations within western Arkansas bordering on the Arkansas River, south and west of Fayetteville (Washington County) during 2004 and 2005. On 27 May 2004, 23 JB yellow funnel traps were set out at 0.5 m height and checked weekly throughout the flight season in Crawford and Sebastian counties. In 2005, 24 JB traps were monitored in Crawford, Sebastian, and Franklin counties.

In 2005, baited JB traps were placed in six locations in northwest Arkansas: central Fayetteville, University of Arkansas, Research and Extension Station Farm (Fayetteville), Elkins, Hindsville and Springdale (Washington County); and an apple orchard in Berryville (Carroll County). The number of traps varied in each location depending upon sampling area and available resources. In 2006 through 2008, 15 traps were placed at approximately 60 m intervals in a line adjacent but in close proximity to the fruit plots. Each baited yellow funnel trap was attached over a 6 cm diameter hole in the cover of an approximately 11 L plastic box to contain the large numbers of JB with the lure and trap 0.5 m above the ground. Each trap was sampled twice weekly from first beetle flight on 1 June until trap catch approached zero in late August. The volume of each trap sample was recorded and converted to the adult JB number per trap (100 ml volume = 350 JB; unpublished preliminary studies). Volume of adult JB was a better estimator of JB numbers than sample weight due to variation caused by trap moisture content.

Fruit crop foliage damage. Between 14 and 30 July, in 2003 and 2004, replicated blocks (n>2, but varied in each trial) of apple (*Malus x domestica*), blackberry (*Rubus*

Table 1. The distribution of Japanese beetle feeding damage rating among genotypes of five fruits in Fayetteville, AR, 2003-2004 growing seasons.

		Number of genotypes showing damage (% of total)					
Damage rating[z]	Relative damage group	Apple scions	Apple rootstocks	Blackberry	Blueberry	Crabapple	Grape
0-0.9	Minimal	1 (0.4)	0 (0)	1 (5)	0 (0)	0 (0)	1 (6)
1.0-1.9	Light	116 (44)	9 (33)	4 (20)	4 (19)	0 (0)	4 (24)
2.0-2.9	Moderate	118 (45)	18 (67)	5 (25)	13 (62)	2 (15)	3 (18)
3.0-3.9	Serious to moderately severe	20 (8)	0 (0)	9 (45)	4 (19)	8 (62)	9 (53)
4.0-5.0	Severe	7 (3)	0 (0)	1 (5)	0 (0)	3 (23)	0 (0)
Total Genotypes Sampled		262	27	20	21	13	17

[z] Rating scale: 0 = no visible damage, 1 = very light damage (<1% of total foliage damaged), 2 = light damage, several terminals damaged, 3 = serious damage, threatens health (25-30% of foliage damaged), 4 = severe damage (>50% foliage damaged), 5 = very severe damage (>75% foliage damaged) with some re-growth or reaction apparent (28)

spp.), blueberry (*Vaccinium* spp.), crabapple (*Malus* spp.) and *Malus* species plantings in cultivar, genotype/selection, and apple rootstock evaluation trials at the UAREC were observed for the degree of JB foliar feeding damage. A grape (*Vitis* spp.) cultivar trial was evaluated in 2003. Blocks were replicated (either randomly or in a block design, depending upon the study) and individual plants of a cultivar, selection, genotype, or species were considered experimental units for observation. Fruit and/or flower feeding damage were not evaluated because they were not present on all plants at the time of leaf skeletonization damage rating. The canopy foliage of all crops was visually rated on a scale of 0-5 where 0 was no canopy defoliation and 5 was severe (>75%) canopy defoliation (Table 1; ref. 28). Additionally, apples and crabapples were also evaluated for visually perceived percent of total canopy defoliation on a 0-100% scale in 5% increments (35). All plants were evaluated by two or more independent evaluators. Evaluators included research personnel and volunteers. Evaluators were trained to use both the visual rating scale and percentage damage systems using trees with defined levels of damage as standards and references. Preliminary analyses indicated that although there were differences in ratings among some evaluators, there was no interaction between evaluators and assessments, and therefore, data of the evaluators were pooled as subsamples. A total of 262 apple, 27 apple rootstocks (with 'Gala' as the scion), 13 crabapple, 20 blackberry, 22 blueberry and 17 grape genotypes were evaluated. Genotypes included both commercial cultivars and breeding selections.

Analysis. The narrow range of percentages of foliar damage of apples and crabapples by JB did not warrant arc sine square root transformation (38). In order to achieve the objectives and determine if genotypes varied in foliar damage, fruit damage ratings were subjected to ANOVA in a General Linear Model (GLM) using SAS software (SAS Institute Inc., 2004, Cary, NC) and means were separated with Tukey's Studentized Range (HSD) Test.

Results and Discussion

Populations indicated by trapping. Total seasonal adult JB trap counts in Washington County increased from 49 adults per trap in Fayetteville to a more than 69,000 beetles per trap in 2005 in the adjacent city of Springdale (Fig. 1). In 2005, peak trap counts occurred

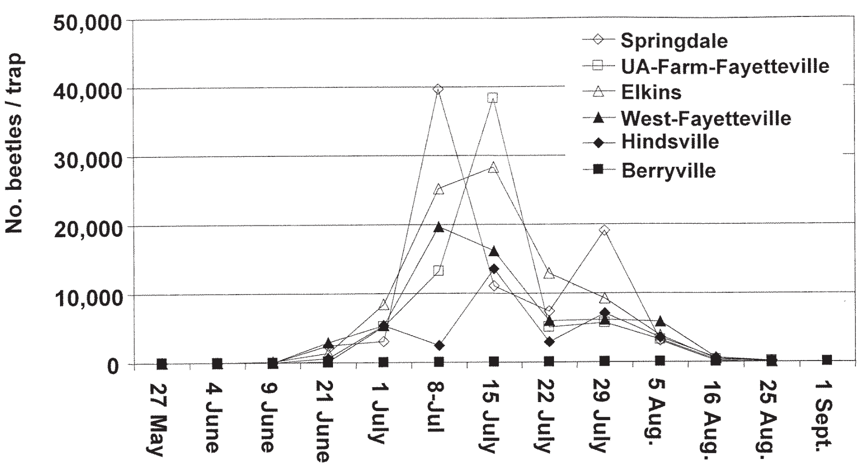

Fig. 1. The number of Japanese beetles per trap in weekly counts in six northwest Arkansas locations during 2005.

in northwest Arkansas between 8 and 15-July. Adult beetles occurred in more southern counties, (Crawford and Sebastian) in 1999 with initial trap counts of 23 beetles per trap (data not presented) and less than 200 beetles per trap in 2004 (Fig. 2) with first appearance of JB in Franklin County in 2005 (Fig. 3). In 2004 in Crawford and Sebastian counties, peak trapping occurred on 9 July, and in 2005 peak trapping occurred on 16 July in Crawford and Franklin counties. Trap monitoring and mass trapping continued at the UAREC-Fayetteville site with total seasonal counts per trap of 71,228 in 2005, 34,633 in 2006, 8,882 in 2007, and 32,914 in 2008. The cause of the trap catch decline in 2006 compared to trap catch in 2004 and 2005 was unknown. In 2007, a record warm March followed by a severe late freeze (-10°C) on 7-9 April may have killed JB larvae that were becoming active in the grass root zone. Previously, it was reported that eggs and first instar JB are sensitive to temperature and moisture extremes which were major determinants of spatial and temporal fluctuations in population density (1, 5, 35). The reduced 2007 population may have also limited populations in 2008 compared to 2004 and 2005.

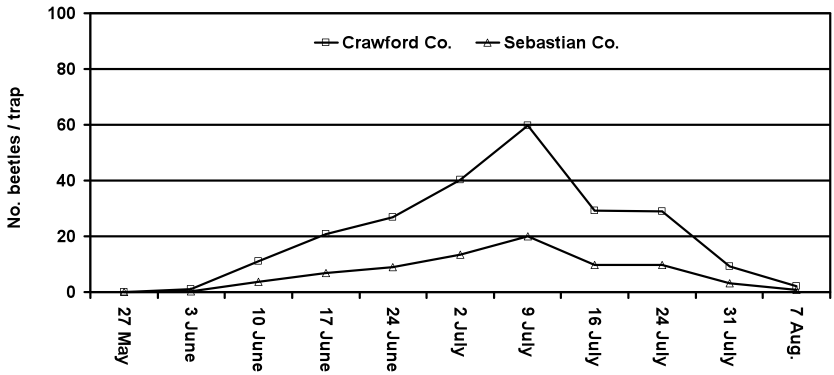

Fig. 2. The number of Japanese beetles per trap in two western Arkansas counties during 2004.

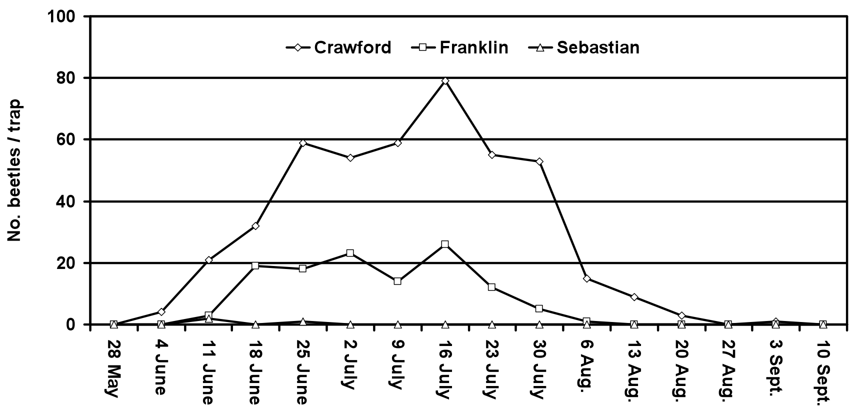

Fig. 3. The number of Japanese beetles per trap in three western Arkansas counties during 2005.

Fruit crop foliage. Adult JB foliar feeding on fruit crops started approximately mid to late June and concluded by early August in Fayetteville, AR. Significant differences in JB foliar damage were observed among apple, blackberry, blueberry, grape and crabapple genotypes, and damage ranged from no foliar feeding to severe damage (Tables 1-11). Among the fruit crops, 89.7% apple, 15.4% crabapple, 50% blackberry, 81% blueberry and 47.1% grape had damage rated as less than serious or severe (≤ 3.0 on the 0 to 5 scale) (Table 1).

<u>Apples</u>: Differences in JB foliar feeding damage were observed among cultivars, rootstocks, and Arkansas breeding selections in several research blocks in Arkansas with damage ranging from light or insignificant to severe defoliation (Tables 2 - 8). Trees in each block were treated, depending upon the study, with conventional or organic pesticides to control primary insect pests but not specifically to control adult JB. All plants within a block were treated similarly and thus, observed differences in damage likely reflected genotypic differences among the plants.

In an apple rootstock trial with 'Gala' as the scion, foliar damage ratings for scions on P22, 'Mark', and M.27 were significantly less (<2.0) than those on V1, M.9 Pajam1, M.9 Pajam2, M.9 NIC29, M.9 FL56, and Ottawa 3 (>2.4) (Table 2). Young trees of 'Gala' on nine apple rootstocks (2nd and 3rd leaf) had foliar damage <27% in 2003 and < 11% in 2004. However, although low overall damage ratings were observed on the young trees, the damage rating for M.26 NAKB was consistently greater than for B.9-Europe (Table 3). The variation in feeding among trees of the same scion genotype but different rootstock indicates that rootstocks may confer characteristics to the scion related to insect feeding. It has been reported that rootstocks can affect the foliar phenolic content which may be related to insect feeding in apple (7). It is noted that rootstocks vary in susceptibility to root infestations of pests such as wooly apple aphid (2) in the rootzone. It is also known that the nutrition of ornamental plants may affect pest susceptibility (12). Therefore, although not well studied in the pomological literature, it is reasonable to assume that rootstocks may affect pest susceptibility of the scion. Such information as observed here would be useful in rootstock breeding program to enhance the pest resistance of trees. Likewise, this information in conjunction with other rootstock reports would be useful in developing rootstock recommendations in states with large JB populations and infestation potential.

Within an apple cultivar trial (on M.26 EMLA rootstock), there were significantly greater damage ratings and percentage foliar damage for 'Spur Law Rome', NY674, AA79, Granny Smith, X6392, X3191, XH982, and 'Sundowner' (ratings of >3.0 or canopy damage of >34%) than 50 other cultivars (Table 4). Interestingly, both NY674 and AA79 were selected because of low flesh browning characteristics. Some Arkansas apple breeding selections (not listed in tables to conserve space) had extreme JB foliar feeding damage ratings and percentage foliar damage (AA-128, AA-141 and AA-69 which were all ≥4.0 and >57%, respectively). Of 83 Arkansas selections evaluated in these studies, 51 had foliar damage ratings ≤2.75 and canopy damage of ≤30.0%, and 35 had ratings ≤2.25 and ≤20.0% damage. In another trial with some of the same selections, but also additional selections, 69 genotypes varied from 3.5 rating and 45.8% damage (AA-82) to a 0.17 rating and 0% damage (AA-158). Of these selections, 8 had ≥2.75 rating and >30% damage (AA-82, AA-63, AA-81, AA-33, AA-107, AA-90, AA-93 and AA-96), whereas 46 had <2.44 rating and ≤20% damage and 25 selections had <2.0 rating and <10% damage (data not reported). However, it is interesting to note that of the 8 selections with moderate to serious damage ratings 'Gala' was a parent of five. Of the 22 least damaged selections, the cultivars 'Jonafree', 'Priscilla', and 'AA18' were parents of

Table 2. Japanese beetle feeding damage and defoliation ratings of foliage of 'Gala' apple on 18 rootstocks in the 1994 NC-140 rootstock trial, in 2003 and 2004 in descending order of average damage, Fayetteville, AR.

	Damage rating (0-5)[z]			Tree defoliation (%)		
Rootstock	2003	2004	2-year avg.	2003	2004	2-year avg.
Ottawa 3	2.8 a	2.6 a	2.7 a	29.4 ab	25.1 a	26.8 a
M.9 FL56	2.7 ab	2.3 a-d	2.5 a	30.6 a	20.0 a-d	26.3 a
M.9 Nic29	2.4 a-c	2.6 ab	2.5 ab	23.8 a-d	24.3 ab	24.1 ab
M.9 Pajam2	2.5 a-c	2.5 ab	2.5 ab	24.4 a-d	23.8 ab	24.0 ab
M.9 Pajam1	2.4 a-c	2.6 ab	2.5 ab	23.4 b-d	23.8 ab	23.7 a-c
V.1	2.5 a-c	2.5 ab	2.5 a-c	26.3 ab	22.6 a-c	24.0 ab
M.9 T337	2.6 ab	2.0 cd	2.4 a-d	25.4 a-c	12.5 d	19.4 b-d
M.26 EMLA	2.2 b-d	2.2 b-d	2.2 b-e	19.0 c-e	16.7 a-d	17.7 c-e
M.9 EMLA	2.1 c-e	2.2 a-d	2.1 c-f	18.1 de	15.3 a-d	16.6 d-f
V.3	1.9 d-f	2.3 a-d	2.1 d-f	13.9 ef	13.6 cd	13.7 d-g
B.9	1.6 ef	2.3 a-d	2.1 d-g	10.7 fg	18.5 a-d	15.5 d-f
P2	1.7 d-f	2.3 a-d	2.0 d-g	12.1 ef	18.5 a-d	15.4 d-f
B.469	1.5 fg	2.4 a-c	2.0 d-g	8.9 fg	21.0 a-d	15.4 d-f
B.491	1.6 f	2.3 a-d	1.9 e-g	8.2 fg	13.4 cd	10.8 fg
P16	1.6 f	2.3 a-d	1.9 e-g	9.4 fg	15.3 b-d	12.1 e-g
Mark	1.4 fg	2.0 cd	1.8 f-h	8.1 fg	13.2 cd	11.1 fg
P22	1.5 fg	2.0 cd	1.7 gh	10.0 fg	13.5 cd	11.7 e-g
M.27	1.1 g	1.9 d	1.5 h	5.0 g	12.1 d	8.6 g
Prob>F	***	**	***	***	**	***

[z] Rating scale: 0 = no visible damage, 1 = very light damage (<1% of total foliage damaged), 2 = light damage, several terminals damaged, 3 = serious damage, threatens health (25-30% of foliage damaged), 4 = severe damage (>50% foliage damaged), 5 = very severe damage (>75% foliage damaged) with some re-growth or reaction apparent (28)

Year 2003 (2 observers, n = 4-10), 2004 (3 observers, n = 4-10), means (calculated with SAS Proc GLM) within a column followed by the same letter are not significantly different using Tukey's Studentized Range (HSD) Test. ($P < 0.05$; ns = not significant; <0.1 = *, <0.05 = **, <0.0001 = ***).

4, 4 and 6 selections, respectively. AA18 was in the lower third of damage ratings (2.35) of the selections evaluated, however, neither 'Jonafree' nor 'Priscilla' was evaluated for these studies. Although no heritability analyses of either parent or offspring damage variation was conducted for this study, the damage variation among these selections implies a potential for breeding and selecting for reduced feeding by adult JB. A review of literature indicates no breeding program currently evaluating apple genotypes for foliar insect feeding, and specifically JB.

Ten year-old 'Liberty', 'Red Delicious', and 'Gala' trees on M.26 rootstock had significantly greater adult JB feeding damage and defoliation ratings than did 'Fuji', with 'Liberty' being the most seriously afflicted (Table 5). 'Braeburn'/M.9 trees in an organically managed apple production block had significantly greater damage and defoliation ratings than 'Gala'/M.9 or 'Jonagold'/M.9 (<2.6) (Table 6). In a collection of *Malus* species, *M. baccata* (L.) Borkh., suffered significant damage to both fruit and foliage compared to several other species. In contrast, *M. baccata* forma *jackii* was found to resist JB feeding in KY (39) and NC (33) as did *M. baccata* forma *jackii*, *M.* x 'Hargozam' Harvest Gold and *M. transitoria* (Balatin) Schneider

Table 3. Japanese beetle feeding damage and defoliation ratings of foliage of 'Buckeye Gala' apple on nine rootstocks in the 2002 NC-140 rootstock trial, in 2003 and 2004, Fayetteville, AR.

	Damage rating (0-5)[z]			Tree defoliation (%)		
Rootstock	2003	2004	2-year avg.	2003	2004	2-year avg.
B.9 Treco	2.3	1.9 ab	2.0 a	25.0	9.8 a	12.8 a
M.26 NAKB	1.7	2.1 a	2.0 a	15.0	10.6 a	11.9 a
Supporter 4	2.3	1.9 ab	2.0 a	26.7	8.0 ab	11.7 a
M.9 Nic29	2.3	1.9 ab	2.0 a	20.0	8.5 a	10.4 a
P14	1.9	2.0 ab	2.0 a	15.0	9.4 a	10.3 a
M.9 T337	1.9	1.9 ab	1.9 a	18.6	7.7 ab	9.4 ab
M.9 Burg756	1.7	2.0 ab	1.9 a	15.7	9.0 a	10.1 a
M.26 EMLA	1.4	1.8 b	1.8 a	15.0	6.8 ab	8.0 ab
B.9-Europe	1.2	1.2 c	1.2 b	5.8	4.0 b	4.3 b
Prob>F	ns	***	**	ns	*	*

[z] Rating scale: 0 = no visible damage, 1 = very light damage (<1% of total foliage damaged), 2 = light damage, several terminals damaged, 3 = serious damage, threatens health (25-30% of foliage damaged), 4 = severe damage (>50% foliage damaged), 5 = very severe damage (>75% foliage damaged) with some re-growth or reaction apparent (28)

Year 2003 (1 observers, n = 8-14), 2004 (6 observers, n = 8-14), means (calculated with SAS Proc GLM) within a column followed by the same letter are not significantly different using Tukey's Studentized Range (HSD) Test. ($P < 0.05$; ns = not significant; <0.1 = *, <0.05 = **, <0.0001 = ***).

'Schmitcutleaf' Golden Raindrops (6).

Crabapples: Crabapple cultivars had varied adult JB feeding damage in 2003 and 2004 (Table 7). In both years, 'Prairie Fire', 'Red Silver', and 'Spring Snow' had significant or heavy damage ratings and defoliation, while 'Golden Raindrops' had significantly less damage than all other cultivars. Annual variation in feeding damage was common in field studies with JB and likely results from fluctuations in the overall beetle population (10, 34). These data could be useful in landscape use recommendations in regions with severe JB infestations, and also may be the basis for developing more resistant landscape and commercial cultivars.

Blackberries: Blackberry cultivars and Arkansas selections 'Apache', A-1818, A-2078, A-2179, A-2200, 'Chickasaw' and A-1981 had significantly greater JB damage ratings (>3.0) than did 'Prime-Jim™', A-2143, 'Ouachita', A-2035, A-2117, and 'Prime-Jan™' (≤2.3 rating) (Table 8). 'Apache' suffered the most damage, with a mean damage rating of 4.0, while 'Prime-JanTM' had the least recorded mean foliar damage rating (0.6). There were no significant interactions between cultivar and year sampled, no significant year effect, and no significant effects due to presence of thorns, although mean damage ratings tended to be greater for the thornless genotypes (2.7) than thorny (2.3).

Adult JB feeding damage to flowers and fruit was not evaluated in this study. Primocane-fruiting genotypes were especially sensitive to this type of damage because they flower and fruit when JB populations were at or near peak emergence (E.T. Stafne, personal observation). Therefore, whereas the damage to floricane fruiting genotypes was foliar damage and the impact on the fruit at harvest is unknown at this time, the impact of flower feeding of the primocane genotypes results in a direct reduction in cropping potential. Therefore, JB could be considered a primary pest of primocane fruiting brambles.

Blueberries: There were no significant year effects, or interactions between year and genotypes for blueberries. Therefore, all data were pooled as a two-year average. Signifi-

Table 4. Japanese beetle feeding damage and defoliation ratings of foliage of 66 apple cultivars, in 2003 and 2004, Fayetteville, AR, ranked in descending order of average damage.

	Damage rating (0-5)[z]			Tree defoliation (%)		
Cultivar or selection name	2003	2004	2-year avg.	2003	2004	2-year avg.
X6392	4.0 a	3.0 b-d	3.4 a	55.0 ab	35.6 a-c	43.9 a
NY674	3.0 b-d	3.3 b	3.2 ab	25.0 f-j	46.7 a	38.0 ab
Cripp's Red (Sundowner)	3.3 a-c	3.0 b-d	3.1 a-c	42.9 b-e	36.1 a-c	39.1 ab
Spur Law Rome	1.8 f-i	4.7 a	3.0 a-d	10.0 k-p	48.3 a	26.4 b-f
X3191	3.5 ab	2.6 b-f	3.0 a-c	48.3 a-d	26.3 b-g	35.7 a-c
X3263	3.5 ab	2.4 b-g	2.9 a-e	49.2 a-c	23.9 b-h	34.0 a-d
XH982	4.0 a	2.2 c-h	2.9 a-d	59.2 a	18.9 e-q	35.0 a-c
AA79	3.5 b	2.0 e-h	2.8 a-d	45 a-c	20.0 g-k	32.5 b-e
Stark Ultragold	2.0 e-h	3.2 bc	2.7 a-f	15.0 i-p	28.3 b-f	23.0 c-g
Earligold	2.8 b-e	2.5 b-g	2.6 a-h	26.3 f-i	20.8 c-m	23.0 c-g
Cameo	2.5 c-f	2.7 b-f	2.6 a-h	22.5 g-k	23.3 b-i	23.0 c-g
Senshu	2.0 e-g	3.0 b-d	2.6 a-h	12.5 j-p	28.3 b-f	22.0 c-h
Zestar!	3.0 b-d	2.3 b-h	2.6 a-h	30.0 e-h	10.0 g-r	18.0 e-k
Pink Pearl	2.5 c-f	2.7 b-e	2.6 a-g	30.0 e-h	25.9 b-g	27.8 b-e
Surprise	2.8 b-e	2.3 b-h	2.5 b-j	35.0 d-g	20.4 c-n	25.3 b-f
Enterprise (Coop 30)	2.3 d-g	2.7 b-f	2.5 b-i	17.5 h-o	31.7 a-e	26.0 b-f
NJ121	2.0 e-h	3.0 b-d	2.5 b-i	20.0 i-n	25.0 b-f	22.5 c-g
Granny Smith	1.5 g-i	3.0 b-d	2.4 b-j	7.5 m-p	38.3 ab	26.0 b-f
Delblush	2.5 c-f	2.0 d-j	2.4 b-j	20.0 h-n	15.0 e-r	22.0 c-h
Pristine (Coop 32)	2.0 e-g	2.5 b-g	2.3 c-m	22.5 g-k	20.0 c-o	21.3 c-h
GE1347	2.0 e-h	2.3b-h	2.3 c-m	12.5 j-p	19.2 d-p	17.5 e-k
Cripp's Pink (Pink Lady)	2.0 e-h	2.5 b-g	2.3 c-l	15.5 i-p	22.3 b-j	19.6 e-j
Arlet	1.5 g-i	2.8 b-d	2.3 c-k	8.8 l-p	26.7 b-g	19.5 d-j
William Crump	3.3 a-c	1.7 f-j	2.3 c-k	37.5 c-f	5.2 l-r	18.1 e-k
Crimson Gala	1.8 f-i	2.5 b-g	2.2 d-n	10.0 k-p	29.2 b-f	21.5 c-h
Autumn Gold	2.0 e-g	2.3 b-h	2.2 d-n	17.5 h-o	20.0 d-o	19.0 e-j
GoldRush (Coop 38)	1.8 f-i	2.5 b-g	2.2 d-n	8.8 l-p	23.3 b-h	17.5 e-k
Scarlet Gala	1.5 g-i	2.7 b-f	2.2 d-n	7.5 m-p	23.3 b-i	17.0 e-k
Thome Empire	1.5 g-i	2.7 b-f	2.2 d-n	5.0 op	21.7 b-l	15.0 e-k
Fuji Nagafu 6	2.5 c-f	2.0 d-j	2.2d-n	22.5 g-k	10.3 g-r	14.3 e-k
NY75413	1.0 ij	2.7 b-f	2.0 e-n	5.0 op	31.7 a-e	21.0 c-l
Golden Delicious (Gibson strain)	2.0 e-h	2.0 d-j	2.0 e-n	20.0 h-n	18.3 e-q	19.0 e-j
Blushing Golden	2.0 e-h	2.0 d-j	2.0 e-n	20.0 h-n	12.5 f-r	16.3 e-k
Ozark Gold	2.3 d-g	1.7 f-j	2.0 e-n	22.5 g-k	5.0 l-r	15.0 e-k
Jonathan	.	2.0 d-j	2.0 e-n	.	15.0 e-r	15.0 e-k
PX4013	2.0 e-h	.	2.0 e-n	15.0 i-p	.	12.5 f-k
Sunrise	.	2.0 d-j	2.0 e-n	.	12.5 f-r	12.5 f-k
Ruby Jon	1.5 g-i	2.5 b-g	2.0 e-n	7.5 m-p	17.5 e-r	12.5 f-k

Suncrisp	1.5 g-i	2.3 c-h	1.9 f-n	6.3 op	22.5 b-h	14.4 e-k
Mother	2.3 d-g	1.7 f-j	1.9 f-n	21.3 h-l	6.8 i-r	12.6 f-k
Hidden Rose	2.3 d-g	1.6 g-j	1.8 g-o	20.7 h-m	8.2 i-r	13.2 e-k
Stellar	1.5 g-i	2.0 d-j	1.8 g-o	5.0 op	16.7 e-r	12.0 f-k
Red Winesap	1.5 g-i	2.0 d-j	1.8 g-o	7.5 m-p	14.3 f-r	11.6 f-k
Ultrared Gala	1.3 h-j	2.2 d-i	1.8 g-o	5.0 op	15.8 e-r	11.5 f-k
Liberty	1.5 g-i	2.2 d-i	1.8 f-o	6.7 n-p	12.5 f-r	9.6 g-k
Delshel	2.0 e-h	1.0 j	1.7 i-o	5.0 op	1.0 r	5.3 jk
Monidel	2.0 e-h	2.0 d-j	1.7 i-o	5.0 op	5.0 l-r	5.0 jk
Dalrouval	2.0 e-h	2.0 d-j	1.7 i-o	5.0 op	20.0 c-o	10.0 g-k
Court Pendu Plat	2.0 e-h	1.6 g-j	1.7 h-o	10.0 l-p	3.20 p-r	5.9 jk
Melrose	2.0 e-h	1.7 f-j	1.6 j-o	10.0 k-p	3.7 n-r	5.2 jk
Calville Blanc D'Hiver	2.0 e-h	1.7 f-j	1.6 j-o	5.0 op	4.5 m-r	4.7 jk
Jonica	1.5 g-i	1.7 f-j	1.6 j-o	7.5 m-p	22.0 b-k	16.2 e-k
Arkansas Black	1.5 g-i	1.9 e-j	1.6 i-o	9.4 k-p	5.7 j-r	7.4 h-k
Rubinstar Jonagold	.	1.5 g-j	1.5 l-o	.	5.0 l-r	5.0 jk
Galaxy Gala	1.5 g-i	.	1.5 k-o	7.5 m-p	.	7.5 h-k
GE1348	1.5 g-i	.	1.5 k-o	7.5 m-p	.	7.5 h-k
Jonagored	1.5 g-i	1.5 g-j	1.5 k-o	5.0 op	5.2 l-r	5.0 jk
NJ139	1.5 g-i	.	1.5 k-o	5.0 op	.	5.0 jk
Orleans Reinette	2.0 e-h	1.0 j	1.4 m-o	17.5 h-o	2.3 qr	8.4 g-k
Starkrimson Red Delicous	2.0 e-h	1.0 j	1.4 m-o	10.0 k-p	1.0 r	6.2 i-k
Cortland	1.5 g-i	1.7 f-j	1.4 l-o	5.0 op	7.0 i-r	5.9 jk
Ben Davis	1.5 g-i	1.4 ij	1.3 no	7.5 m-p	2.4 p-r	4.7 jk
PX6329	1.5 e-h	1.0 j	1.3 no	10.0 k-p	1.0 r	12.5 jk
PX6629	1.0 ij	1.0 j	1.0 o	5.0 op	5.3 k-r	5.3 jk
NJ134	1.0 ij	.	1.0 o	5.0 op	.	5.0 jk
Tsugara	0.5 j	1.3 h-j	1.0 o	2.5 p	6.7 i-r	5.0 jk
Delkistar	1.0 ij	1.3 j	1.0 o	5.0 op	2.3 qr	3.4 k
Prob>F	***	***	***	***	***	***

[z] Rating scale: 0 = no visible damage, 1 = very light damage (<1% of total foliage damaged), 2 = light damage, several terminals damaged, 3 = serious damage, threatens health (25-30% of foliage damaged), 4 = severe damage (>50% foliage damaged), 5 = very severe damage (>75% foliage damaged) with some re-growth or reaction apparent (28)

Year 2003 (2 observers, n = 1-6), 2004 (3 observers, n = 1-6), means (calculated with SAS Proc GLM) within a column followed by the same letter are not significantly different using Tukey's Studentized Range (HSD) Test. (P < 0.05; ns = not significant; <0.1 = *, <0.05 = **, <0.0001 = ***).

cant differences among the 21 blueberry genotypes were observed, though the range of rating was much narrower than that observed in the blackberries. Four blueberry cultivars ('Bluecrop', 'Duke', 'Brigitta', 'Reka') and 11 Arkansas selections (A-12, 299, 265, 326, 342, 23, 209, 259, 308, 4) had damage ratings significantly greater than ratings for A-330, A-263, A-363, 'Ozarkblue', A-98 and A-272, ≥2.4 and <2.1, respectively (Table 8). Arkansas selection A-12 had the highest mean damage rating (3.5), whereas A-272 had the lowest (1.3). Among named cultivars, damage of 'Bluecrop', 'Duke', 'Brigitta', and 'Reka' was moderately high but not statistically different. However, 'Ozarkblue'

Table 5. Japanese beetle feeding damage and defoliation ratings of foliage of four apple cultivars on M.26 rootstocks in the 1994 NC-140 rootstock trial, in 2003 and 2004, Fayetteville, AR.

	Damage rating (0-5)[z]			Tree defoliation (%)		
Cultivar	2003	2004	2-year avg.	2003	2004	2-year avg.
Liberty	3.4 a	2.9 a	3.1 a	44.7 a	32.6 a	37.4 a
Red Delicious	2.3 b	2.5 ab	2.4 b	21.1 b	22.1 b	21.7 b
Gala	2.2 b	2.2 bc	2.2 b	19.0 b	16.7 bc	17.7 b
Fuji	1.4 c	2.0 c	1.7 c	7.2 c	11.4 c	9.7 c
Prob>F	***	***	***	***	***	***

[z] Rating scale: 0 = no visible damage, 1 = very light damage (<1% of total foliage damaged), 2 = light damage, several terminals damaged, 3 = serious damage, threatens health (25-30% of foliage damaged), 4 = severe damage (>50% foliage damaged), 5 = very severe damage (>75% foliage damaged) with some re-growth or reaction apparent (28).

Year 2003 (2 observers, n = 4-9), 2004 (3 observers, n = 4-9), means (calculated with SAS Proc GLM) within a column followed by the same letter are not significantly different using Tukey's Studentized Range (HSD) Test. ($P < 0.05$; ns = not significant; <0.1 = *, <0.05 = **, <0.0001 = ***).

Table 6. Japanese beetle feeding damage and defoliation ratings of foliage of three apple cultivars on M.9 rootstocks in an organically managed system, in 2003 and 2004, Fayetteville, AR.

	Damage rating (0-5)[z]			Tree defoliation (%)		
Cultivar	2003	2004	2-year avg.	2003	2004	2-year avg.
Braeburn	3.3	3.2 a	3.3 a	44.7 a	39.6 a	40.7 a
Gala	3.1	2.6 b	2.6 b	40.8 a	24.3 b	26.1 b
Jonagold	2.8	2.5 b	2.5 b	31.4 a	23.1 b	24.4 b
Prob>F	ns	***	***	ns	***	***

[z] Rating scale: 0 = no visible damage, 1 = very light damage (<1% of total foliage damaged), 2 = light damage, several terminals damaged, 3 = serious damage, threatens health (25-30% of foliage damaged), 4 = severe damage (>50% foliage damaged), 5 = very severe damage (>75% foliage damaged) with some re-growth or reaction apparent (28)

Year 2003 (2 observers, n =10-20), 2004 (6 observers, n =10-20), means (calculated with SAS Proc GLM) within a column followed by the same letter are not significantly different using Tukey's Studentized Range (HSD) Test. ($P < 0.05$; ns = not significant; <0.1 = *, <0.05 = **, <0.0001 = ***).

had significantly lower mean damage rating (1.6) than 'Bluecrop' and 'Duke' (≥2.9), but was not different statistically from 'Brigitta' or 'Reka' (≤2.6). Blueberries appeared to be a less preferred crop of JB with less overall damage than other fruit crops in adjacent plots.

Grapes: Grape genotypes had significant variation in feeding damage with a broad range of damage observed in 2003 (data not shown). 'Neptune' and 'Jupiter', along with other breeding selections, had mean damage ratings greater than 3.0, while 'Mars' averaged 0.3, significantly less damage than on any of the other genotypes. 'Mars' has characteristic thick leaves with pubescent abaxial surface as found in its parent, *Vitis labrusca*. Similarly, in Springdale, AR in 2005, an abandoned 'Concord' (*V. labrusca* L.) vineyard realized <22% foliar skelotonizing (D.T. Johnson, personal observation). In Purdy, Missouri in 2008, 'Cabernet Franc', 'Vignoles' and 'Norton' blocks realized >25% upper canopy foliage loss before the grower began three weekly insecticide applications in July (D.T. Johnson, personal observation).

Summary. The potential for foliar dam-

Table 7. Japanese beetle feeding damage and defoliation ratings of foliage of 13 crabapple genotypes on unknown rootstocks, in 2003 and 2004, Fayetteville, AR.

	Damage rating (0-5)[z]			Tree defoliation (%)		
Cultivar	2003	2004	2-year avg.	2003	2004	2-year avg.
Prairie Fire	.	4.4 a	4.4 a	.	67.0 a	67.0 a
Red Silver	3.0 ab	4.2 ab	4.0 ab	40.0 a-c	66.0 a	61.7 ab
Spring Snow	2.0 bc	4.3 a	4.0 ab	25.0 bc	65.0 ab	59.3 a-c
Liset	4.0 a	3.8 bc	3.8 bc	65.0 a	51.3 bc	53.2 a-d
Guinivere	4.0 a	3.5 cd	3.6 b-d	57.5 ab	48.3 c	50.6 b-e
Brandywine	2.3 a-c	3.6 cd	3.4 c-e	26.7 bc	51.1 bc	46.8 c-f
Selkirk	4.0 a	3.2 de	3.3 c-e	55.0 ab	41.5 cd	42.9 d-g
Dolgo	4.0 a	3.2 de	3.3 c-e	65.0 a	38.3 cd	42.1 d-g
Mary Potter	2.5 a-c	3.2 c-e	3.2 de	27.5 a-c	43.6 cd	42.0 d-g
Ormiston Roy	3.5 ab	3.1 de	3.1 de	47.5 ab	37.5 cd	38.9 e-g
Thunderchild	3.0 ab	3.0 de	3.0 e	37.5 a-c	34.2 d	35.0 fg
Candied Apple	2.5 a-c	2.9 e	2.9 e	27.5 a-c	33.8 d	32.9 g
Golden Raindrops	1.0 c	2.2 f	1.9f	5.0c	17.2e	14.1h
Prob>F	**	***	***	*	***	***

[z] Rating scale: 0 = no visible damage, 1 = very light damage (<1% of total foliage damaged), 2 = light damage, several terminals damaged, 3 = serious damage, threatens health (25-30% of foliage damaged), 4 = severe damage (>50% foliage damaged), 5 = very severe damage (>75% foliage damaged) with some re-growth or reaction apparent (28)

Year 2003 (2 observers, n = 1-4), 2004 (6 observers, n = 1-4), means (calculated with SAS Proc GLM) within a column followed by the same letter are not significantly different using Tukey's Studentized Range (HSD) Test. (P < 0.05; NS = not significant; <0.1 = *, <0.05 = **, <0.0001 = ***).

age of plants by JB should be considered in breeding programs, and crop or landscape genotype selection, and pest management plans (10). Genotypic differences in JB damage were discovered within the plant populations studied, thus suggesting that resistance to JB feeding damage may be genetically controlled and quantitative in nature. This also suggests that classical breeding could be used to incorporate more resistance, and that molecular analysis might define markers that segregate with the resistant/tolerant trait.

In this study a wide range in adult JB feeding damage of fruit plants growing in South Central United States was observed similar to previous observations (33). This study confirmed previous reports of relative JB preference and damage for various fruits and crabapples, and identified additional cultivars with varying leaf damage ratings for apple rootstocks, cultivars and breeding selections, *Malus* spp., blackberry, blueberry, crabapple and grape genotypes which had not been previously evaluated.

The presence of JB has the potential to reduce effective photosynthetic leaf area, negatively affect overall plant health, cropping and crop quality, or to increase insecticides used to prevent feeding damage. These findings can be integrated into crop pest management programs that will minimize JB damage in infested regions of the South Central United States. Grower and homeowner selection of fruit genotypes not preferred by JB could significantly reduce the incidence and effects of adult feeding damage as well as reduce insecticide use in areas where JB feeding could be significant (e.g. >25% canopy defoliation), or may have impacts on fruit, plant growth, or attractiveness of the plant.

Future studies should focus on the morphological or chemical characteristics, and genetic

Table 8. Japanese beetle damage across two years (2003 and 2004) of blackberry and blueberry cultivars and Arkansas selections in Fayetteville, AR.

Blackberry Cultivar or Selection	Damage rating (0-5)[z]	Blueberry Cultivar or Selection	Damage rating (0-5)
Apache	4.0 a[z]	A-12	3.5 a
A-1818	3.9 ab	Bluecrop	3.1 ab
A-2078	3.8 ab	A-299	3.1 ab
A-2179	3.6 ab	A-265	3.0 ab
A-2200,	3.6 ab	A-326	2.9 ab
Chickasaw	3.1 bc	Duke	2.9 ab
A-1981	3.1 bc	A-342	2.8 a-c
A-2047	2.9 cd	A-23	2.8 a-c
A-2095	2.5 cd	A-209	2.8 a-d
Arapaho	2.5 cd	A-179	2.7 a-d
A-2046	2.4 c-e	A-259	2.6 a-d
A-2091	2.4 c-e	A-4	2.6 a-d
Prime-Jim	2.3 de	A-308	2.6 a-d
A-2143	1.6 ef	Brigitta	2.6 a-d
Ouachita	1.6 ef	Reka	2.5 a-d
A-2035	1.1 fg	A-330	2.1 b-e
A-2117	1.1 fg	A-263	2.1 b-e
Prime-Jan	0.6 g	Ozarkblue	1.6 c-e
		A-363	1.6 c-e
		A-98	1.5 de
		A-272	1.3 e

[z] Rating scale: 0 = no visible damage, 1 = very light damage (<1% of total foliage damaged), 2 = light damage, several terminals damaged, 3 = serious damage, threatens health (25-30% of foliage damaged), 4 = severe damage (>50% foliage damaged), 5 = very severe damage (>75% foliage damaged) with some re-growth or reaction apparent (28)

Data is the mean of two years observations, (year 2003 [2 observers, n = 1-4], 2004 [6 observers, n = 1-4]), means (calculated with SAS Proc GLM) within a column followed by the same letter are not significantly different using Tukey's Studentized Range (HSD) Test. (P < 0.05; NS = not significant; <0.1 = *, <0.05 = **, <0.0001 = ***).

mechanisms that make certain fruit genotypes unattractive to adult JB. This should include identifying the role of certain endogenous phenolics, especially phloridzin, in feeding resistance to JB in fruit as was reported for apple (6) and saponins in holly (15).

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