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DAMAGE POTENTIAL OF ROSE CHAFER AND JAPANESE BEETLE (COLEOPTERA: SCARABAEIDAE) IN MICHIGAN VINEYARDS

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ABSTRACT

Responses of young non-fruiting grapevines, *Vitis labrusca* (L.) var. 'Niagara', to defoliation were examined at two stages of vine growth when beetles typically infest vineyards. In the first experiment, vines were caged and subjected to two weeks of feeding by 0, 10, 20, or 40 adult *Macrodactylus subspinosus* Fabricius (Scarabaeidae: Macrodactylini) during bloom, or to the same range of adult *Popillia japonica* Newman (Scarabaeidae: Anomalini) during veráison, when berries begin changing color. Leaf area removed increased with beetle density, but less than 1% of the leaf area was removed at the highest density of *M. subspinosus*, and less than 7% at the highest density of *P. japonica*. Vine growth measurements taken during the year of injury and prior to bloom during the following season indicated no significant impacts of this leaf injury on vegetative growth. In the second experiment, mechanical injury was induced by removing 0, 10, 20, or 30% of the total leaf area of every fully expanded leaf at bloom or veráison. A significant effect of mechanical injury at bloom was found on cane diameters when measured at veráison, indicating that a carbon source limitation was induced in these vines. By the time of leaf loss, cane diameters were not significantly different across treatments, indicating that vines may have been able to compensate for the earlier defoliation. Injury at veráison had no significant effect on vine growth parameters. These results suggest that young 'Niagara' vines are able to tolerate foliar injury far exceeding that caused by two weeks of exposure to 40 beetles of either species. Surveys of Michigan vineyards containing different grape varieties indicated that although both beetle species could be found in high abundance, leaf injury levels were low. The implications for management of beetle foliar herbivory in vineyards are discussed.

The rose chafer, *Macrodactylus subspinosus* (Fabricius) (Scarabaeidae: Macrodactylini), and the Japanese beetle, *Popillia japonica* Newman (Scarabaeidae: Anomalini), are two leaf skeletonizing scarab beetles which are considered pests of economic importance in vineyards of eastern North America. Emergence of adult rose chafers coincides with grape bloom in most of the beetle's geographic range, while Japanese beetle emergence overlaps with veráison (when berries begin changing color). The rose chafer and Japanese beetle are both gregarious species attracted to conspecifics and feeding induced leaf volatiles (Leal 1998, Heath et al. 2002). This behavior leads to large aggregations on suitable host plants, creating visually apparent infestations in vineyards and other affected crops. In response to these infestations, both species are controlled by insecticide sprays (Wise et al. 2003; Isaacs et al. 2004) to prevent leaf injury.

The detrimental effects of foliar herbivory are often attenuated by plant compensatory responses to foliar injury (Trumble et al. 1993). In grapevines, several studies have indicated that tolerance to foliar injury may be particularly

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high (Boucher and Pfeiffer 1989, Candolfi-Vasconcelos et al. 1994, Petrie et al. 2000a,b), and therefore foliar injury may often be below levels that impact vine growth and productivity. The relationship between the level of herbivory and the impact on *Vitis labrusca* (Linnaeus) growth and production is not well understood, particularly in young establishing vineyards that typically do not have a crop. However, in bearing vines, Boucher and Pfeiffer (1989) found that natural infestations of Japanese beetle failed to have any significant impacts upon fruit quality, quantity, or growth of *Vitis vinifera* (Linnaeus) var. 'Seyval Blanc', whereas artificially-enhanced infestation during veráison caused some reduction in fruit quality. In addition, young fruitless vines have been shown to tolerate high levels of mechanical and beetle-caused defoliation, and that injury early in the growing season can compromise the vine's ability to tolerate injury later in the season (Mercader and Isaacs 2003, 2004).

Plant responses to foliar injury may be affected by the seasonal change in demands placed upon the available carbohydrate sources and reproductive sinks. The relative sink strength of various tissues in grapevines changes significantly throughout the growing season, in accordance to their physiological stage of development, or phenophase (Williams and Matthews 1990). In young woody plants, including grapes, relatively few clusters are produced. Indeed, viticultural recommendations include cluster removal in the first years of growth to ensure that energy is directed toward vine establishment (Zabadal 1997). The lack of fruit as carbohydrate sinks may create a differential response to foliar herbivory late in the season in young plants when compared to mature fruiting plants.

While vineyards are being established and no fruit is cropped, the photosynthetic and storage tissues act as the main sources of carbon, while actively growing tissues and injured tissues act as the main sinks. During and prior to bloom, there is active vegetative growth in mature grapevines but by veráison, shoot and leaf growth slows considerably (van Zyl 1984, Williams 1987). Because of this variation in the production and need for carbohydrates by different vine tissues, there is a low carbon source and high carbon sink strength during bloom, whereas during veráison there is high source and low sink strength. Foliar injury at bloom is therefore expected to cause greater reduction of carbon assimilation and growth in non-bearing potted vines than injury at veráison, as demonstrated recently for potted *V. labrusca* vines (Mercader and Isaacs 2003). Young fruitless 'Niagara' vines have also been shown to have greater tolerance to foliar injury at veráison than at bloom during establishment in Michigan vineyards (Mercader and Isaacs 2004).

Variation in feeding intensity across grape cultivars has been demonstrated for leafhoppers (Martinson and Dennehy 1995), with greatest feeding injury generally in *V. vinifera*, intermediate injury in hybrid cultivars, and the least in native North American cultivars including *V. labrusca*. Japanese beetle has distinct interspecific variation in host plant preference (Fleming 1976) and has intraspecific preference within some agricultural crops, including apple (Ranney and Walgenbach 1992).

Management of foliar herbivores on grapevines requires an understanding of the vine's ability to tolerate feeding and the vine's relative susceptibility to feeding. This study examined the response of young (1 yr after planting) grape vines, *Vitis labrusca* L. var. 'Niagara', to varying levels of beetle and mechanical defoliation during bloom and veráison. Our goals were to quantify the level of feeding by *M. subspinosus* and *P. japonica* on young *V. labrusca* vines, and to determine the response of young grapevines to different levels of mechanical and beetle injury during the different phenophases. In addition, we surveyed vineyards in viticultural regions of Michigan to quantify potential pest pressure by both species and the relative preference of Japanese beetle for different grape varieties.

MATERIALS AND METHODS

Beetle injury. These experiments were conducted in a *V. labrusca* var. 'Niagara' vineyard planted in 1999, at the Trevor Nichols Research Complex in Fennville, Michigan. Two shoots from two canes (total of four shoots) of each vine were trained onto a 1.37 m high bilateral cordon Hudson River Umbrella trellis system. There were seven vines per row, with 1.8 m between vines and 3 m between rows. Vines were maintained using 45.5 kg of Urea fertilizer (46% Nitrogen) per acre applied on 16 March 2000 and 102.3 kg of urea per acre on 25 March 2001, and a standard plant protection program (Gut et al. 2002), except on rows where vines were caged with beetles. On these rows, no insecticides were applied at least one month prior to beetles being caged on vines and insecticide and fungicide applications were postponed until cages were removed, after which carbaryl was used to protect vines from subsequent beetle injury. Bloom and veráison were marked on neighboring cluster bearing vines.

Four densities of rose chafer or Japanese beetles were maintained inside caged vines during bloom or veráison of 2000, respectively. Four vines in a row of seven vines were selected with a cane length between 0.5 m and 1 m. Cages containing 0, 10, 20, or 40 beetles were placed on selected vines within a row for two weeks during bloom or veráison. Treatments were arranged as two randomized complete block designs (one for bloom and one for veráison) with ten replicates each. During bloom, vines were infested using adult rose chafers collected from traps (Great Lakes IPM, Vestaburg, Michigan) in Oceana County, Michigan. During veráison, Japanese beetles were collected from traps (Trécé Inc., Salinas, California) in Allegan County, Michigan. For both beetle species, traps were emptied the day before beetles were collected, so that only recently-caught beetles were used. To ensure beetle densities remained constant in cages, beetles were counted every other day and any dead beetles were replaced with live ones. Cages consisted of a highly porous bridal illusion plastic mesh (Fabric Gallery, Williamston, Michigan) draped over the trellis and suspended from a 0.3 m radius horizontal wire ring taped onto the trellis. Mesh was fastened to the base of the vine with garden wire and the side of the cage was sealed with binder clips. This created a cone-shaped cage that encased all of the above-ground vine tissues, and allowed for plant growth and beetle movement. Vines were larger during veráison so the ends of the cage were expanded along the trellis to encompass the entire vine.

Adult rose chafers were placed on vines on 20 June 2000 and removed on 4 July 2000. The level of defoliation was determined within 5% using visual aids adapted from those used by Boucher and Pfeiffer (1989). Cane and trunk diameters were measured using Vernier calipers at bloom (19 June), veráison (30 August), and leaf senescence (29 October), and prior to bloom the following season (9 May 2001). The number of mature nodes was determined after leaf loss (11 November).

Adult Japanese beetles were placed on separate vines on 3 August, 2000 and removed on 17 August 2000, and the level of defoliation determined. On these vines, cane diameters were measured just prior to veráison (26 July) and at leaf senescence (29 October). The number of mature nodes was determined after leaf loss (11 November).

Vines injured by beetles in 2000 were pruned to 15 nodes per cane (30 total) between 26 January and 6 February 2001. For each vine, the weight of mature cane prunings (pruning weights) was determined by bundling and weighing them with a digital scale in the field. This provided a measure of the vine's overall growth during the season in which injury occurred. To determine the possible second-year impacts of beetle feeding on vine storage, growth parameters were measured prior to bloom in 2001, the season after caging. We recorded the diameters of canes and trunks (9 and 14 May 2001, respectively), and the number of nodes remaining dormant after the 16-inch shoot growth stage had been reached (22 May 2001).

Mechanical Injury. To determine the effect of leaf area loss during bloom and veráison on vine development, vines were subjected to mechanical injury during each of these phenophases. Either 0, 10, 20, or 30% of the total leaf area was removed from every fully-expanded leaf during bloom or veráison (Fig. 1). Leaf area was removed using 38.5 mm^2 hole punchers, avoiding all major veins. This was done to imitate the interveinal nature of beetle feeding and to avoid the differences in photosynthetic impact caused by interveinal injury when compared to whole leaf removal or treatments causing vein damage (Hall and Ferree 1975, Boucher et al. 1987). To ensure appropriate injury levels, visual aids were used while applying treatments.

For vine defoliation treatments during bloom, thirty-two vines with cane height between 0.5 m and 1 m were separated into two blocks of 16 plants each. Within each block, selected vines were randomly assigned to one of the four injury levels, creating eight replicates of each treatment. These vines were injured at bloom to the appropriate level between 15 and 23 June 2000.

Larger canopy size during veráison restricted the number of vines that could be treated, and only four replicates were possible. Four vines from a row of seven were selected (vines with cane height between 0.5 m and 1 m) and randomly assigned to one of the four injury levels (0, 10, 20, or 30% defoliation), which were each replicated four times. Each row was considered a block in a randomized complete block design. These vines were injured on 14 and 15 August, 2000 in an identical fashion to vines injured during bloom.

During the 2000 growing season, vine vegetative growth parameters were measured at trace bloom (13-14 June), at veráison (6-11 August), and at leaf senescence (21 October). On each vine, the number of nodes on every shoot was counted and the cane diameters were measured. In addition, the number of mature nodes was counted and the total shoot length was measured on each shoot after leaf loss (10-11 November).

On 16 and 26 January 2001, all vines were pruned to 15 nodes per shoot and the pruning weights recorded as described above. Prior to bloom in the season following injury (2001) the diameter of canes and trunks (9 May) and the number of nodes remaining dormant after the 16 inch shoot growth stage had been reached (22 May) were recorded on all vines.

Statistical Analysis. Vine growth data were analyzed as one-way blocked ANCOVA (PROC GLM, SAS Institute, 1999). Cane diameters measured prior to applying treatments were used as covariates as there was an *a priori* assumption that cane diameter, as a surrogate for size, would have a significant relationship

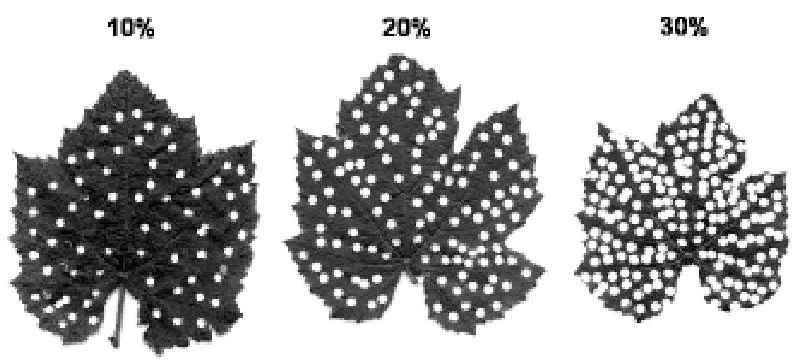

Figure1. Leaves of 'Niagara' grapevines after using a hole-puncher to apply mechanical damage treatments to remove 10, 20, or 30% of the interveinal leaf area.

with growth. This assumption was verified by cane diameter being statistically significant in all the analyses (data not shown). Blocks of vines mechanically damaged at bloom consisted of two rows in a generalized randomized complete block design. Blocks in beetle injured vines and vines damaged mechanically at veráison consisted of single rows in a randomized complete block design. The discrepancy between mechanical damage experiments was due to vine size at veráison restricting the number of vines that could be damaged. Mean separations were performed where appropriate using the Student Newman-Keuls method.

Vineyard sampling for beetle defoliation. Boucher and Pfeiffer (1989) previously showed little injury from Japanese beetle feeding in Seyval Blanc vineyards in Virginia so in this study, vineyards were chosen in which significant beetle injury had occurred in the past. These vineyards tend to be small vineyards where edge effects are exaggerated; thereby vineyards in this study indicate the high end of beetle infestations.

Rose chafer. Three vineyards in Grand Traverse County, Michigan were sampled during June and July 2002 for rose chafer. The first of these vineyards was planted with *Vitis vinifera* (L.) cv. 'Chardonnay' and the French-American hybrid 'Vignoles'. Rose chafer populations were greater next to the Chardonnay vines, where the soil was sandy. Samples were taken on the edge row and on three randomly-chosen rows of Chardonnay, and on the first row of Vignloes and three other randomly chosen rows of this cultivar. Within each row, four vines were randomly chosen and the number of beetles per vine was counted on 26 June 2002 when beetles were first noticed on vines. On 3 July 2002, the number of beetles, defoliation index, number of injured leaves, total number of clusters, and the total number of clusters injured were measured. The defoliation index was measured as a percentage of leaf area following Boucher and Pfeiffer (1989), where images of leaves injured to 10, 20, 30, 40, 50, and 60 % were carried by the observer and each injured leaf was scored for injury to the nearest 5%. These values were then summed to calculate the defoliation index for each vine. Feeding injury by rose chafers to clusters was scored by assigning each cluster on the four sampled vines to one of four injury categories of 0, 1-33 (33%), 34-66 (66%), and 67-100% (100%) of the flowers injured. All values were averaged for each vine to provide a cluster injury index.

The second and third vineyards consisted of the French-American hybrid Marechal Foch and Chardonnay cultivars, respectively. In both sites, four rows were sampled starting with the edge row where rose chafer pressure was considered highest by the grower and three other randomly chosen rows within the vineyard. As with the first vineyard, four plants were chosen per row and sampled for number of beetles on 27 June and again on 4 July 2002 for number of beetles, total leaves, defoliation index, total clusters, and cluster injury index, as described above.

Japanese beetle. The first site sampled for Japanese beetle was a backyard planting consisting of individual rows of French-American hybrid cultivars; Frontenac, Cayuga White, Marechal Foch, Golden Muscat, Seyval Blanc, and *V. labrusca* c.v. Niagara and Concord. On 11 July 2002 the number of beetles and the defoliation index (as described above) was recorded on 7-9 vines of each cultivar.

Defoliation was measured on vines in four small commercial vineyards consisting of several different varieties per site. The first vineyard sampled consisted of individual rows of *V. vinifera* (L.) var. Chardonnay, and the French-American hybrids Vignoles and Seyval Blanc. Here, 20 vines of Chardonnay, 20 vines of Seyval, and 40 vines of Vignoles were sampled. For each cultivar, four vines were randomly selected from an edge row and from four or more randomly-selected interior rows. The second vineyard sampled consisted of *V. labrusca* cv. Niagara and Concord, and the French-American hybrid Delaware. Twenty vines of each variety were sampled as above, with the exception that no edge row existed for Delaware vines and therefore 5 randomly-chosen rows were sampled. The third vineyard sampled consisted of *V. labrusca* cv. Concord and French-

American hybrid Vanessa. Twenty four vines of each variety were sampled as above. The fourth vineyard sampled consisted of a mixed planting of the French-American hybrid Himrod and *V. labrusca* cv. Niagara, and a separate *V. labrusca* cv. Concord planting. Himrod and Niagara vines were first season plantings and therefore the 17 largest plants of each variety were sampled. Twenty Concord vines were sampled as in the first vineyard.

RESULTS

Beetle Injury. The level of defoliation caused by rose chafers was minimal even at the highest beetle density, with less than one percent of the leaf area removed when 40 beetles were caged on a vine for 14 days. The same level of exposure to Japanese beetle caused much greater defoliation, approaching 7% (Fig. 2). This inter-specific difference in defoliation intensity was even greater when the relative canopy size present during veráison is considered (approximately 2-3 times larger during veráison than during bloom). However, even at the highest beetle density, neither beetle species had any significant effect upon the growth parameters measured. The diameter of canes on rose chafer injured vines was not significantly affected by beetle foliar injury, when measurements were taken at the end of veráison or at leaf senescence ($F = 0.75$, df = 3, 26, $P = 0.53$, and $F = 0.52$, df = 3, 26, $P = 0.67$, respectively). In addition, there was no significant effect of foliar herbivory on above-ground growth in the year of injury, whether measured as the number of mature nodes after leaf loss ($F = 0.31$, df = 3, 26, $P = 0.82$) or pruning weights ($F = 1.09$, df = 3, 26, $P = 0.37$). Growth parameters measured prior to bloom the following season (2001) also indicated no impact of rose chafer injury; cane diameters and number of shootless nodes were not impacted by the treatments imposed ($F = 0.64$, df = 3, 26, $P = 0.60$ and $F = 0.42$, df = 3, 26, $P = 0.74$ respectively).

On vines subjected to Japanese beetle feeding, a similar result was found; cane diameters measured at leaf senescence ($F = 1.06$, df = 3, 26, $P = 0.38$), mature node numbers measured at leaf loss ($F = 1.26$, df = 3, 26, $P = 0.31$), and pruning weights ($F = 0.55$, df = 3, 26, $P = 0.65$) did not differ significantly when vines were injured by Japanese beetles. Growth parameters taken prior to bloom the following season (2001) also indicated no impact of Japanese beetle injury; cane diameters and number of shootless nodes for Japanese beetle injured vines were not impacted by the treatments imposed ($F = 0.81$, df = 3, 26, $P = 0.50$ and $F = 0.87$, df = 3, 26, $P = 0.85$ respectively).

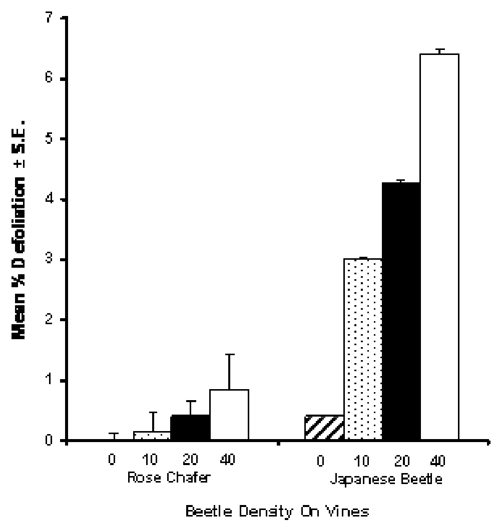

Figure 2. Percent defoliation of total vine canopy area caused by two weeks of exposure to different densities of adult rose chafer and Japanese beetle.

Mechanical Injury. Mechanical injury during bloom did not affect vegetative growth of the vines, measured as the number of nodes at veráison (F= 1.12, df = 3, 25, P = 0.67). However, a reduction in cane diameter (F = 5.3, df = 3, 26, P = 0.006) was observed on bloom injured plants, when measured at veráison (Fig. 3). Although the 20% leaf area removal treatment was not significantly different from the control, the overall pattern indicates that early season foliar injury induced a source limitation, reducing the amount of resources allocated to cane growth. When these vines were measured at leaf senescence, there were no significant differences between treatments in the number of nodes (F= 0.21, df = 3, 26, P = 0.89) or cane diameters (F= 2.22, df = 3, 26, P = 0.11). In addition, total shoot length (F= 0.39, P = 0.76) and mature node number at leaf loss (F= 0.86, df = 3, 26, P = 0.48) were not impacted by early season defoliation. The total weight of new shoots produced, measured as pruning weights, was not affected by defoliation at bloom (F= 1.19, P = 0.33). Finally, the diameter of canes (F= 1.39, df = 3, 26, P = 0.27) and number of shootless nodes (F= 1.33, df = 3, 26, P = 0.29) recorded the following season (2001) were not impacted by bloom injury treatments (F= 0.71, df = 3, 26, P = 0.56).

Mechanical injury during veráison had no significant effect upon any of the vine growth parameters measured after leaf senescence. Cane diameters (F= 0.73, df = 3, 8, P = 0.56), number of nodes (F= 0.97, df = 3, 8, P = 0.45), shoot length (F= 1.49, df = 3, 8, P = 0.29), and mature node numbers (F= 0.97, df = 3, 8, P = 0.45) were not significantly different between the different injury levels. In addition, pruning weights were not significantly impacted by the defoliation treatments during veráison (F= 0.24, df = 3, 8, P = 0.86). Growth measurements taken early the following season also indicated no significant impacts of injury at veráison on subsequent vine growth (cane diameters F= 0.5, df = 3, 8, P = 0.69 and shootless nodes F= 0.97, df = 3, 8, P = 0.45).

Vineyard sampling for beetle defoliation

Rose chafer. Vineyard sampling detected a rapid increase in beetle abundance over a seven day period, from a maximum of 66 beetles on a single vine on 27 June to 758 on a single vine on 4 July (Table 1). Defoliation and cluster injury were greatest on vines at edge rows, with an average of 11 injured clusters per Chardonnay vine on the border vines in Vineyard 1, and 14 injured vines on the border of Chardonnay in Vineyard 2. Overall, however, the level of defoliation and cluster injury were low across the infested vineyards (Table 1).

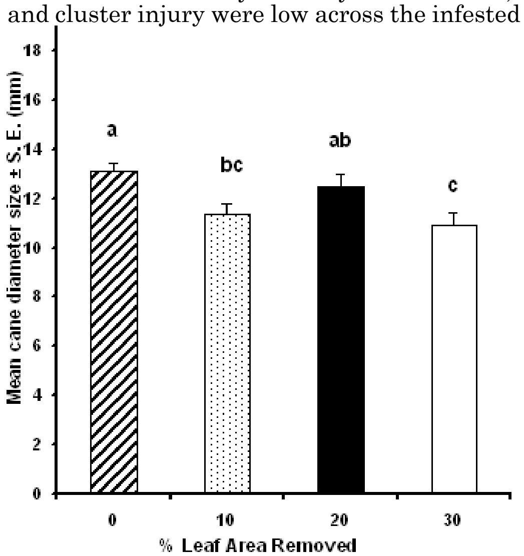

Figure 3. Cane diameter of vines damaged at bloom to different levels of defoliation, measured at veráison. Means separation by Student Newman Keuls method. Treatments with different letters are significantly different at P < 0.05.

Table 1. Summary of vineyard surveys taken in Grand Traverse county, Michigan on 26-27 June 2002 and 3-4 July 2002 . Row numbering begun on edge closest to rose chafer emergence. The mean number ± S.E. of rose chafers found per vine on both dates is given along with the defoliation index, total leaf number, number of injured clusters, and number of uninjured clusters on July 3. The defoliation index was measured on a percentage basis following Boucher and Pfeiffer (1989), and summed for each vine. Cluster injury was scored by dividing clusters into four categories as described in the methods section. Maximum signifies the highest value scored for an individual vine.

Vineyard	Row	Variety	# Beetles 26-27 June	# Beetles 3-4 July	Defoliation Index	Total leaves	Uninjured clusters	Injured clusters
1	1	Chardonnay	6 ± 3	427 ± 49	55 ± 25	200 ± 17	6 ± 4	11 ± 3
1	3	Chardonnay	30 ± 10	87 ± 48	8 ± 5.0	161 ± 29	12 ± 6	4 ± 2
1	4	Chardonnay	21 ± 11	246 ± 172	38 ± 36	209 ± 21	14 ± 6	4 ± 3
1	8	Chardonnay	27 ± 11	62 ± 49	3 ± 1	173 ± 35	18 ± 6	2 ± 1
Maximum			66	758	145	249	36	16.8
1	12	Vignoles	27 ± 11	19 ± 4	2 ± 0.5	457 ± 82	28 ± 9	1 ± 1
1	16	Vignoles	11 ± 8	16 ± 6	2 ± 0.3	517 ± 23	35 ± 2	1 ± 0.4
1	19	Vignoles	6 ± 3	11 ± 4	2 ± 0.3	515 ± 59	38 ± 5	1 ± 0.3
1	29	Vignoles	14 ± 4	11 ± 2	2 ± 0.1	447 ± 59	35 ± 4	1 ± 0.5
Maximum			58	30	2.9	647	52	3
2	1	M. Foch	2 ± 1	14 ± 5	2 ± 1	509 ± 97	30 ± 5	1 ± 1
2	5	M. Foch	0.5 ± 0.5	3 ± 2	0.3 ± 0.2	425 ± 60	36 ± 4	0.5 ± 0.4
2	13	M. Foch	0 ± 0	5 ± 4	0.5 ± 0.4	474 ± 104	34 ± 7	0.2 ± 0.2
2	18	M. Foch	1 ± 0.5	5 ± 2	0.4 ± 1	50 ± 22	45 ± 4	0.3 ± 0.2
Maximum			4	23	3.2	775	51	2.8
3	1	Chardonnay	81 ± 23	50 ± 9	11 ± 5	562 ± 40	11 ± 4	14 ± 3
3	3	Chardonnay	4 ± 3	17 ± 3	1 ± 0.1	639 ± 88	57 ± 7	0.4 ± 0.2
3	8	Chardonnay	6 ± 4	4 ± 2	1 ± 0.4	463 ± 65	58 ± 5	0.2 ± 0.1
3	15	Chardonnay	11 ± 6	4 ± 1	1 ± 0.2	450 ± 47	47 ± 4	1 ± 0.1
Maximum			120	67	25	798	75	22

Japanese beetle. Results for the four commercial vineyards sampled are summarized in Table 2. All vineyards were treated with some insecticides by the growers, so the results are an underestimate of the potential injury of Japanese beetle on vines. However, only a small level of defoliation was seen (Table 2) on most cultivars, though Vanessa vines received by far the greatest injury levels. Results from the vineyard that contained multiple cultivars are summarized in Table 3. These results indicate a potential for high levels of injury from Japanese beetle in small home plantings.

DISCUSSION

This study indicates that two of the primary scarab beetle pests of vineyards in eastern North America remove a small proportion of the leaf area on *V. labrusca* vines. This level of herbivory caused no significant impact on the above ground vegetative growth of young vines, even when 40 beetles were allowed to feed for two weeks. In addition, mechanical removal of leaf area at much greater

Table 2 . Summary of mean defoliation indices per vine caused by Japanese beetles in four small commercial vineyards in southwest Michigan, measured during July 2002.

Vineyard	Variety	Sample Size	Defoliation Index	Maximum	Minimum
1	Chardonnay	20	14.0 ± 1.3	29	5
	Seyval	20	11.5 ± 1.2	24	3
	Vignoles	40	4.5 ± 0.5	13	0
2	Concord	20	3.4 ± 0.5	7	0
	Delaware	20	13.5 ± 1.3	25	5
	Niagara	20	13.7 ± 2.1	38	0
3	Concord	24	4.2 ± 0.9	17	0
	Vanessa	24	48.2 ± 8.4	153	8
4	Concord	20	4.2 ± 0.5	9	1
	Himrod	17	10.9 ± 1.2	27	5
	Niagara	17	4.2 ± 0.9	15	0

Table 3. Summary of mean defoliation indicies (see table 1) caused by Japanese beetles and mean number of beetles per vine in a small backyard planting measured 11 July 2002.

Variety	Sample Size	Beetles on Plants	Max	Min	Defoliation Index	Max	Min
Concord	8	7.75 ± 2.8	22	0	1.2 ± 0.3	2.9	0.4
Niagara	7	10.7 ± 2.7	24	5	8.9 ± 0.8	13.3	6.8
Cayuga white	8	25.1 ± 6.8	63	7	8.0 ± 1.1	13.4	4.1
Frontennac	6	79.3 ± 9.1	119	56	33.4 ± 5.2	55.3	15.4
Marechal Foch	8	27.5 ± 7.8	60	4	10.7 ± 2.4	21.4	5.6
Golden Muscat	9	24.7 ± 7.7	75	0	4.9 ± 0.6	8.8	3.1
Seyval Blanc	8	13.4 ± 3.8	35	3	11.4 ± 1.7	22.1	6.6

levels than that caused by beetles showed that vines were negatively impacted by injury early in the season, but no significant impacts were found in above-ground tissues by the end of the season or at the beginning of the following season.

Vine growth between bloom and veráison resulted in approximately two to three times the leaf area being present at veráison, compared to that at bloom. Because mechanical injury treatments were applied on a percentage basis, the total amount of leaf area removed during veráison far exceeded that removed during bloom. Despite the greater leaf area removed during veráison, no impact of this injury was observed in above-ground tissues. These results agree with previous findings on young *Vitis labrusca* vines (Mercader and Isaacs 2003, 2004).

Mechanical injury to vines at bloom had a significant impact on storage tissues, measured as cane diameters, but no impact upon shoot growth, measured as node number, when measured at veráison. This indicates that defoliation during bloom in young vines may have induced a source limitation. However, no impact upon above ground storage tissues was detected by the time of leaf loss in the study reported here, and vegetative growth parameters measured the following season did not differ between injury treatments. Although this study did not examine root growth, the extremely high defoliation rates applied to the vines far exceeded that caused by 40 rose chafer beetles (Fig. 1). These results suggest that unless exceptionally high numbers of beetles are present, the impact on vine growth will be minimal.

The lack of any detectable effect of mechanical injury during veráison on cane diameter or shoot growth indicates that at this point of the season, when sink demands are low in non-fruiting vines, the creation of a source limitation is unlikely, even with the highest injury treatments (Fig. 1). Despite the intensity of injury applied during this period, vines with 30% leaf area removed were able to produce enough photosynthate to mature the same number of nodes as the uninjured vines. Furthermore, no impacts on initial growth parameters were observed the following season, suggesting a high level of tolerance to herbivory.

We propose that mechanical injury during veráison did not affect vine growth because non-bearing vines have relatively few sinks and a full vegetative canopy, suggesting a sink-limitation. Other studies on grapevines have found similar results. For example, using potted vines with and without fruit, Petrie et al. (2000 a) found that despite a higher leaf area in non-bearing vines compared to bearing vines, no significant differences in total dry weight were found. Furthermore, Layne and Flore (1995) have demonstrated the impact of end-product inhibition in sour cherry, *Prunus cerasus* (L.), as a mechanism for sink limitations at a whole plant level. These studies illustrate the importance of source to sink ratios in understanding a plant's ability to assimilate carbon, and therefore their ability to respond to leaf area loss.

In light of the lack of significant differences in above ground growth by the end of the season among vines in the mechanical defoliation experiment, it is not surprising that the level of herbivory caused by beetles did not impact their growth. This study illustrates the low level of defoliation that *M. subspinosus* and *P. japonica* may cause on *V. labrusca* var. 'Niagara' vines. Based on these findings we expect defoliation in establishing 'Niagara' vineyards to be below levels likely to affect vineyard establishment, though longer term studies are needed.

Due to the large canopies present at veráison, the proportion of leaf area injured by Japanese beetles in established *V. labrusca* vineyards ought to have little viticultural significance, but long term studies with chronic pest pressure are required to test this prediction. Boucher and Pfeiffer (1989) found no effect of natural infestations of Japanese beetle (6.5% defoliation) on vine growth or fruit quality and quantity in 'Seyval blanc' vines, even though these vines had fruit as an active sink for carbon during the time of insect injury. Due to the relatively small level of defoliation by 40 adult Japanese beetles on establishing vines in our study (6.4% mean defoliation in small vines, mean leaf number at veráison = 187), we expect lower defoliation levels in established *V. labrusca* vineyards than were found by Boucher and Pfeiffer (1989) on mature 'Seyval blanc' vines. However, viticulture in cool climates such as Michigan requires consideration of the environmental conditions that the vines are growing in (Howell 2001). Shorter growing seasons reduce the post-harvest carbon assimilation period, limiting the available time to recover and sequester enough carbohydrates to tolerate cold temperatures. Cropping level is expected to be an important factor that will impact tolerance to grapevine foliar herbivory. Further studies should include different cropping levels in order to develop 'integrated economic injury thresholds' for these or any other foliar pests on fruiting grapevines under different viticultural situations.

Rose chafer density in vineyards purposefully chosen for their high infestation rates only exceeded an average 40 beetles per plants in one vineyard. These mature vineyards had far greater leaf area than the establishing vines we caged, and therefore with the exception of one site rose chafers are unlikely to have had a significant impact on growth. The aggregative nature of these beetles leads to a visually impressive infestation (R.J. Mercader, personal observation), yet the numbers rarely exceed 40 beetles per vine. Future studies on this beetle should concentrate on their impacts upon flower clusters, as there is potential for concern in fruiting vineyards due to feeding on flower clusters during bloom (Chittenden 1916, R.J. Mercader unpublished data). In our vineyard surveys we found high levels of cluster injury on edge rows of two vineyards with Chardonnay vines (Table 1). However, cluster injury levels were much lower beyond the first row. The importance of edge effects may make the rose chafer a pest of greater importance in small vineyards or home plantings.

It is apparent from these studies that young *V. labrusca* vines have a significant ability to tolerate foliar injury, in particular after the initial vegetative growth has occurred. This tolerance was seen in above ground growth at levels of leaf area loss far beyond the defoliation potential of 40 rose chafers or Japanese beetles per vine. This indicates that even under intense infestations of these two pests, the injury caused may not warrant chemical control unless other forms of stress such as disease or drought have critically stressed the vines. Sustainable grape production, as defined by Howell (2001), refers to maintaining the highest yields of ripe fruit per unit area without reducing vegetative growth and doing so over a period of years at costs which return a net profit. Within this framework, it is important to consider the unique characteristics of the initial years of vineyard establishment in which no crop is produced, and vines therefore have fewer carbohydrate sinks.

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