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Research

Impact of Brown Marmorated Stink Bug (Hemiptera: Pentatomidae) Feeding on Tart Cherry (Rosales: Rosaceae) Quality and Yield in Utah

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Abstract

Brown marmorated stink bug (*Halyomorpha halys* Stål) is an invasive and economically important agricultural and ornamental insect pest now established in 46 U.S. states. It was first detected in Utah in 2012 and began causing agricultural damage in 2017. Tart cherry (*Prunus cerasus* Linnaeus) is a major processed agricultural commodity in Utah; yet, its susceptibility to brown marmorated stink bug is unstudied. Limb cages with six brown marmorated stink bug adults, nymphs, or no brown marmorated stink bug were established in a randomized complete block design in a tart cherry orchard to determine feeding impact on different fruit developmental stages. After 1 wk of feeding, half of the fruits in each cage were removed to assess feeding intensity, and the remainder left through maturity to assess marketability and quality. Feeding by adults and nymphs between petal fall and fruit pit hardening, even at feeding pressures as low as 1.7–4.0 feeding sites per fruit, caused 100% abscission of fruits, significantly reducing marketability when compared with the control treatment. For fruits that escaped abscission and matured, few quality differences were detected among treatments, indicating that brown marmorated stink bug feeding caused minimal detectable quality loss to this processed tree fruit crop. We conclude that tart cherries are at risk of abscission with short-term brown marmorated stink bug feeding between petal fall and pit hardening when overwintered adults or F_1 nymphs are present in orchards, and suggest that longer-term feeding may be necessary to cause quality and yield reductions after pit hardening.

Key words: brown marmorated stink bug, feeding damage, *Prunus cerasus*, yield, quality

Brown marmorated stink bug (*Halyomorpha halys* Stål) is an invasive agricultural and nuisance pest native to China, Japan, Korea, and Taiwan (Hoebeke and Carter 2003, Lee et al. 2013). Since its introduction to the United States in the 1990s, brown marmorated stink bug has become a severe pest in tree fruit, nut, vegetable, and field crops (Nielsen and Hamilton 2009, Leskey and Hamilton 2010, Kuhar et al. 2012, Leskey et al. 2012a, Rice et al. 2014). Brown marmorated stink bug is known to feed on over 100 plant hosts, including both vegetative and reproductive plant structures, such as stems, leaves, fruiting bodies, and seed pods (Bergmann et al. 2013, Haye et al. 2015, Wiman et al. 2015). Feeding damage can range from localized wilting and necrosis, to abscission or deformation of fruiting bodies, resulting in fruit quality and/or yield loss (Strong 1970, Tingey and Pillimer 1977, Hori 2000). If feeding occurs early in fruit development, then abscission, or premature abortion, of fruits is more probable (Nielsen and Hamilton 2009, Rice et al. 2014). Late-season feeding can result in several outcomes including discoloration, necrosis, deformation at feeding sites, and cat-facing (extensive deformation) of fruits, all of which can impact crop marketability (Pfeiffer et al. 2012, Rice et al. 2014). Additionally, when brown marmorated stink bug pierce plant structures with their stylet, secondary infections caused by yeast may occur, resulting in additional damage and crop loss (Mitchell 2004).

Studies to characterize brown marmorated stink bug damage to some vegetable and fruit crops have found high vulnerability among pepper, sweet corn, and okra, with losses exceeding 50% due to scarring, sunken lesions, and fruit deformation (Kuhar et al. 2012, Rice et al. 2014). Orchard fruits are often attacked season-long by brown marmorated stink bug, placing them at greater risk to crop loss (Nielsen and Hamilton 2009, Leskey et al. 2012b). Injury to apple can be severe, with losses exceeding 90% during periods of high brown marmorated stink bug infestations (Leskey and Hamilton 2010). Stone fruits, such as peach and nectarine, are susceptible to cat-facing and premature fruit abortion (Nielsen and Hamilton

2009). Additionally, sweet cherries targeted by brown marmorated stink bug may exhibit reduced fruit weight, lower marketability, and increased susceptibility to fungal infections (Moore et al. 2019). Few studies have assessed susceptibility of other stone fruit and berry crops or have determined the impact of brown marmorated stink bug on processed fruit crops.

Utah is the second largest producer of tart cherry (*Prunus cerasus* Linnaeus) in the United States, with an average annual production of 17,899 metric tons on 1,287 hectares, and a utilized value of production over $14.5 million (from 2013 to 2017; UDAF 2018). As brown marmorated stink bug continues to spread and establish in tart cherry-producing states, such as Utah and Michigan, a better understanding of the susceptibility of tart cherry to brown marmorated stink bug feeding is needed. Brown marmorated stink bug was first detected in Utah in 2012, and agricultural damage was first reported in 2017 (Holthouse et al. 2017). It is established in the highly urbanized areas of northern Utah, and its populations continue to expand. Northern Utah is unique compared with other geographic areas where brown marmorated stink bug has invaded due to its comparatively high elevation (>1,200 m), aridity, hot summers, and cold winters (NOAA NECI 2019). Agricultural production areas in northern Utah are often adjacent to or surrounded by urban/suburban development. Brown marmorated stink bug will typically feed on host plants adjacent to overwintering sites inside human structures after spring emergence (Rice et al. 2014). Therefore, the close proximity between agricultural production and overwintering areas may facilitate higher brown marmorated stink bug impacts to Utah specialty crop production, particularly in the early season shortly after termination of overwintering diapause.

The objective of this study was to examine the impact of brown marmorated stink bug adult and nymph feeding on early to mature developmental stages of tart cherry ('Montmorency') in regards to quality and yield. Tart cherry is a processed crop, utilized for dried, frozen, canned, and juiced products; therefore, damage thresholds and economic impacts will probably differ from those of freshly consumed fruit crops. An economic assessment of the potential impact of brown marmorated stink bug infestation on tart cherry will offer monitoring and management support to Utah growers and other tart cherry-producing regions to better manage economic loss as brown marmorated stink bug continues to increase its distribution in the United States.

Materials and Methods

Experimental Design

Experiments were conducted at the Utah State University Horticultural Research Farm in Kaysville, UT (N 41° 1′ 20.88″, W 111° 56′ 5.544″). In 2018, beginning at the bud stage of tart cherry (18 April), cylindrical sleeve cages (30 × 80 cm; open at both ends), made of white no-see-um mesh (Mosquito Curtains, Alpharetta, GA), were placed over the terminal end of 12 limbs on 12 individual trees in an orchard row of tart cherry; the base secured with a zip tie. Branches were selected to include a similar number of buds at approximately breast height and were not exposed to direct sunlight. Selected branches were checked for other arthropods, which were removed prior to introducing treatments. All fruit buds inside the cage were counted, and replicates of six brown marmorated stink bug adults or nymphs (second to third instar), or no bugs (control), were added to cages in a randomized complete block design (see Brown marmorated stink bug sources). The terminal end of each cage was sealed with a twist of the cloth and zip tie. Brown marmorated stink bug remained in cages for 1 wk to allow for feeding, and then removed, along with half of the fruit bud structures with stems still attached (selected evenly along the bagged section of limb). Cages were then resealed to allow for development of remaining fruit structures. This procedure was repeated for the petal fall (3 May), first blush (24 May), pit hardening (14 June), and mature fruit stages (9 July).

In 2019, using knowledge of negative effects of brown marmorated stink bug feeding on early fruit developmental stages from 2018, the experimental design was expanded to include a total of nine fruit developmental stages: petal fall (21 May), mid green (28 May), late green (4 June), first blush (11 June), pit hardening (18 June), half red (25 June), full red (2 July), near mature (9 July), and mature (16 July) fruit stages.

Brown Marmorated Stink Bug Sources

Brown marmorated stink bug were acquired from wild and colony-reared populations at Utah State University and supplemented in 2019 with individuals from the New Jersey Department of Agriculture colony. The colony was fed a combination of organic store-bought apple, pepper, carrot, and string beans; and maintained at 23°C, 60% RH, and 16:8 (L:D) h photoperiod. Due to low availability of wild brown marmorated stink bug for early-season tart cherry bud stages, primarily colony-reared insects were used, whereas mid and late-season cages included a mixture of colony-raised and wild brown marmorated stink bug. Brown marmorated stink bug were not starved before initiation of experiments.

Feeding Injury

Fruit transported to the laboratory following 1 wk of exposure to brown marmorated stink bug in field cages were placed into a 500-ml glass beaker containing acid fuchsin stain (250-ml 95% Ethanol, 250-ml acetic acid, 1-g acid fuchsin powder) for 5 s, air-dried, and then observed under a dissecting microscope at 10× magnification to count the number of brown marmorated stink bug feeding sites (presence of a stylet sheath or a hole penetrating the fruit).

Fruit Abscission and Marketability

When fruits remaining inside sleeve cages reached maturity (16 July in 2018; 25 July in 2019), they were removed and assessed for abscission and marketability. Fruits that did not develop, or abscised (the fruit pit without flesh attached to the stem), were counted. In 2018, fruit marketability was determined with a visual assessment (i.e., fruits were deemed unmarketable if any damaged, deeply scarred, or rotting tissue was present). In 2019, an additional marketability assessment was conducted using a TOMRA laser sorting machine (TOMRA, Asker, Norway) at the Payson Fruit Growers, Inc. processing plant in Payson, UT. All fruits were run through the laser and unmarketable fruits were ejected based on laser detection of decay or discolored flesh that would deem a tart cherry unfit for processing.

Fruit Quality

Quality measurements were collected on all fruits that did not abscise and reached maturity, including mass (g), diameter (mm), and sugar content (% brix) using an analytical balance, manual calipers, and a refractometer (Atago ATC-1, Tokyo, Japan), respectively.

Statistical Analyses

Generalized linear mixed effects models and analysis of variance were used to compare fruit injury (mean number of brown marmorated stink bug feeding sites per structure; Poisson distribution), fruit marketability (binomial distribution), fruit abscission (binomial distribution), and quality among treatments (normal distribution). Data met distributional requirements and were not transformed. Models were run separately for each response variable at each fruit stage and for each year. Following significant results, pairwise comparisons were used to differentiate treatments. Models and post hoc comparisons were performed using the *glmer*, *aov*, *emmeans*, and *TukeyHSD* functions in the lme4 and *stats* packages distributed with base R Version 1.2, run using RStudio for Mac (R Core Team 2017). Significance for all tests was set at α ≤ 0.05. Figures were made in the *ggplot2* package version 3.2.1 in the Tidyverse Environment for RStudio (Wickham 2016, Wickham et al. 2019).

Results

Feeding Injury

Treatments resulted in significant differences in the mean number of brown marmorated stink bug feeding sites per tart cherry fruiting structure in both years. Mean number of feeding sites ranged from 0 to 1.0 sites per fruit in the control treatment, 0.5 sites per bud to 13.3 sites per mature fruit in the nymph treatment, and 0.4 sites per bud to 37.8 sites per mature fruit in the adult treatment. Notably, feeding sites were found uniformly on fruiting structures and were seldom found on stems.

In 2018, feeding intensity differed significantly among treatments at all fruit development stages (Table 1). Fruits exposed to adult or nymph brown marmorated stink bug exhibited significantly more feeding sites per fruiting structure than were present on structures in the control at all fruit stages; exposure to adults additionally resulted in more feeding sites per structure than exposure to nymphs at all stages except the bud stage (Fig. 1a).

In 2019, feeding intensity differed significantly among treatments at all fruit development stages (Table 1). Exposure to adults and nymphs resulted in significantly more feeding sites per fruit compared with the control treatment in all developmental stages. Adult exposure additionally resulted in more feeding sites per fruit than nymph exposure at all stages except the petal fall stage, where effects from nymphal feeding were greater than adult feeding (Fig. 1b).

Fruit Abscission and Marketability

Overall, 3% of control fruits (SD = 0.07), 22% of nymph-fed fruits (SD = 0.34), and 31% of adult-fed fruits abscised (SD = 0.45) across 2018 and 2019. Fruit abscission did not occur in the bud, petal fall, and mature fruit stages in 2018 or in the near mature and mature fruit stages in 2019, regardless of treatment.

In 2018, the proportion of abscised fruits did not differ significantly among treatments in any fruit stage (Table 1). However, exposure to either adults or nymphs resulted in 100% fruit abscission in the first blush stage, whereas no control fruits abscised. This biologically significant difference was not detectable in the statistical models due to complete separation in outcomes among the treatments, and lack of within-treatment variability (Fig. 2a).

In 2019, the proportion of abscised fruits differed significantly among treatments in all stages from petal fall to first blush (Table 1). In the petal fall stage, exposure to adults resulted in a higher proportion of abscised fruits than the control treatment (Fig. 2b). Adult and nymph exposure resulted in a higher proportion of abscised fruits than the control treatment from mid green to first blush, with adult exposure additionally resulting in more abscission than nymph exposure. Although this is biologically significant, it was not picked up by the model in the mid green and late green stages because 100% of adult-fed fruits abscised (Fig. 2b).

Overall, 71% of control fruits (SD = 0.18), 51% of nymph-fed fruits (SD = 0.29), and 47% of adult-fed fruits were deemed marketable (SD = 0.34) as determined by visual assessments in 2018 and the laser sorter in 2019.

Adult and nymph brown marmorated stink bug feeding was associated with significant differences in marketability of fruits in both years. In 2018, only the pit hardening stage experienced a difference in marketability among treatments as determined by visual assessments (Table 1). In this stage, adult-fed fruits were significantly more marketable than nymph-fed fruits. However, in the first blush stage, both adult and nymphal feeding reduced marketability of fruits by 100% compared with the control treatment, in which 35% of fruits were

Table 1. Generalized linear mixed effects model results for tart cherry feeding intensity, marketability, and abscission at each developmental stage in 2018 and 2019

		Feeding intensity			Abscission			Marketability		
Year	Fruit stage	*F*	df	*P*	*F*	df	*P*	*F*	df	*P*
2018										
	Bud	**6.06**	**2**	**<0.01**	—	—	—	0.37	2	0.68
	Petal fall	**208.36**	**2**	**<0.01**	—	—	—	1.37	2	0.29
	First blush	**18.76**	**2**	**<0.01**	0*	2	1*	0*	2	1*
	Pit hardening	**92.57**	**2**	**<0.01**	1.09	2	0.33	**4.93**	2	**<0.01**
	Mature	**461.30**	**2**	**<0.01**	—	—	—	2.70	2	0.07
2019										
	Petal fall	**25.84**	**2**	**<0.01**	**5.92**	**2**	**<0.01**	**3.58**	**2**	**0.03**
	Mid green	**70.06**	**2**	**<0.01**	**11.92**	**2**	**<0.01**	**19.24**	**2**	**<0.01**
	Late green	**145.50**	**2**	**<0.01**	**8.23**	**2**	**<0.01**	**10.26**	**2**	**<0.01**
	First blush	**76.28**	**2**	**<0.01**	**12.75**	**2**	**<0.01**	**25.50**	**2**	**<0.01**
	Pit hardening	**80.14**	**2**	**<0.01**	0	2	1	0.99	2	0.36
	Half red	**159.49**	**2**	**<0.01**	0	2	1	0.53	2	0.59
	Full red	**139.45**	**2**	**<0.01**	0	2	1	2.80	2	0.06
	Near mature	**393.56**	**2**	**<0.01**	—	—	—	**7.55**	2	**<0.01**
	Mature	**231.95**	**2**	**<0.01**	—	—	—	**3.35**	2	**0.04**

Numbers in bold indicate significant differences among treatments ($P < 0.05$).

*A lack of variability within treatments.

marketable (Fig. 3a). Again, the model was unable to pick up these key biologically significant differences due to complete separation.

In 2019, there were significant differences in marketability among treatments in every fruit stage from petal fall to first blush, and additionally in the near mature and mature stages as determined by the laser sorting machine (Table 1). In the petal fall stage, adult-fed fruits were significantly less marketable than control fruits (Fig. 3b). Furthermore, adult and nymph-fed fruits were less marketable than control fruits in the mid green, late green, and first blush stages. The model could not pick up the biologically significant effect of adult feeding on marketability in the mid and late green stages because 0% of adult-fed fruits were marketable. Additionally, nymph-fed fruits were less marketable than adult-fed and control fruits in the near mature stage. Although the model also suggested a significant difference in marketability in the mature fruit stage in 2019, follow-up pairwise comparisons did not reveal significant differences between any two treatments (Fig. 3b).

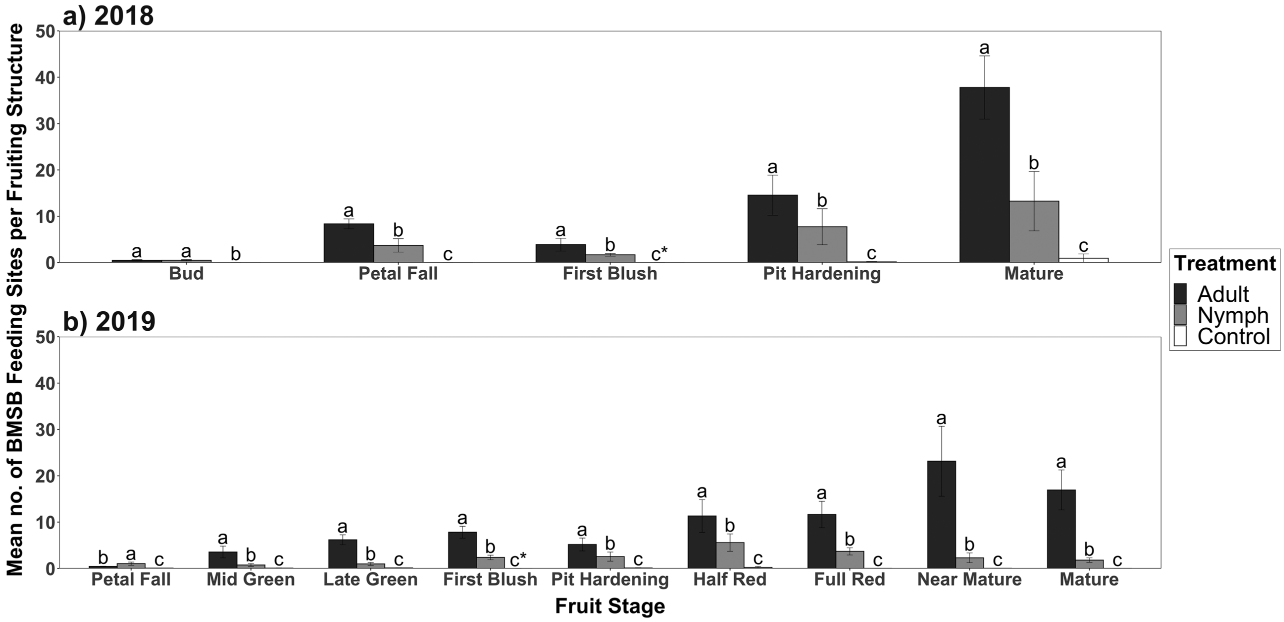

Fig. 1. Mean number of feeding sites (± SE) per fruiting structure for each tart cherry developmental stage in 2018 (a) and 2019 (b) (five and nine developmental stages were tested in respective years). Different letters indicate significant differences in means among treatments (Tukey's HSD; $P < 0.05$). Asterisks indicate a lack of variability within treatment(s).

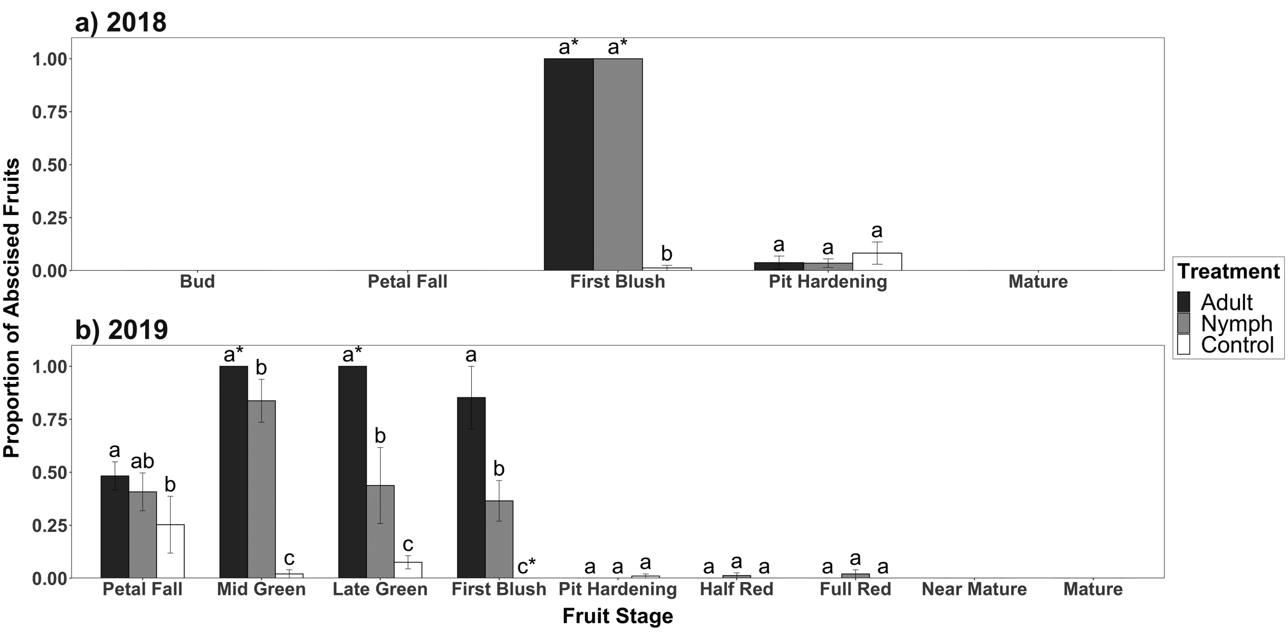

Fig. 2. The mean proportion of fruits that abscised or did not develop (± SE) for each treatment and fruit stage in 2018 (a) and 2019 (b). Brown marmorated stink bug, especially adults, caused high rates of abscission between petal fall and pit hardening fruit stages in both years. Different letters indicate significant differences in means among treatments (Tukey's HSD; $P < 0.05$). Asterisks indicate a lack of variability within treatment(s).

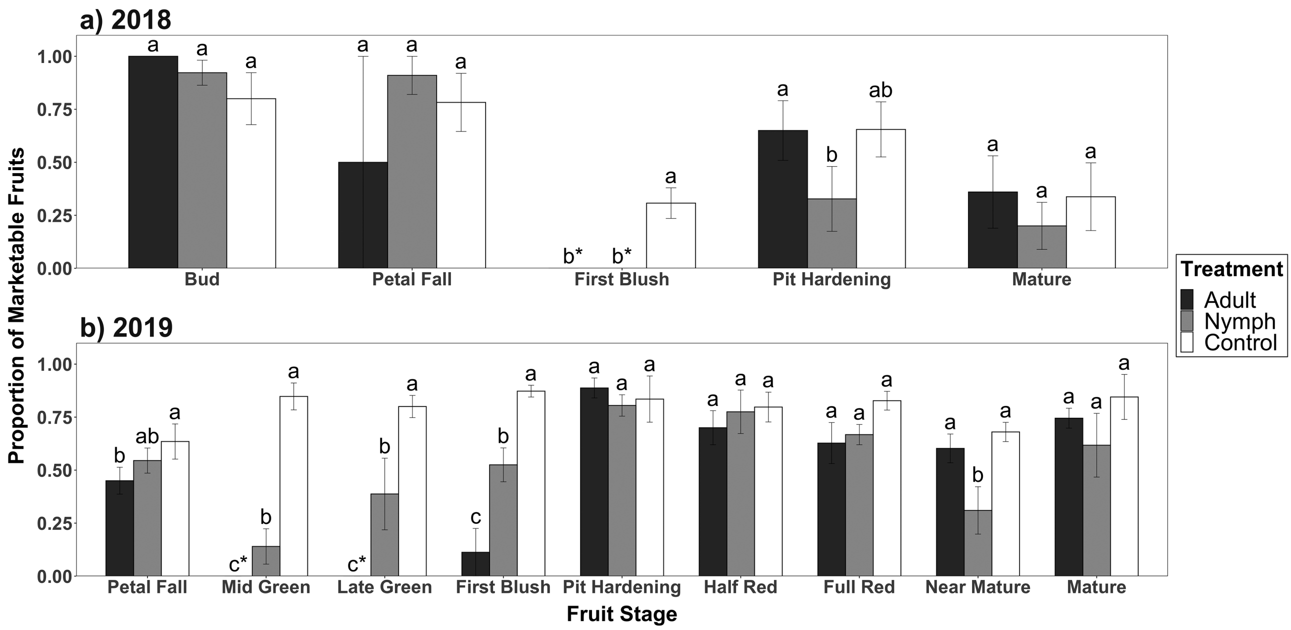

Fig. 3. Proportion of fruits remaining that were marketable (± SE) at harvest for each tart cherry developmental stage in 2018 (a) and 2019 (b). Different letters indicate significant differences in means among treatments (Tukey's HSD; $P < 0.05$). Asterisks indicate a lack of variability within treatment(s).

Fruit Quality

In 2018, there was a significant sugar content difference among treatments in the pit hardening stage, but no other quality differences were detected in any other fruit stage (Table 2). Pairwise comparisons revealed that adult and nymph treatments resulted in significantly lower sugar content (15.7 and 14.6% brix, respectively) compared with control fruits (17.6% brix). In 2018, during the first blush stage, no fruits from the adult or nymph treatments developed to maturity (Figs. 2a and 3a). In 2019, there were no significant differences in fruit quality metrics (mass, diameter, and sugar content) among treatments in any fruit stage (Table 2).

Discussion

Our study provides the first in-depth analysis of the potential impacts of brown marmorated stink bug feeding on tart cherry. We determined that tart cherry fruits are highly susceptible to yield loss if brown marmorated stink bug feeding occurs from petal fall to pit hardening. During these early-season stages, the trees are allocating energy to fruit ovary production and protection and will allocate energy to fruit swelling and ripening after the pits harden. These results are supported by other studies that report fruit abortion to peach and apple if feeding occurs during early fruit developmental stages (Nielsen and Hamilton 2009, Rice et al. 2014). More concerning for tart cherry production, however, is that low levels of brown marmorated stink bug feeding pressure can cause fruit abortion. For example, nymphal feeding for the mid and late green stages in 2019 was less than 1.0 site per fruit; however, nymph feeding still caused high rates of abscission and significantly lower marketability than control treatments for these fruit stages (84 and 44% abscission, respectively). Interestingly, as fruits developed, i.e., increased in size and pits hardened, nymph-fed fruit marketability substantially increased in 2019.

We included peach ('Suncrest') in our original experiment; however, due to spring freeze damage to peach flowers in 2018 and reduced availability of brown marmorated stink bug in 2019, only limited replication of selected peach developmental stages was included in our study. The peach data suggest, however, that fruit abscission in peach occurs less often than in tart cherry if feeding occurs between first blush and pit hardening of fruits (Z. Schumm, unpublished data). We postulate that lower abscission in peach is due to greater fruit size. In stone fruits, the development and hardening of pits and seeds are a precursor to expansion of the fruit exocarp (flesh; Zavalloni et al. 2006). Furthermore, damage to young, developing fruit ovaries is known to increase abscission and negatively affect fruit set (Sawicki et al. 2015, Liu et al. 2018).

During our study, the mean distance from the fruit skin to the pit during stages prior to pit hardening was less than 3.2 mm, whereas once the pit hardened this distance increased substantially to 4.5 mm and reached ~11 mm by fruit maturity. Therefore, a plausible reason that brown marmorated stink bug adults caused more abscission of tart cherry fruits than second- and third-instar nymphs may be due to stylet length and their ability to penetrate into the developing ovaries, potentially feeding through the exocarp and into the endocarp (pit) and seed while the pit is soft. Reduced stylet length in second- and third-instar nymphs, and an inability to reach developing pits and seeds during feeding may explain why nymph-fed fruits were generally more marketable when exposed to brown marmorated stink bug between petal fall and pit hardening. Additionally, it may explain why marketability of fruits with nymph feeding increased as fruits increased slightly in size as they reached the pit hardening stage. Further research should be conducted to test this hypothesis and to determine other plausible explanations such as differing feeding strategies by adults and nymphs. We do however note that we seldom found feeding sites on cherry stems, indicating that brown marmorated stink bug adults and nymphs prefer fruiting structures over stems.

Our study addressed impacts to tart cherry fruit yield and quality from relatively short-term brown marmorated stink bug feeding, 1 wk. Longer-term feeding is known to cause severe damage in several other *Prunus* fruit crops (Leskey et al. 2012b, Rice et al. 2014), including tart cherry observed during other Utah studies where

Table 2. ANOVA results for tart cherry fruit quality, including mass, diameter, and sugar content (% brix), at each developmental stage in 2018 and 2019

		Mass			Diameter			Sugar content (% brix)		
Year	Fruit stage	*F*	df	*P*	*F*	df	*P*	*F*	df	*P*
2018										
	Bud	0.70	2,5	0.54	0.93	2,5	0.45	1.03	2,5	0.24
	Petal fall	0.54	2,2	0.65	0.14	2,2	0.88	3.56	2,2	0.22
	First blush	—	—	—	—	—	—	—	—	—
	Pit hardening	3.39	2,6	0.10	0.34	2,6	0.73	**16.02**	**2,6**	**<0.01**
	Mature	0.71	2,6	0.53	0.77	2,6	0.51	0.84	2,7	0.47
2019										
	Petal fall	0.79	2,6	0.50	1.59	2,6	0.28	1.02	2,6	0.42
	Mid green	2.20	1,1	0.38	15.98	1,1	0.15	0.12	1,1	0.79
	Late green	0.42	1,3	0.56	<0.01	1,3	0.98	0.00	1,3	1.00
	First blush	6.56	2,3	0.08	1.89	2,3	0.29	1.92	2,3	0.29
	Pit hardening	0.36	2,6	0.71	0.23	2,6	0.80	0.25	2,6	0.79
	Half red	0.86	2,6	0.47	1.02	2,6	0.42	0.74	2,6	0.52
	Full red	1.31	2,6	0.34	1.68	2,6	0.26	2.33	2,6	0.18
	Near mature	2.00	2,6	0.22	1.83	2,6	0.24	0.34	2,6	0.72
	Mature	<0.01	2,6	0.99	0.04	2,6	0.96	0.29	2,6	0.76

Numbers in bold indicate significant differences among treatments for the indicated metric and developmental stage ($P < 0.05$).

over 2 wk of brown marmorated stink bug feeding resulted in severe tissue damage and dry, shriveled fruits (C. Holthouse, unpublished data). Overall, we suggest that short-term feeding by adults and nymphs can cause severe yield loss via fruit abscission if feeding occurs from petal fall to fruit pit hardening. Interestingly, in contrast, we seldom found quality effects from brown marmorated stink bug feeding in late-season fruit stages that received the highest feeding pressure (1.8–13.3 nymph feeding sites per fruit and 5.2–37.8 adult feeding sites per fruit). Additionally, the single significant quality difference seen in sugar content during this study could have been due to chance alone based on an alpha value of 0.05 and 39 separate quality analyses being conducted (Table 2). This suggests that long-term feeding (more than 1 wk) under substantial feeding pressure may be needed to induce quality loss in tart cherry fruit due to it being a processed versus fruit market product. Our results for tart cherry support those for other tree fruit crops that early-season injury by brown marmorated stink bug can result in economically significant fruit yield loss (Anthon et al. 2007, Nielsen and Hamilton 2009, Rice et al. 2014).

In sweet cherry fruits, early-season feeding by stink bug pests is known to cause cat-facing and dimpling of fruits, and late-season feeding can cause discoloration of the flesh surrounding the pit (Anthon et al. 2007). Additionally, brown marmorated stink bug feeding is known to lower quality and marketability of sweet cherry (Moore et al. 2019). Although our results for tart cherry found different early-season feeding outcomes than for sweet cherry (fruit abscission vs cat-facing), the processed nature of tart cherry alters fruit quality standards when compared with fresh market sweet cherry fruits. We found only minor reductions in quality for tart cherry fruits fed on mid and late season when brown marmorated stink bug populations are likely at their highest levels in commercial orchards. We importantly note that the laser sorter did not reject many fully formed fruits, even when visible external tissue damage was present. Therefore, our results support the hypothesis that although brown marmorated stink bug feeding to tart cherry fruits induces visual quality reduction, the fruits are still readily marketable for processing, including dried, juiced, canned, and frozen products. Importantly, some control fruits also experienced slight visual quality reduction, which resulted in overall marketability to be lower in 2018 when only visual checks were used to confirm marketability.

The first in-depth look into the potential impacts of brown marmorated stink bug injury to tart cherry fruits suggests high susceptibility to abscission and yield loss when feeding occurs between petal fall and pit hardening when trees are investing energy into the development of seeds and pits of fruits. For growers, this suggests that monitoring and management, while beneficial season-long, is critical during pre-pit hardening stages of fruit development. We do not anticipate high populations of brown marmorated stink bug to be in the agricultural landscape in the early season, particularly nymphs that do not emerge until overwintering adults oviposit at the end of May. However, brown marmorated stink bug is active in the Utah agricultural landscape from petal fall until maturity of tart cherries (Z. Schumm, unpublished data). Therefore, the primary concern for growers appears to be yield loss caused by overwintering adults. Additional studies are necessary to test the impact of longer-term late-season feeding to the quality of processed tart cherry fruits. Furthermore, we suggest that while brown marmorated stink bug abundance is probably low in tart cherry cropping systems during the stages most vulnerable to yield loss, monitoring is still important given that even low levels of feeding can cause fruit abscission. A full understanding of the impact of brown marmorated stink bug feeding to all developmental stages of tart cherry and associated quality loss for this processed stone fruit crop is pivotal to the development of best management practices for this highly destructive invasive insect pest.

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References Cited

Anthon, T. W., E. H. Beers, and C. Krupke. 2007. Stink bugs. (http://treefruit.wsu.edu/crop-protection/opm/stink-bugs/).

Bergmann, E., K. M. Bernhard, G. Bernon, M. Bickerton, S. Gill, C. Gonzales, G. C. Hamilton, C. Hedstrom, K. Kamminga, C. Koplinka-Loehr, *et al.* 2013. Host plants of the brown marmorated stink bug in the U.S. (http://www.stopbmsb.org/where-is-bmsb/host-plants/#host_plants_table).

Haye, T., T. Gariepy, K. Hoelmer, J.-P. Rossi, J.-C. Streito, X. Tassus, and N. Desneux. 2015. Range expansion of the invasive brown marmorated stinkbug, *Halyomorpha halys*: an increasing threat to field, fruit and vegetable crops worldwide. J. Pest Sci. 88: 665–673.

Hoebeke, E. R., and M. E. Carter. 2003. *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae): a polyphagous plant pest from Asia newly detected in North America. Proc. Entomol. Soc. Wash. 105: 225–237.

Holthouse, M. C., D. G. Alston, L. R. Spears, and E. Petrizzo. 2017. Brown marmorated stink bug [*Halyomorpha halys* (Stål)], p. 8. Utah State University Extension Fact Sheet, Logan, UT. (https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=2785&context=extension_curall).

Hori, K. 2000. Possible causes of disease symptoms resulting from the feeding of phytophagous Heteroptera, pp. 10–35. *In* C. Schaefer and A. R. Panizzi (eds.), Heteroptera of economic importance. CRC Press, Boca Raton, FL.

Kuhar, T. P., K. L. Kamminga, J. Whalen, G. P. Dively, G. Brust, C. R. R. Hooks, G. Hamilton, and D. A. Herbert. 2012. The pest potential of brown marmorated stink bug on vegetable crops. Plant Health Prog. 13: 41.

Lee, D. H., B. D. Short, S. V. Joseph, J. C. Bergh, and T. C. Leskey. 2013. Review of the biology, ecology, and management of *Halyomorpha halys* (Hemiptera: Pentatomidae) in China, Japan, and the Republic of Korea. Environ. Entomol. 42: 627–641.

Leskey, T. C., and G. C. Hamilton. 2010. Brown marmorated stink bug working group meeting. (https://projects.ipmcenters.org/Northeastern/FundedProjects/ReportFiles/Pship2010/Pship2010-Leskey-ProgressReport-237195-Meeting-2010_11_17.pdf).

Leskey, T. C., G. C. Hamilton, A. L. Nielsen, D. F. Polk, C. Rodriguez-Saona, J. C. Bergh, D. A. Herbert, T. P. Kuhar, D. Pfeiffer, G. P. Dively, *et al.* 2012a. Pest status of the brown marmorated stink bug, *Halyomorpha halys* in the USA. Outlooks Pest Manag. 23: 218–226.

Leskey, T., B. Short, B. Butler, and S. Wright. 2012b. Impact of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål), in mid-Atlantic tree fruit orchards in the United States: case studies of commercial management. Psyche 2012: 535062.

Liu, C.-Q., Y. Niu, D.-L. Peng, and H. Sun. 2018. Are superior ovaries damaged by the bills of flower-visiting birds and does this preclude adaptation to bird pollinators? Bot. J. Linn. Soc. 187: 499–511.

Mitchell, P. L. 2004. Heteroptera as vectors of plant pathogens. Neotrop. Entomol. 33: 591–545.

Moore, L., P. Tirello, D. Scaccini, M. D. Toews, C. Duso, and A. Pozzebon. 2019. Characterizing damage potential of the brown marmorated stink bug in cherry orchards in Italy. Entomol. Gen. 39: 271–283.

(NOAA NECI) National Oceanic and Atmospheric Administration National Centers for Environmental Information. 2019. Climate data online. (https://www.ncdc.noaa.gov/cdo-web/).

Nielsen, A. L., and G. C. Hamilton. 2009. Seasonal occurrence and impact of *Halyomorpha halys* (Hemiptera: Pentatomidae) in tree fruit. J. Econ. Entomol. 102: 1133–1140.

Pfeiffer, D. G., T. C. Leskey, and H. J. Burrack. 2012. Threatening the harvest: the threat from three invasive insects in late season vineyards, pp. 449–474. *In* N. J. Bostanian, C. Vincent, and R. Isaacs (eds.), Arthropod management in vineyards: pests, approaches, and future directions. Springer, Dordrecht, The Netherlands.

R Core Team. 2017. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rice, K. B., C. J. Bergh, E. J. Bergmann, D. J. Biddinger, C. Dieckhoff, G. Dively, H. Fraser, T. Gariepy, G. Hamilton, T. Haye, *et al.* 2014. Biology, ecology, and management of brown marmorated stink bug (Hemiptera: Pentatomidae). J. Integr. Pest Manag. 5: A1–A13.

Sawicki, M., E. Aït Barka, C. Clément, N. Vaillant-Gaveau, and C. Jacquard. 2015. Cross-talk between environmental stresses and plant metabolism during reproductive organ abscission. J. Exp. Bot. 66: 1707–1719.

Strong, F. E. 1970. Physiology of injury caused by *Lygus hesperus*. J. Econ. Entomol. 63: 808–814.

Tingey, W. M., and E. A. Pillimer. 1977. Lygus bugs: crop resistance and physiological nature of feeding injury. Bull. Entomol. Soc. Am. 23: 277–287.

(UDAF) Utah Department of Agriculture and Food. 2018. 2018 Annual summary report. (https://ag.utah.gov/documents/2018AgriculturalStatistics.pdf).

Wickham, H. 2016. ggplot2 elegant graphics for data analysis, 2nd ed. Springer-Verlag, New York.

Wickham, H., M. Averick, J. Bryan, W. Chang, L. McGowan, R. François, G. Grolemund, A. Hayes, L. Henry, J. Hester, *et al.* 2019. Welcome to the Tidyverse. J. Open Source Soft. 4: 1686.

Wiman, N. G., J. E. Parker, C. Rodriguez-Saona, and V. M. Walton. 2015. Characterizing damage of brown marmorated stink bug (Hemiptera: Pentatomidae) in blueberries. J. Econ. Entomol. 108: 1156–1163.

Zavalloni, C., J. A. Andersen, and J. A. Flore. 2006. Phenological models of flower bud stages and fruit growth of 'Montmorency' sour cherry based on growing degree-day accumulation. J. Am. Soc. Hort. Sci. 131: 601–607.