Project Title: Biology, Monitoring and Management of Brown Marmorated Stink Bug in Almond Orchards

Project No.: **Ento23.Rijal**

Project Leader: Jhalendra Rijal, Area IPM Advisor-Northern San Joaquin Valley
UC Cooperative Extension-Stanislaus County
3800 Cornucopia Way, Ste. A, Modesto, CA 95358;
209-525-6800; *jrijal@ucanr.edu*

Project Cooperators and Personnel:
Frank Zalom and Joanna Fisher
Dept. of Entomology and Nematology, UC Davis

Sudan Gyawaly, *Associate Research Specialist, UCCE Stanislaus*

A. Summary

Brown marmorated stink bug (BMSB) is an invasive stink bug species from Asia. In California, we, for the first time, detected and reported BMSB population in a commercial almond orchard in Stanislaus county in 2017. Since then, the reproducing populations of BMSB have been found in several almond orchards in Stanislaus and Merced counties, with substantial crop damage in some cases. In this project, we studied biology, monitoring, and management of BMSB in almond orchards.

Our studies conducted over the past three years suggest that BMSB can damage all stages of developing almond fruits since they are present in the orchard throughout the season. Early season feeding by BMSB causes nut abortion, resulting in substantial nut drop. After shell hardening, infestations result in kernel necrosis ‘brown spots.’ Although other true bugs such as leaffooted bugs, native stink bugs can be present in almond orchards, a season-long, and often in high abundance of BMSB make it a challenging pest. There are some differences in varietal susceptibility, but no variety is immune to BMSB infestation. We studied and found that the sticky panel trap with BMSB lures, which is commercially available, is useful in detecting and monitoring the BMSB population in almond orchards. Our study also found that BMSB damage tends to be higher in orchard edges.Therefore, for pest detection, it is crucial to pay close attention to those areas first, especially in other hosts such as trees of heaven in proximity. For control, our study found that pyrethroid insecticides, bifenthrin, lambda-cyhalothrin are moret efficacious against BMSB adults. These findings will help implement integrated pest management (IPM) practices to manage BMSB in almonds.

B. Objectives

Obj. 1. Conduct BMSB seasonal detection and monitoring in almond orchards, and optimize monitoring tools, including newer lures and trap types

Milestones: Determined BMSB phenology and developed useful monitoring tools. Growers and PCAs will be able to utilize an effective strategy for BMSB monitoring in almond orchards.

Obj. 2. Characterized the nature of feeding damage by BMSB feeding and compare it with the leaffooted bug and other stink bugs damage

Milestones: The severity of damage BMSB can cause to almonds at different fruit development stages identified. This information helps growers to make monitoring and management decisions.

Obj. 3. Assessed the BMSB damage in commercial almond orchards

Milestones: The degree of BMSB damage in commercial orchards was evaluated to determine potential risk factors. This information is useful for BMSB management.

Obj. 4. Evaluated unregistered and new insecticides against BMSB adults.

Milestones: Insecticide and other control choices for growers targeting the brown marmorated stink bug evaluated to provide growers an informed decision on pesticide selection.

C. Results and Discussion

Obj. 1. Conduct BMSB seasonal detection and monitoring in almond orchards, and optimize monitoring tools, including newer lures and trap types

Detection survey. BMSB was captured in traps in 6 (out of 6), 6 (out of 7), and 6 (out of 7) almond orchards monitored, respectively, in 2018, 2019, and 2020 in north San Joaquin Valley (Fig 1). BMSB pressure was high in three of those six orchards while moderate-to-low in the other three orchards.

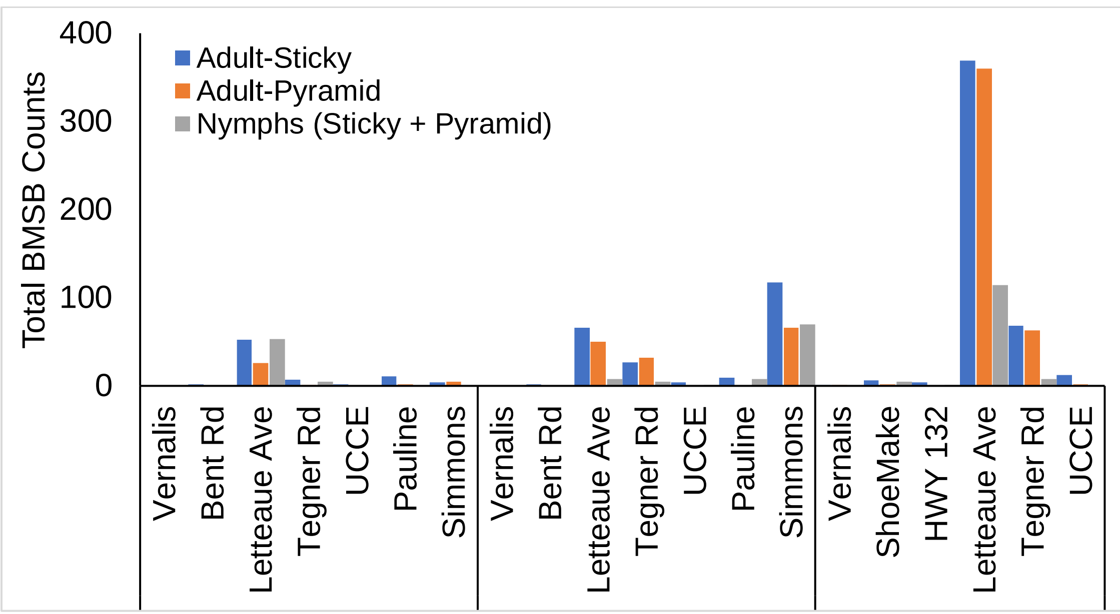
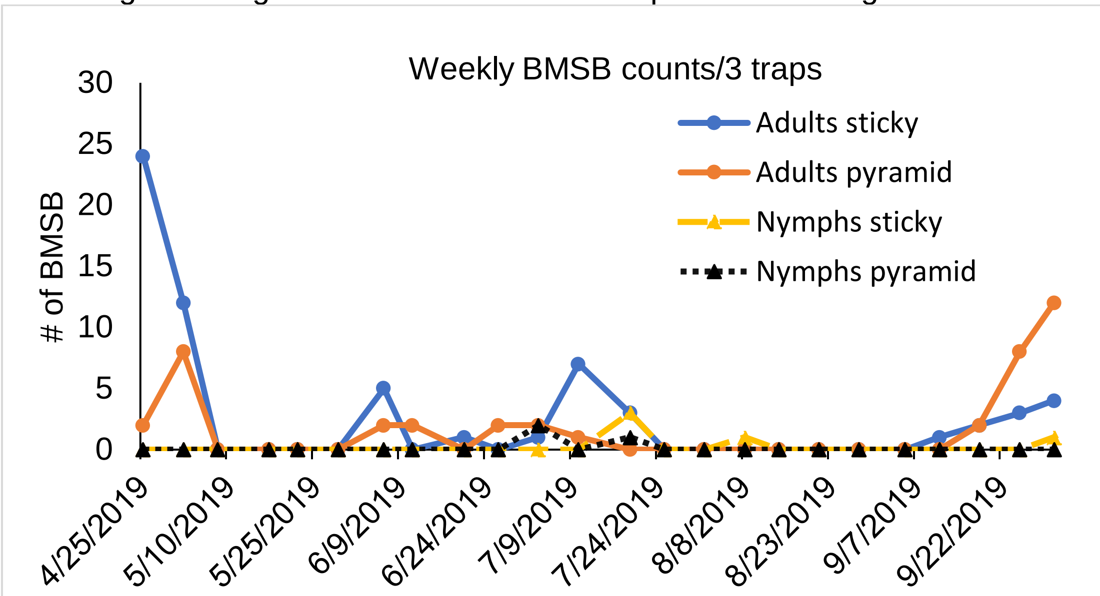


Fig. 1. Cumulative number of BMSB-adults and nymphs captured in almond orchards

Using trap-based monitoring, our study showed that BMSB activity could begin as early as mid-March and continue throughout the season in an almond orchard. Based on the studies conducted in the last 3 years, we recommend using multiple sticky panel traps baited with BMSB lure (Fig. 7) for BMSB detection and monitoring in almond orchards.

***BMSB phenology*.** Our study confirms the previous reports that BMSB has two generations per year in California. BMSB population abundance varied with orchards. In the orchard with a moderate BMSB population, BMSB were captured in traps throughout the season. BMSB has an overlapping life cycle indicated by adults and nymphs' presence simultaneously at different times of the year. The earliest adult capture in the northern San Joaquin Valley area was in late March, and the capture was continued through November (Fig 2). Early season activity of overwintering adults peaked around late April, another peak 1st generation activity occurring in

June-July, and the 2nd generation in September-October. Understanding BMSB phenology provides a guide for growers and PCAs to make potential management decisions.



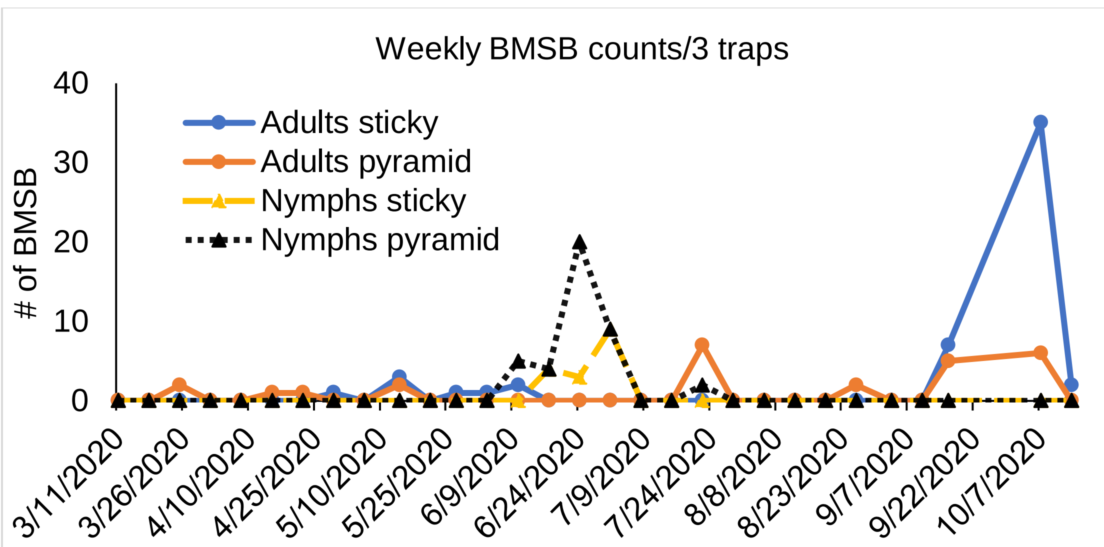


Fig. 2. Seasonal BMSB activity in almond orchards 2019 (top) and 2020 (bottom)

Obj. 2. Characterize the nature of feeding damage by BMSB feeding, and compare it with the leaffooted bug and other stink bugs damage

BMSB feeding damage and susceptibility assessment. A feeding study conducted to assess the nature and risk of BMSB damage in almonds showed a substantial nut drop (40-98% Nonpareil; 28-96% Monterey) due to BMSB feeding in the early season (March-April, i.e., the first 6-wks of the study) for both varieties (Fig 3). Dropped nuts showed feeding injury on the hull (gumming, pinholes) and kernels. The nut drop intensity was reduced significantly from the beginning of May when the kernel-filling begins (i.e., conversion of the 'jelly' endosperm into the solid nutmeat). At that time, the shell (endocarp) starts to harden, resulting in a reduced nut drop.

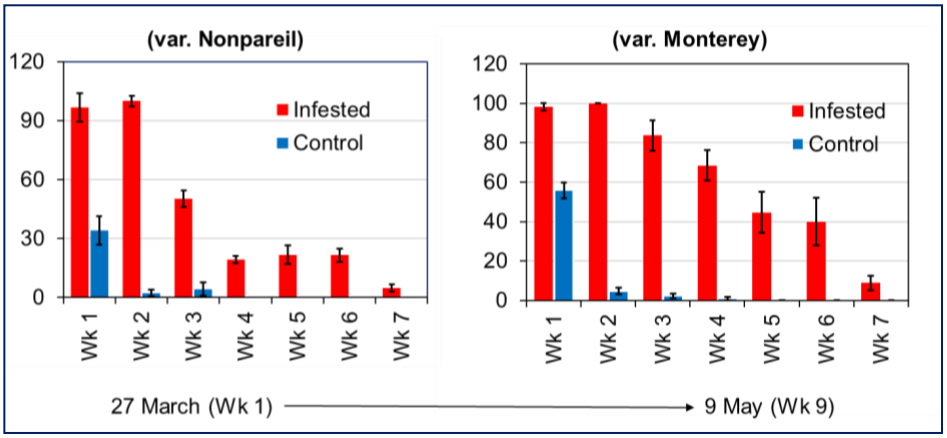


Fig. 3. Percent nut drop by BMSB feeding early in the season in almonds

After mid-May, most infested nuts did not drop; instead they showed signs of feeding damage to kernels (gumming and presence of multiple dark spots and dimples/shriveling) at harvest (Fig. 4).

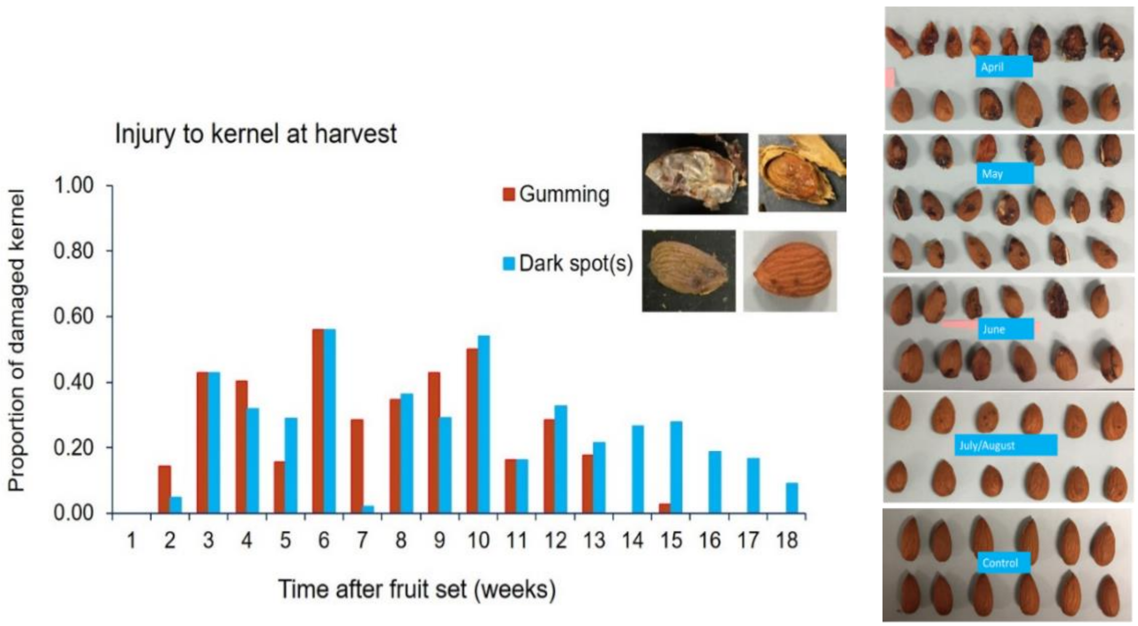


Fig. 4. Proportion of damaged kernels (var. Nonpareil) evaluated at harvest by BMSB feeding at different times of the year (Wk 1: last wk. of March; Wk 18: July 25)

Comparing commercial almond varieties for their susceptibility to BMSB. Using the exclusion cages, we compared ten commonly grown almond varieties for their relative vulnerability to the BMSB attack in 2019. Almond fruits were covered with fabric cages (Fig. 8) in early March, and two BMSB adults were released into 3 cages/variety in mid-May for 7 days. All caged nuts were harvested in August, and the proportion of hull damage (i.e., gummy hull) and kernel damage was summarized (Fig 6). There were some differences among varieties in terms of kernel damage at harvest, although we did not make any statistical comparison because of the limited sample sizes.

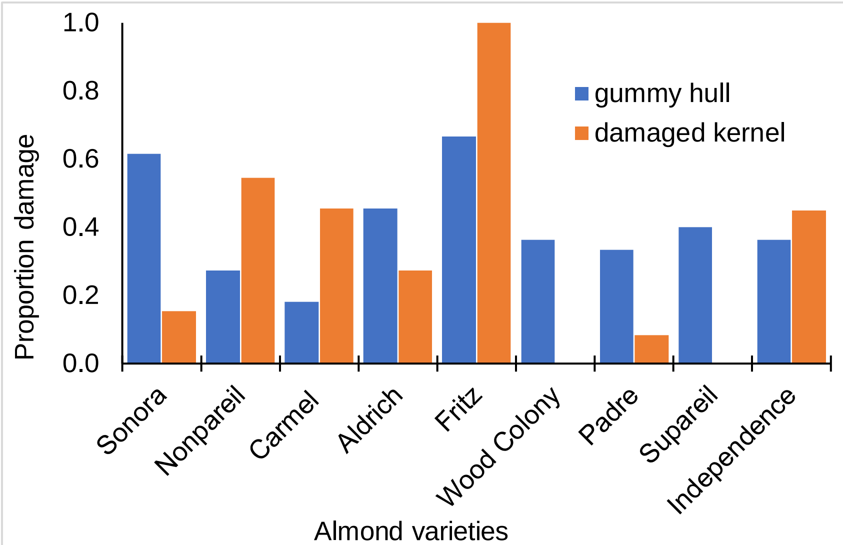


Fig. 6. Comparison of 10 commonly grown almond varieties in kernel damage at harvest due to BMSB feeding in mid-May

Comparing feeding damage by BMSB with the leaffooted bug (LFB). This study examined the differences in LFB and BMSB feeding damage by infesting the caged nuts with BMSB and LFB separately and evaluated the injury after three weeks and at harvest.

At the 3-week evaluation of the April infestation, on average, 8% and 25% of the caged nuts were dropped across three varieties used due to feeding by BMSB and leaffooted bug, respectively. No fruit drop was observed during the June infestation. In April infestation, the leaffooted bug caused a higher level of injury than BMSB, while it was reverse during the June infestation as BMSB feeding resulted in a higher hull level kernel injuries (Table 1). This is potentially due to the larger body and feeding stylet size of LFB, and early season fruits are much vulnerable to larger bugs attack in general.

Table 1. Feeding injuries by BMSB and leaffooted bug (LFB) at 3-week evaluation

		1st infestation (April 24) (at 3-week evaluation)			2nd infestation (June 6) (at 3-week evaluation)		
		% nut drop	**% hull injury**	**% kernel injury**	**% nut drop**	**% hull injury**	**% kernel injury**
Nonpareil	BMSB	6.67	100.0	85.7	0.00	80.0	80.0
	LFB	18.89	100.0	100.0	0.00	0.00	80.0
Fritz	BMSB	0.00	0.00	0.00	0.00	100.0	80.0
	LFB	0.00	71.4	71.4	0.00	60.0	60.0
Monterey	BMSB	17.00	71.4	71.4	0.00	100.0	80.0
	LFB	56.67	71.4	71.4	0.00	100.0	60.0
Avg. BMSB		**7.89**	**57.14**	**52.38**	**0.00**	**93.33**	**80.00**
Avg. LFB		**25.19**	**80.95**	**80.95**	**0.00**	**53.33**	**67.67**

Since most of the nuts from the April infestationdropped or were severely injured, we evaluated the harvest damage from the June infestation (Table 2). We combined data from all three varieties and used one-way ANOVA for statistical comparison. BMSB feeding in June resulted in statistically significant percent kernel damage at harvest compared to the leaffooted bug for two damage categories -dark spots and shriveled/dimpled nuts, while no difference in the gummy kernel category (Table 2). Greater damage by BMSB might be due to the release of salivary enzymes that facilitate the penetration into the hardened shell.

There was no noticeable difference between BMSB and leaffooted bug in signs of feeding on the kernels. However, we observed few fundamental differences between BMSB and LFB damage, especially in population dynamics and infestation timing. BMSB can attack the crops throughout the season, beginning mid-March by causing both nut drop (March-May) and kernel necrosis (after mid-May until the harvest), while leaffooted bug is a significant issue mostly in the early part of the season when nuts are smaller in size (March-April). Also, once established, the population of brown marmorated stink bugs moving to the orchard tends to be much bigger than the leaffooted bug and native stink bug and likely inflict more damage relatively quickly.

Table 2. Kernel damage by in-season BMSB and leaffooted bug (LFB) feeding in almonds, evaluated at harvest

	Mean kernel damage at harvest (%)					
	Gumming		Dark spot		Dimples/shriveled	
Variety	BMSB	LFB	BMSB	LFB	BMSB	LFB
Nonpareil	8.00	5.00	74.00	53.00	43.33	57.00
Fritz	5.00	18.75	40.00	18.75	75.00	25.00
Monterey	49.44	25.00	67.24	14.00	60.09	10.00
Overall avg.	**20.81[a]**	**16.25[a]**	**60.41[a]**	**28.58[b]**	**59.48[a]**	**30.67[b]**

Obj. 3. Assess the BMSB damage in commercial almond orchards

In 2019, we conducted a study in a heavily infested almond orchard to compare the degree of BMSB damage in five different distances from the edge. We found that BMSB is a heavily border-driven pest as nut damage was significantly higher (P>0.5) in border rows compared to the interior of the orchard (Fig. 7).

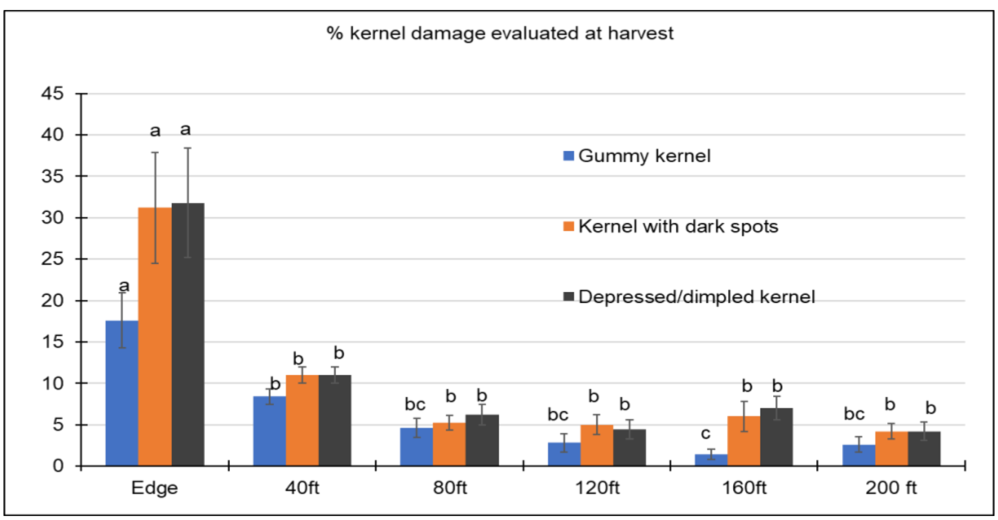


Fig. 7. Average almond kernel damage evaluated at different distances from the edge of the almond orchard.

Obj. 4. Evaluate unregistered and new insecticides against BMSB adults.

We conducted series of laboratory studies to evaluate a few insecticide ingredients against BMSB using the almond fruit ‘dip method.’ Since a high number of BMSB adults are needed to conduct a well-replicated trial, the results we present here are only preliminary. However, this should provide enough guidance to manage BMSB in almonds, at least for the time being. Our study found that pyrethroid insecticides (bifenthrin and lambda-cyhalothrin) are most effective, with over 70% BMSB adult mortality after 3 days of application.

Conclusions and Future Direction. Through several studies in this BSMB comprehensive project, we were able to 1) establish that BMSB can be a serious pest in almonds; 2) characterize and compare the damage it can cause at different times of the year; 3) identify the pest's seasonal phenology in almond orchards, 4) identify and recommend the ways to monitor BMSB in almonds, 5) suggest insecticides that are effective to manage BMSB in almonds. Future studies should include BMSB monitoring in Sacramento and San Joaquin Valleys. Additionally, it is crucial to assess the several external and orchard factors such as varietal difference, orchard edge, the prevalence of other hosts nearby, and establish their contributions to the BMSB population and damage. Also, exploring further options in terms of control, such as exploring biocontrol agents locally, using attract-and-kill systems, etc.

D. Outreach Activities (selected)

- Rijal, J.P. 2021. Monitoring and management of plant and stink bugs in almonds. UCCE San Joaquin Valley Almond Day (Virtual). (14 January, 250 PCAs/growers)
- Rijal, J.P. 2020. Biology and management of plant and stink bugs in almonds and pistachios. Madera Farm Bureau meeting (Virtual) (15 December, 27 PCAs/growers).
- Rijal, J.P. 2020. Biology and management of plant and stink bugs in almonds and pistachios. Merced County CE Seminar (Virtual) (13 October, 45 PCAs/growers).
- Rijal, J. P. 2019. Invasive pests (BMSB, spotted lanternfly, spotted wing drosophila) to watch for in the vines in 2019. Annual Grape Day, Lodi Wine Grape Commission, (5 February, Lodi, 400 PCAs/growers).
- Rijal, J. P. 2019. Brown marmorated stink bug infestation in local peach orchards and tools for monitoring and management, North San Joaquin Valley Cling Peach Day (30 January, Modesto, 50 PCAs/growers).
- Rijal, J. P. 2019. Biology, Monitoring and Management of Brown Marmorated Stink Bug (BMSB) in Almond and Peach Orchards. Wilbur-Ellis PCAs meeting (30 July, Hughson, 15 PCAs).
- Rijal, J. P. 2019. Brown Marmorated Stink Bug (BMSB) Activity in CA Crops – Peach, Almond. San Joaquin Agricultural Commissioner's CE Seminar (12 July, Ripon, 40 PCAs/growers).

E. Materials and Methods :

BMSB detection, monitoring, and seasonal phenology (Objective 1).

For this objective, we monitored a total of 7 orchards in 2018 and 2019 each, and 5 orchards in 2020 using the sticky panel and pyramid traps baited with the BMSB lure (Trece Inc., Adair, OK). Both traps were installed in the ground are 4-ft. tall (Fig. 8). Traps were placed between the trees in the border row and checked and cleaned weekly. The lure was changed based on the manufacturer's recommendation. Traps were placed in the Spring (April-May) through the Fall (October-November). BMSB adults and nymphs were recorded weekly.

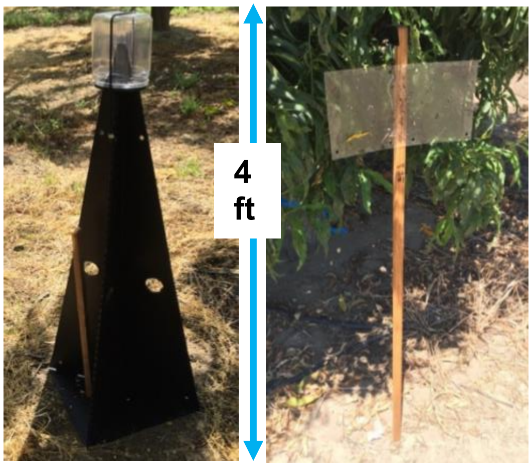


Fig. 8. BMSB traps: Black pyramid (left), sticky panel

Fig. 9. BMSB feeding studies set up using exclusion cages/sleeves

BMSB feeding-nature of feeding, varietal difference, feeding differences among true bugs. (Objective 2).

These studies were conducted in a small almond orchard at the UC Cooperative Extension, Modesto. Nylon mesh cages (20x30 cm) were used in all three experiments (Fig. 9), 1) *Characterizing BMSB feeding damage in almonds, 2) comparing almond varieties for their susceptibility to BMSB feeding, 3) comparing feeding damage by BMSB with the leaffooted bug*. These cages were placed in trees covering 7-15 developing nuts/cages early in the season (March) to protect the nuts from other insects or external injuries. Depending on the experiments, 2-3 BMSB adults were released into the cages and removed after seven days. Depending on the purpose of the study, the infestation was done at a particular time(s) of the season (e.g., every week from April through July for feeding damage study; two time- April and June for BMSB vs. leaffooted bug study; and mid-May for varietal susceptibility study) 7-15 nuts/cage at the early fruit development stage (March 25). Three weeks after the BMSB release, sample fruits were taken from the cages and evaluated for injuries. The rest of the fruits were continually growing inside the cages until harvest, and harvest samples were assessed for the bug damage.

Assess the BMSB damage in commercial orchards by collecting and evaluating the fruit samples at different times of the year (Objective 3)

For this objective, we collected fruit samples in a heavily infested almond orchard and evaluated them for the degree of BMSB damage in five different distances from the edge (0 ft, 40 ft, 80 ft, 120 ft, 160 ft, 200 ft). For each distance, 10 samples (50 nuts/sample) were collected from the field at harvest and evaluated the percent kernel damage (gummy, kernels with dark spots, dimpled kernels).

Evaluate unregistered and new insecticides against BMSB in the laboratory and the field (Objective 4)

This study was conducted using 5 insecticides, Actara (Thiamethoxam, 5.5 oz), Besiege (Chlorantraniliprole, Lambda-cyhalothrin,12.5 oz), Warrior II (Lambda-cyhalothrin, 2.56 oz), Agriflex (Abamectin, Thiamethoxam, 8.5 oz), Bifenthrin (Bifenthrin, 6.4 oz), and untreated control treatments. For each treatment, 10 unsplit almonds were individually dipped in insecticide solution (prepared by mixing the indicated amount per 100 G of water) for 5 seconds and were air-dried for 1.5 hours. Almond fruits treated with insecticides or water were individually put into plastic containers. In each of these containers, 1 BMSB male was introduced and left for exposure for 4 hours (10 replication for each treatment, with one BMBS in each container). After 4 hours, BMSB were transferred individually into a small clear plastic container with a grape tomato and checked for mortality after 4 hr infestation first then every 24 hr that after. The experiment was repeated twice.

F. Publications that emerged from this work

Peer-reviewed

- Fisher, J., F. Zalom, and J.P. Rijal. 2020. Temperature and humidity interact to influence brown marmorated stink bug (Hemiptera: Pentatomidae), survival. *Environmental Entomology.* https://doi.org/10.1093/ee/nvaa146.
- Rijal, J.P., and F.G. Zalom. 2020. Provisional guidelines for brown marmorated stink bug control in almond. (UCIPM peer-reviewed). http://ipm.ucanr.edu/PMG/r3303211.html.
- Rijal, J. P., and S. Gyawaly. 2018. Characterizing brown marmorated stink bug injury in almond, a new host crop in California. Insects. 9(4), 126. https://doi.org/10.3390/insects9040126
- Rijal, J., A. Medina, J. Fisher, F. Zalom. 2019. Monitoring and abundance of brown marmorated stink bug in peach and almond orchards in the Northern San Joaquin Valley. Proceedings of the American Society of Agronomy-California Chapter annual meeting, 5-6 February, Fresno, CA. pp 81-86.

Extension articles

- Rijal, J. P. 2020. How nut growers can get the best of brown marmorated stink bugs. https://bit.ly/2JlMWFo
- Rijal, J. P. 2019. Invasive pests to watch out for in the vines in 2019. A special newsletter issue published for the 67th Annual Grape Day. Lodi Grape Growers and Lodi Wine Commission (February).
- Rijal, J. 2018. New pest of almond: knowns and unknowns of brown marmorated stink bug in California orchards. Progressive Crop Consultant. July/August Issue. pp 8-13.
- Rijal, J. P. 2018. Brown marmorated stink bug-keep an eye out for potential damage. Sacramento Valley Orchard Source. http://www.sacvalleyorchards.com/almonds/brown-marmorated-stink-bug-keep-an-eye-out-for-potential-damage/