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

Project No.: **Ento23.Rijal**

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A. Summary

Brown marmorated stink bug (BMSB) is an invasive stink bug species from Asia and has been spread to over 43 U.S. states causing a significant economic burden to growers. In California, we reported the first find of the BMSB population in a commercial almond orchard in Stanislaus county in 2017. Since then, the reproducing populations of BMSB have been in several almond orchards in Stanislaus and Merced counties with substantial crop damage in some cases. BMSB has a 'straw-like' mouthpart to pierce into the fruit, release digestive enzymes, and suck the liquified fruit content. BMSB adults overwinter in human-made structures such as houses, barns, shops, and even in woodpiles, and migrate to crops for an extended period beginning in Spring (March-June).

Our study in the past two years suggested that BMSB can do damage to all stages of the fruit development in almonds and that they are present in the orchard throughout the season. Early season feeding causes nut abortion, resulting in substantial nut drop. Mid-to-late season infestations result in gummy, darken-spots, or dimpled kernels. Although there are other true bug pests such as leaffooted bug, native stink bugs can be present in almond orchards as well. The presence of BMSB throughout the season is often in high numbers which makes the BMSB a risky pest. We also found that some varieties are more susceptible to the damage than others. For example, Monterey, Fritz showed a higher level of damage compared to Padre, Wood colony varieties; Nonpareil is in between. The bottom line is that none of the varieties are immune to BMSB damage. Although we are using two trap types for research purposes, based on previous year's studies, we found that the sticky panel trap is equally effective in detecting BMSB adults compared to the standard pyramid trap. Sticky trap is much more user-friendly and cheaper than the pyramid trap, and we recommend the sticky trap with BMSB lure for growers and PCAs for monitoring, which should start in mid-March. Our study also found that BMSB infestation was much higher in the edge of the orchard compared to the internal part. We recommend that growers and pest control advisers (PCAs) pay close attention to BMSB activities in orchards and monitor the BMSB population at least in orchards in the area with high risks (i.e., area with a known infestation, near to highways; near to other hosts (e.g., tree of heaven).

Future studies include the continuation of monitoring of BMSB activity in San Joaquin Valley and evaluate the BMSB feeding damage in almonds by addressing questions related to external factors such as the presence of other hosts near to the orchard, varietal difference,

edge vs. internal damage, use of the potential of attract-and-kill. We have initiated insecticide bioassays and will continue to test relevant products in the lab as well as in the field.

B. Objectives

1. Conduct BMSB seasonal detection and monitoring in almond orchards, and optimize monitoring tools including newer lures and trap types
   Milestones: We will be able to determine the phenology of this pest and develop effective monitoring tools for BMSB. Growers and PCAs will be able to utilize an effective strategy for BMSB monitoring in almond orchards

2. Characterize the nature of damage by BMSB feeding in almonds, and compare BMSB damage with the leaffooted bug and other stink bugs
   Milestones: We will be able to identify the severity of damage that BMSB can do in different stages of fruit development. This information helps growers to make monitoring and management decisions.

3. Assess the BMSB damage in commercial orchards by collecting and evaluating the fruit samples at different times of the year (2020-2021)
   Milestones: Overall damage evaluation in different orchards would help in estimating the potential yield loss by this pest, and also determine the risk factors. This information is useful for BMSB management.

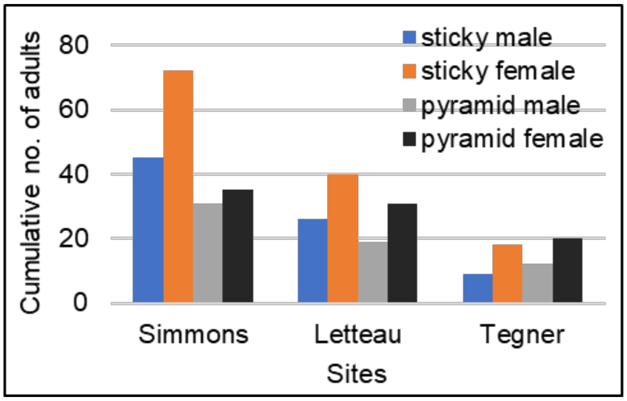
4. Evaluate unregistered and new insecticides against BMSB in the laboratory and the field (2020-2021)
   Milestones: We will be able to provide insecticide and other control choices for growers targeting the brown marmorated stink bug.

C. Annual Results and Discussion

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

<u>BMSB detection, monitoring, and seasonal phenology</u>

Detection survey. We used sticky panel and pyramid traps for BMSB detection in seven almond orchards in 2019. BMSB was captured in traps in 6 of 7 almond orchards monitored. Of 6 orchards, BMSB pressure was high in three (Fig 1), while moderate-to-low in the other three orchards (Table 1).



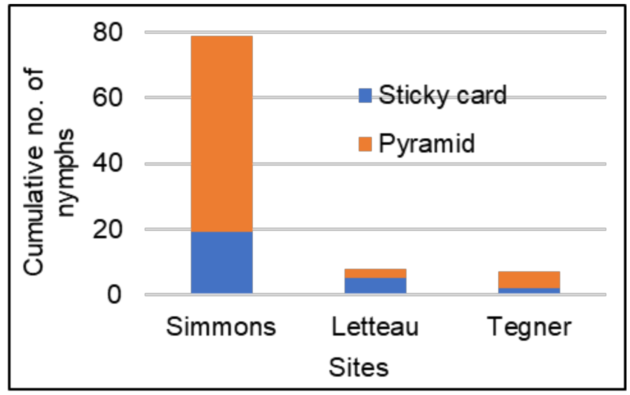


Fig. 1. Cumulative number of BMSB-adults (right), nymphs (left), captured in three almond orchards with the relatively high infestation, 2019

In addition, we recommend to use visual and beat tray sampling methods to confirm the BMSB infestation in the orchard. Using trap-based monitoring, we concluded 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 past two years in 14 commercial orchards, we recommend the use of sticky panel trap baited with BMSB lures (Fig. 7), to 1) detect BMSB adults when moving into the orchard from the overwintering places, 2) perform seasonal monitoring of the population and tracking BMSB life stages and generations.

Table 1. Cumulative BMSB adults and nymphs captured in sticky and pyramid traps across seven almond orchards, 2019

Trap type-stage	BMSB counts across seven almond orchard sites, 2019						
	Vernalis	**Bent**	**Letteau**	**Tegner**	**UCCE**	**Pauline**	**Simmons**
Sticky-adults	0	2	66	27	4	9	117
Sticky-nymphs	0	0	5	0	0	4	10
Pyramid-adults	0	0	50	32	0	0	66
Pyramid-nymphs	0	0	3	5	1	4	60

***BMSB phenology*.** BMSB has two generations per year. The earliest adult capture in the northern San Joaquin Valley area was in April this year and continued through November (Fig 2). BMSB population abundance varied with orchards. In the orchard with a decent BMSB population, BMSB were captured in traps throughout the season. BMSB has an overlapping life cycle. Early season activity of overwintering adults started in April and continued through June in some cases. In a few orchards early activity was limited to April-May with another peak activity occurring in July, and late in September-October. Understanding BMSB phenology provides a guide for growers and PCAs to make potential management decisions if needed.

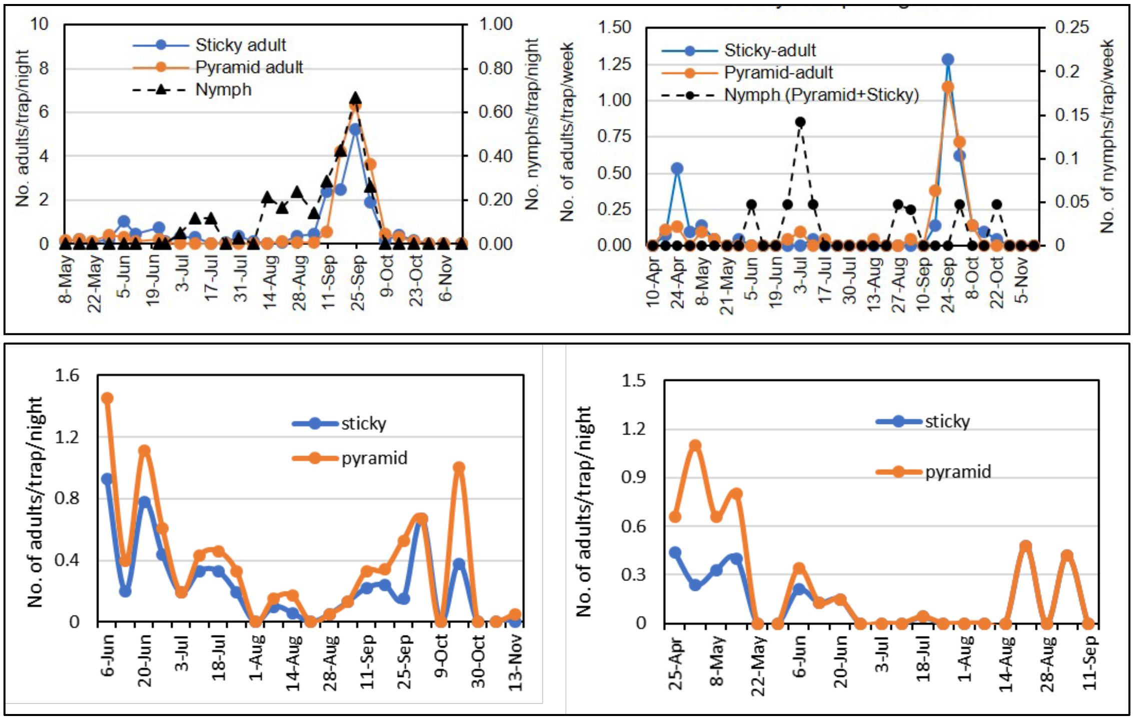


Fig. 2. Seasonal BMSB activity in almond orchards 2018 (top) and 2019 (bottom)

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

Characterizing BMSB feeding damage and susceptibility in almonds. A feeding study was conducted to assess the nature and risk of damage in almonds by BMSB throughout the season using exclusion feeding cages. Small fabric bags (referred to as 'cages' hereafter) were placed in late March in trees covering 7-15 nuts/cage. Nine fresh cages were selected and infested with 3 BMSB adults/cage weekly from March through harvest (August). We observed a substantial nut drop (40-98% Nonpareil; 28-96% Monterey) early in the 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 developing kernels. The intensity of the nut drop was reduced significantly from the beginning of May when the kernel-filling begins (conversion of the 'jelly' endosperm into the solid nutmeat) inside the nut. At that time, the shell (endocarp) starts to harden, which might have resulted in reduced nut drops.

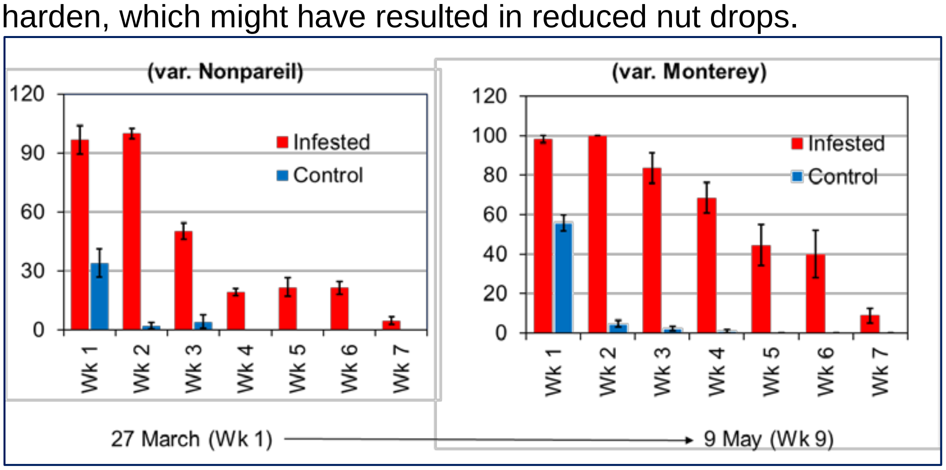


Fig. 3. Percent nut drop by BMSB feeding early in the season in almonds

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

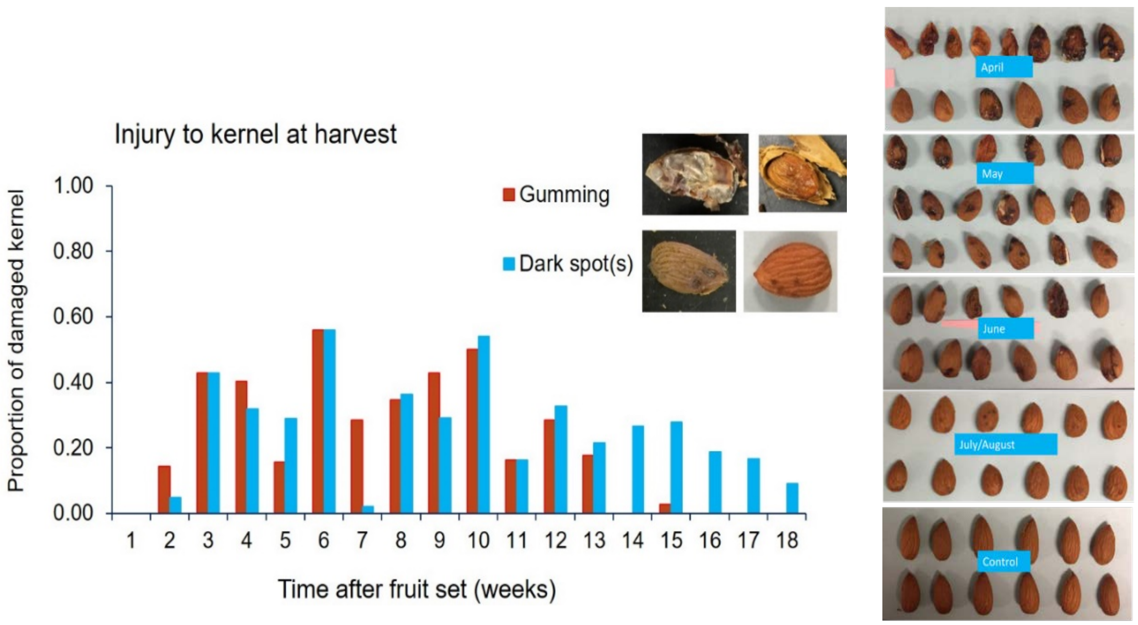


Fig. 4. Proportion of damaged kernels (var. Nonpareil) evaluated at harvest by BMSB feeding at different times of the year (Wk 1: last wk. of March; Wk 18: July 25)

We collected and measured the shell hardness of the nuts weekly using fruit penetrometer, and developed a relation between percent healthy kernel with the penetration force. The penetration force is the indicator of the force that is needed by BMSB to feed on those nuts sampled weekly throughout the season. A significant positive correlation between percent nut percent and the penetration force indicated that the impact of the BMSB feeding reduced as the fruit development stage advanced (Fig. 5).

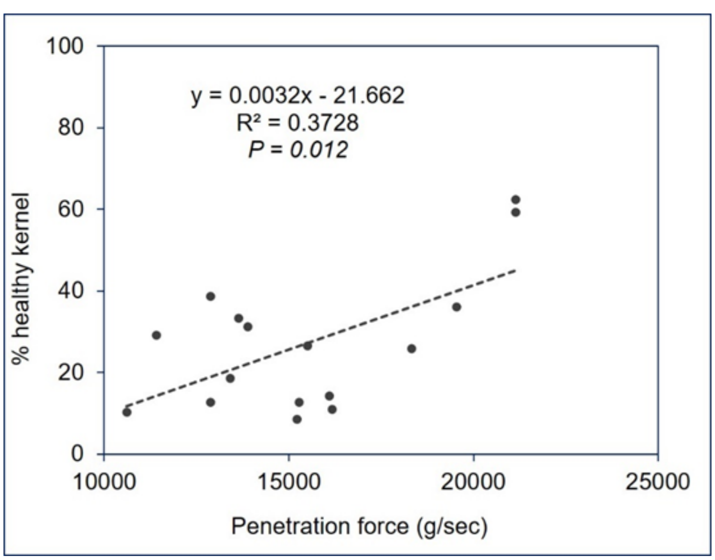


Fig. 5. Proportion of damaged kernels at harvest by BMSB feeding at different times of the year (Wk 1: last wk. of March; Wk 18: July 25)

Comparing commercial almond varieties for their susceptibility to BMSB. Using the exclusion cages, we compare ten commonly grown almond varieties for their relative susceptibility to the BMSB attack in 2019. Almond fruits were covered with cages (Fig. 8) early in the season, and the cages were infested with 2 BMSB adults in mid-May for seven days, and the nut damage was assessed at three weeks of that initial bug release and also at harvest. We observed injury to the fruit and the kernel across varieties at a 3-week evaluation. All nuts from all three cages for each variety were harvested, and the proportion of hull damage (i.e., gummy hull) and kernel damage (combined three categories-dark spots, gummy, and dimpled kernels) was calculated (Fig 6). At harvest, there were some differences among varieties in terms of kernel damage, although we did not make any statistical comparison on this data as these are the preliminary summary for this reporting purpose.

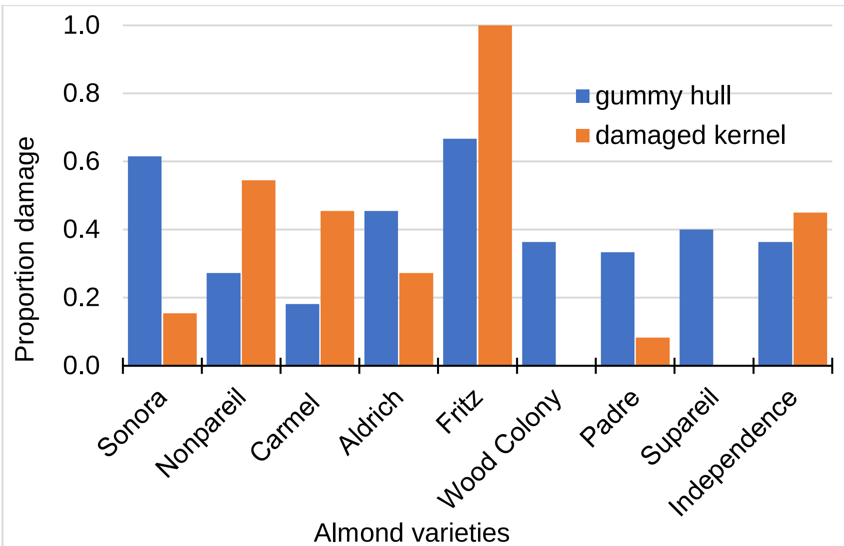


Fig. 6. Comparison of 10 commonly grown almond varieties in kernel damage at harvest due to BMSB feeding in mid-May

Comparing feeding damage by BMSB with the leaffooted bug (LFB). Since leaffooted bug has a similar type of feeding habit to BMSB, we were interested to see whether there is any difference in overall damage by these two true bug pests in almonds. Similar to previous studies, we conducted this study using fabric cages in almond trees. Both BMSB and leaffooted bugs were allowed to feed on almonds inside the cages for seven days, and the nuts were evaluated after three weeks of that initial bug release, and also at harvest. This study was conducted two times - last week of April (referred to as April infestation hereafter) and the first week of June (referred to as June infestation hereafter).

At the 3-week evaluation of the April infestation, on average, 8% and 25% of the caged nuts were dropped across three varieties due to feeding by BMSB and leaffooted bug, respectively. While no fruit drop was observed during the June infestation, this is potentially due to the bigger body size and longer stylet of leaffooted bug compared to BMSB, and early season fruits are much vulnerable to hemipteran bug attacks in general. For hull and kernel injury evaluation, we randomly selected five nuts from the cages that were infested with BSMB and leaffooted bug and dissected sampled nuts for injuries. In April infestation, leaffooted bug caused a higher level of injury compared to BMSB, while it was reverse during the June infestation as BMSB feeding resulted in a higher level of hull and kernel injuries (Table 1).

Table 2. Feeding injuries by BMSB and leaffooted bug (LFB) at 3-week evaluation

Variety		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**

The majority of the nuts from the April infestation were dropped or severely injured (no hull split) due to bug feeding. Therefore, we only evaluated and summarized the harvest damage data from June infestation (Table 2). For statistical analysis using one-way ANOVA, we combined data from three varieties. BMSB feeding in June resulted in statistically greater percent kernel damage compared to leaffooted bug for two damage categories -dark spots and shriveled/dimpled nuts compared to leaffooted bug. No difference in the gummy kernel category between BMSB and leaffooted bug feeding damage (Table 2). This difference might have been due to the feeding persistence of BMSB and the capability of releasing salivary enzymes that facilitate the penetration into the hardened shell at that time.

There was no noticeable difference in terms of the nature of feeding damage to kernels (gummy, presence of dark spots, dimpled/shriveled) between BMSB and leaffooted bug. However, there are a few fundamental differences that we observed based on cage study and field observations. BMSB can attack the crops throughout the season beginning mid-March, although the extent of economic damage to a different time of the year is different. The leaffooted bug is a major issue in April, while native stink bugs are a problem during June-July. Also, once established, the population of brown marmorated stink bug moving to the orchard tends to be much bigger compared to the leaffooted bug and native stink bug and is capable of inflicting damage relatively quickly.

Table 3. Kernel damage by in-season BMSB and leaffooted bug (LFB) feeding in almonds, evaluated at harvest

Variety	Mean kernel damage at harvest (%)					
	Gumming		Dark spot		Dimples/shriveled	
	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 orchards by collecting and evaluating the fruit samples at different times of the year (2020-2021)
In the original proposal (3-year plan), we proposed to accomplish objective 3 in 2020 and 2021 seasons. Although we started collecting some data from the growers' field, all activities of this objective will continue in 2020 and 2021 field seasons as one year is not enough to produce meaningful results. Under this objective, we will start looking at potential factors that influence the BMSB infestations in almond orchards. For example, edge effect, presence/absence of the alternate host plants (e.g., trees of heaven) near to the orchard, stage of the fruit development and type of damage in different stages in the field, etc. 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 the degree of damage to the almond was substantially higher in border rows compared to the internal part of the orchard (Fig. 7). We will report the comprehensive results in the next reporting cycle.

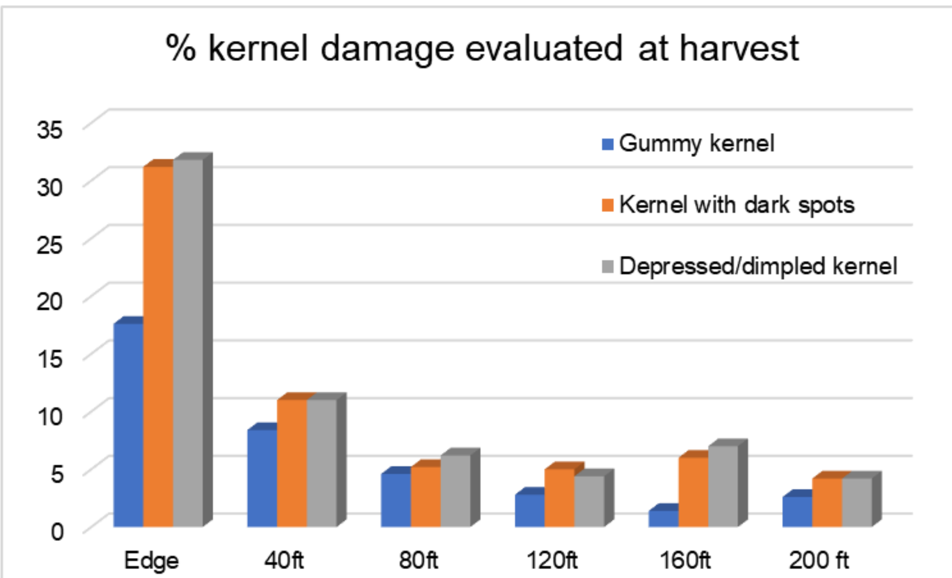


Fig. 7. Average almond kernel damage evaluated at different distances from the edge of the almond orchard. This commercial orchard had a substantial BMSB population in 2019.

Obj. 4. Evaluate unregistered and new insecticides against BMSB in the laboratory and the field (2020-2021)
Objectives 1 and 2 of this proposal were geared towards how, when and what type of damage that we expect from BMSB in almonds, what is the seasonal phenology of BMSB in the northern San Joaquin Valley, and what kinds of monitoring tools can be used, and we addressed all of these research questions in one season or one funding cycle. Now, the next step of the research focus is what insecticides can be used to control BSMB in almond orchards.

Objective 4 that covers the insecticide evaluation work was originally proposed to accomplish in 2020 and 2021 seasons. With that timeline, we have made progress in evaluating a few active ingredients in the lab against BMSB, and based on ongoing preliminary research results, we found that pyrethroid insecticides (bifenthrin and lambda-cyhalothrin) are most effective with over 80% adult mortality. BMSB cannot be easily collected from the field, so we rely on lab colonies to do these trials, and it takes a significant amount of time and effort to produce enough adults for the experiments. We continue to perform these bioassays in the lab as well as in the field in the upcoming two field seasons.

D. Outreach Activities

1. Rijal, J. P. 2017. New Pest Update: Brown Marmorated Stink Bug (BMSB). Annual Almond Board Conference, Dec. 6-8, Sacramento, CA (Talk & Poster).
2. Rijal, J. P. 2017. Be on the Alert for Brown Marmorated Stink Bug (BMSB): ID, Monitoring Tools, and Crops at Risk. Extension talk at Mid-Valley PCA meeting, October 31, Oakdale, CA.
3. Rijal, J. P. 2018. Brown Marmorated Stink Bug: Identification, Biology, and Status of the Pest Status in California. CAPCA Seminar, 25 January, Tracy, CA.
4. Rijal, J.P. 2018. Brown Marmorated Stink Bug Invasion in California: What's New? PAPA Seminar, 15 February, Stockton, CA
5. Rijal, J.P. 2018. Updates on Brown Marmorated Stink Bug Invasion in California. PAPA Seminar, 14 March, Sacramento, CA
6. Rijal, J.P. 2018. Navel orangeworm mating disruption and BMSB. Bayer Winter Meeting, 31 January, Hilmar, CA
7. Rijal, J.P. 2018. Updates on BMSB spread and infestation. Tree and Vine IPM Breakfast meeting, 4 April, Modesto, CA
8. Rijal, J.P. 2018. Seasonal pest management in almonds and updates on BMSB. Almond Board Pest Management CASP Field meeting, 20 April, Modesto, CA
9. Rijal, J. 2018. Brown marmorated stink bug: ID, biology, monitoring and management. Contra Costa Agricultural Commissioner's CE Seminar, Dec 5 & 8, 2018 Knighten, CA.
10. Rijal, J. 2018. Brown marmorated stink bug activity in California crops including almonds, Madera Agricultural Commissioner's CE Seminar, 28 November, Madera, CA.
11. 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, CA
12. 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, January 30, Modesto, CA
13. 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 2019, Hughson, CA
14. Rijal, J. P. 2019. Brown Marmorated Stink Bug (BMSB) Activity in CA Crops – Peach, Almond. San Joaquin Agricultural Commissioner's CE Seminar, July 12, 2019, Ripon, CA.

E. Materials and Methods:

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

BMSB detection, monitoring, and seasonal phenology. Two types of traps (pyramid and sticky panel) which were baited with the *BMSB* lure (Trece Inc., Adair, OK) were used. Both traps were installed in the ground are 4-ft. tall. Three traps of each type were used to monitor seven commercial almond orchards from Stanislaus and Merced Counties in 2019. Traps were placed in between the trees in the border row, checked, and cleaned them 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.

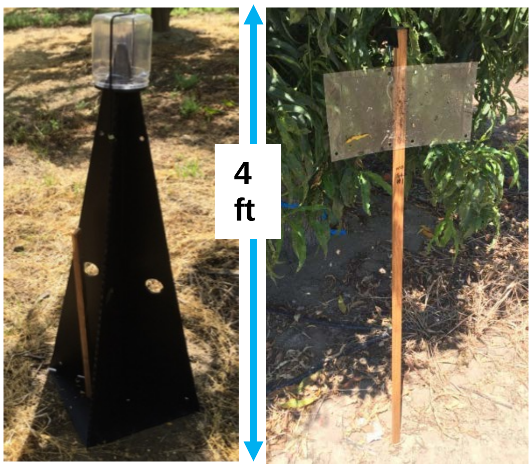


Fig. 7. BMSB traps: Black pyramid (left), sticky panel

Fig. 8. BMSB feeding studies set up using exclusion cages/sleeves

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

BMSB feeding-nature of feeding, varietal difference, feeding differences among true bugs. 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, 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/cage 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). After three weeks after the BMSB release, sample fruits were taken from the cages and evaluated for injuries. All of these cages were continued until harvest, and harvest samples were evaluated for the bug damage.

Obj. 3. Assess the BMSB damage in commercial orchards by collecting and evaluating the fruit samples at different times of the year (2020-2021)

In this objective, the edge effect of the BMSB infestation in a commercial orchard was evaluated by collecting the harvest samples at various distances from the field edge (edge, 40 ft, 80 ft, 120 ft, 160ft, and 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).

F. Publications that emerged from this work

1. 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 (Peer-reviewed)
2. 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.
3. 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).
4. 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.
5. 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/