Applications of Kaolin Protect Fruiting Vegetables from Brown Marmorated Stink Bug (Hemiptera: Pentatomidae)[1]

T.P. Kuhar[2], J.A. Morehead, and A.J. Formella

Department of Entomology, Virginia Tech, Blacksburg, Virginia 24061-0319 USA

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Abstract The brown marmorated stink bug *Halyomorpha halys* (Stål) is a serious pest of many horticultural crops in the United States, and organic growers, in particular, have very few effective control options. We evaluated the efficacy of two commercially available natural products, kaolin and essential oils (rosemary oil and peppermint oil), to reduce *H. halys* feeding on tomato (*Solanum lycopersicum* L.) and pepper (*Capsicum anuum* L.). Laboratory choice tests were conducted assessing stink bug occurrence on a cherry tomato fruit placed atop a freshly picked *Paulownia tomentosa* (Thunberg) Steudel leaf that was treated with either kaolin or essential oils compared to an untreated control of the same food within the same cage. Significantly fewer *H. halys* nymphs and adults occurred on kaolin-treated fruit and leaves than an untreated control, whereas there was no significant difference between the essential oils and the control. In a field experiment, kaolin applications to peppers resulted in significantly less stink bug-injured fruit than the untreated control in all harvests. In one of two harvests in 2014 and in one of the three harvests in 2015, the essential oil treatment reduced the percentage of stink bug-injured fruit versus the untreated control. Natural repellents or deterrents such as kaolin have a great potential for reducing *H. halys* feeding in horticultural crops and may provide a management option in organic production systems.

Key Words repellents, deterrents, organic, pest management

Brown marmorated stink bug, *Halyomorpha halys* (Stål), is an invasive insect that has become a significant pest of tree fruit and various vegetables in the United States (Kuhar et al. 2012c, Rice et al. 2014, Leskey and Nielsen 2018). Among the vegetable crops attacked, peppers (*Capsicum annum* L.) can be heavily damaged if control measures are not taken (Kuhar et al. 2012a, 2012b, 2012c, 2013a, 2013b, 2013c, Philips et al. 2017). Insecticides including several pyrethroids, organophosphates, carbamates, and neonicotinoids can reduce *H. halys* densities and fruit damage (Nielsen et al. 2008, Leskey et al. 2012b, 2013, Kuhar and Kamminga 2017). However, virtually all of these insecticides are toxic to beneficial arthropod predators, parasitoids, and pollinators (Leskey et al. 2012b), and can lead to secondary pest outbreaks of aphids, mites, or scales in tree fruit and vegetables after repeated use, especially with pyrethroids (Kuhar et al. 2011, Leskey et al. 2012a).

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[2]Corresponding author (e-mail: tkuhar@vt.edu).

Control of *H. halys* is a greater challenge for organic farmers, with insecticide options limited to naturally derived compounds such as pyrethrins, spinosad, azadirachtin, and sabadilla (Lee et al. 2014, Kuhar and Kamminga 2017). Although several of these insecticides have shown activity on *H. halys* under laboratory conditions (Lee et al. 2014), they have not performed well in the field in protecting vegetables from stink bug damage (Kuhar and Morehead 2017). Therefore, alternative strategies are needed for management of *H. halys*. One potential strategy is the use of repellents or deterrents. Kaolin is a white, nonporous, low-abrasive, fine-grained, aluminosilicate [$Al_4Si_4O_{10}(OH)_8$] clay mineral derived from weathered feldspar and quartz (Harben 1995). This inert powder is applied to plants to reduce heat stress, water loss, and sunscalding of fruit (Puterka et al. 2000). Particle films of kaolin have also been shown to alter the appearance, tactile nature, and taste of a plant to insects (Puterka and Glenn 2003). Kaolin films may also mask the plant by turning it white as well as limit the insect's ability to move and grasp the plant surface (Unruh et al. 2000, Puterka et al. 2003, Puterka and Glenn 2003).

Other natural insect repellents include terpenes and terpenoids produced by *Rosmarinus officinalis* L. (rosemary) and *Mentha piperita* L. (mint) that contain essential oils rendering the plant distasteful or toxic to feeding upon the plant (Nerioa et al. 2010). These essential oils including rosemary and spearmint oil, as well as the individual compounds that comprise them, have demonstrated repellent activity against *H. halys* under laboratory conditions (Zhang et al. 2014). Herein, we evaluated kaolin and a blend of rosemary and peppermint oils in repelling *H. halys* nymphs and adults in laboratory choice tests and protecting fruiting bell peppers in the field with weekly applications of the products.

Materials and Methods

Laboratory choice test. Laboratory choice bioassays were replicated five or six times for both *H. halys* adults and nymphs (mix of 2nd–4th instars). Insects used in the bioassays were from field-collected *H. halys* from trees [primarily *Ailanthus altissima* (Miller) Swingle and *Catalpa speciose* (Warder)] near Blacksburg, VA. Insects were maintained in a chamber (Percival Scientific Inc., Perry, IA) at a temperature of 26°C ± 2°C, 50% relative humidity, 16:8-h light:dark photoperiod, and were provided with a water wick and fresh snap beans, *Phaseolus vulgaris* L. (Fabales: Fabaceae); carrots, *Daucus carota* L. (Apiales: Apiaceae), and peanuts, *Arachis hypogaea* L. (Fabales: Fabaceae) (Medal et al. 2012). A total of 360 individuals (nymphs or adults) was used for the experiment. For each replicate, 60 individuals were separated into groups of 10, starved for 24 h, and placed in 0.5-L plastic containers.

The two repellents tested in this study were 95% powdered kaolin clay (Surround WP Crop Protectant, Novasource; Tessenderlo Kerley, Inc., Phoenix, AZ) and a commercially available blend of 10% rosemary oil and 2% peppermint oil (EcoTec, Brandt Consolidated, Inc., Springfield, IL). The experimental arenas were 30.5 × 30.5 × 30.5cm fine mesh insect rearing cages with vinyl windows (Bug Dorm; BioQuip Products, Rancho Dominguez, CA). Within each cage, two 20-cm-diameter petri dish halves were placed on opposite corners of the cage, roughly 75 cm apart, and served as a choice test for treated versus untreated. Freshly picked leaves from a *Paulownia tomentosa* (Thunberg) Steudel tree were trimmed to fit the petri dish and were treated with the repellents (kaolin or essential oils) or left untreated prior to placement in the arena. Kaolin was applied in a plastic bag by placing the trimmed leaves and tomato fruit, *Solanum lycopersicum* L. (variety = NatureSweet Glorys), inside the bag with 120 g of dry kaolin powder and shaking the container until leaves and fruit were coated. Excess powder was shaken gently from the leaves and tomato fruit before they were removed from the bag. For the essential oil treatment, a concentration of 12.36 ml of EcoTec was mixed in 1 L of water/L, which represented a high labeled field rate for the product. The solution was applied with a hand sprayer to the leaves and tomato fruit until run off, shaken gently to remove excess, and then allowed to air dry.

To begin each experiment, the plastic container with the bugs was gently tapped to release them into a corner of the arena so they started the same distance from each treatment. Insect position within the arena was noted at 20, 40, and 60 min and 2, 4, 6, 8, and 24 h after the start of the experiment. Insects observed on the leaf or tomato fruit were recorded as a positive response, and all others were assumed to be elsewhere within the arena. The effect of treatment on cumulative numbers of bugs observed on the food was analyzed with a paired Student's *t* test at the $P < 0.05$ level of significance using JMP Pro 11 (SAS Institute 2013). Data were analyzed as cumulative numbers over the sample intervals because there were many time intervals in which no insects were observed on the food.

Field efficacy trials. The experiment was conducted in 2014 and 2015 at Kentland Farm in Whitethorne, VA, which regularly suffers infestations of *H. halys* on peppers since 2011 (Kuhar et al. 2012b, 2013a, 2013b, 2013c). Bell peppers ('Aristotle') were transplanted on 1 June from greenhouse-grown seedlings into raised beds covered with black plastic mulch and drip irrigation. Plants were spaced 0.3 m apart. Individual plots were 4 rows $\times$ 6.1-m-long beds with 1.5-m unplanted alleys to separate treatments. Plots were arranged in a randomized complete block design with four replicates ($n = 4$), and each plot was four rows, each 6 m long. Treatments were separated from each other by a 6-m-long buffer block. A CO_2 backpack sprayer at 256 kPa with a three-nozzle drop boom was used to apply the treatments at a volume of 356 L/ha. Kaolin was applied at 8.4 kg/ha, and the essential oil mixture was applied at a rate of 2.9 L of Ecotec product/ha. Treatments were applied five times in 2014: 22 August, 29 August, 5 September, 12 September, and 19 September; and four times in 2015: 31 July, 7 August, 14 August, and 21 August. During 2014, pepper fruit were harvested from each plot on 29 August and 22 September, and a subset of 50 fruit were examined for insect damage. In 2015, peppers were harvested on 12 August, 21 August, and 28 August. Stink bug feeding injury was determined by the presence of circular discoloration zones with a small ring in the middle due to the shedding of the bug's stylet sheath. Percentages of stink bug injury were calculated by dividing the number of damaged fruit by the total number of peppers harvested for each treatment. All data were initially tested for normality using the Normal Test (Shapiro–Wilk Test), and when necessary, the proportion fruit injury data from the field experiments were transformed using an arcsine square root transformation to normalize the variances (Sokal and Rohlf 1995) and then analyzed with a two-way analysis of variance for randomized complete block designs where both treatment

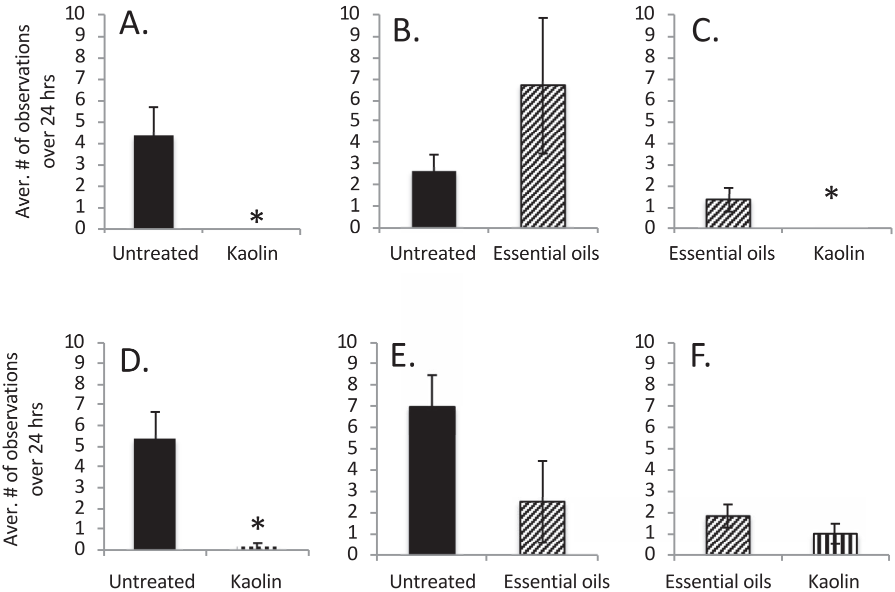

Fig. 1. Cumulative numbers of *H. halys* nymphs (top three graphs) or adults (bottom three graphs) observed over a 24-h span on food items (*Paulownia tomentosa* leaf paired with a cherry tomato) from choice test bioassays with 10 bugs in cages comparing food items treated with potential repellent compounds or not treated (control). * indicates significantly fewer bugs observed on treated food based on Student's *t* test at the $P < 0.05$ level of significance.

and block were factors using JMP version 10.0 (SAS 2013, SAS Institute, Cary, NC). Means were separated using Fisher's protected least significant difference at the $P < 0.05$ level of significance. Data are presented as original mean.

Results

Laboratory choice test. Significantly fewer *H. halys* nymphs ($t = 2.78$; $df = 5$; $P < 0.034$) and adults ($t = 5.063$; $df = 4$; $P < 0.01$) were observed on kaolin-treated food than on untreated food during a 24-h observation period (Figs. 1A and 1D). No differences were observed in the number of *H. halys* nymphs ($t = 1.00$; $df = 4$; $P = 0.821$) or adults ($t = 1.69$; $df = 5$; $P = 0.062$) observed on essential oil-treated food compared to untreated food (Figs. 1B and 1E). Significantly fewer *H. halys* nymphs ($t = 2.169$; $df = 5$; $P < 0.041$) were observed on kaolin-treated food than on essential oil-treated food during a 24-h observation period between those treatments (Fig. 1C); however, no differences were seen in adult *H. halys* numbers between these two treatments ($t = 1.39$; $df = 4$; $P = 0.1004$; Fig. 1F).

Field efficacy trials. In 2014, pepper fruit from the untreated control plots averaged between 21% and 12% stink bug feeding injury (Fig. 2A). In 2015, the untreated control averaged >30% injury (Fig. 2B). There was a significant effect of

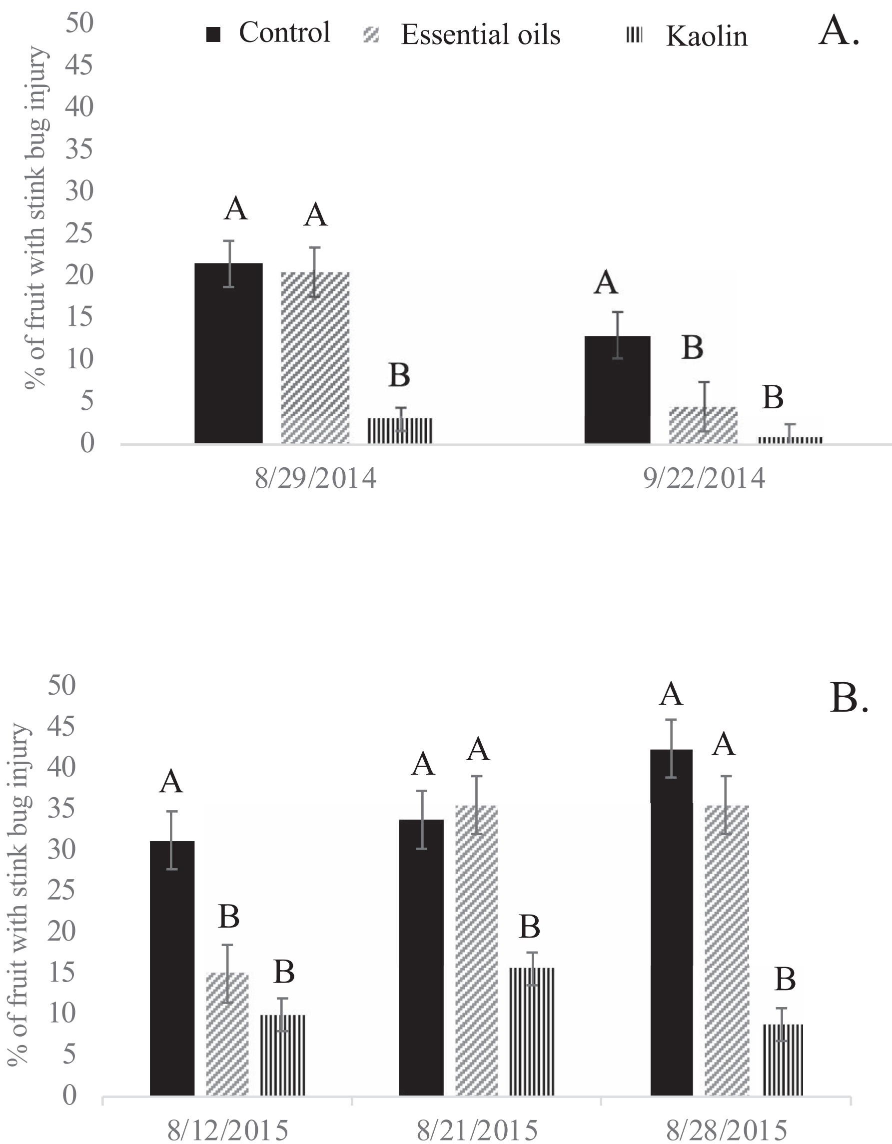

Fig. 2. Percentage of harvested peppers with stink bug feeding injury (mean ± SEM) from field experiments conducted in Whitethorne, VA in 2014 (A) and 2015 (B) where treatments were applied five times in 2014: 22 August, 29 August, 5 September, 12 September, 19 September; and four times in 2015: 31 July, 7 August, 14 August, and 21 August (B).

treatment on injury at each harvest, 29 August ($F = 5.53$; df $= 2,6$; $P < 0.044$) and 22 September ($F = 15.36$; df $= 2,6$; $P < 0.004$) in 2014, and 12 August ($F = 7.64$; df $= 2,6$; $P < 0.0022$), 21 August ($F = 5.77$; df $= 2,6$; $P < 0.040$), and 28 August ($F = 23.12$; df $= 2,6$; $P < 0.0015$) in 2015. Kaolin reduced stink bug feeding injury in peppers from 76% to 90% in the two field seasons.

The effects of the essential oils were inconsistent with significantly less stink bug injury than the control in two of the five harvests, with a 27% reduction in injury compared to the control across all harvests and years (Fig. 2A and 2B).

Discussion

Arthropods rely on touch, taste, sight, and smell to locate and accept host plants (Miller and Strickler 1984). The purpose of particle films in pest management is to alter the behavior of an insect pest either before or after the insect makes contact with the plant. Particle films of kaolin cover leaves with a white coating, which prevents insects from recognizing the leaf surface and holding onto plant surfaces (Puterka and Glenn 2003). Particle film may camouflage the plant by turning it white (Puterka et al. 2003).

Our laboratory bioassay demonstrated that *H. halys* avoided plant material that was treated with kaolin. Furthermore, in the field, kaolin significantly reduced stink bug feeding injury to bell peppers in all harvests. Our data associated with the essential oils, however, was inconsistent and inconclusive. Zhang et al. (2014) examined several essential oils as repellents against *H. halys* and tested the primary components to determine what compounds in each oil were responsible for repellent activity; two compounds that elicited a strong repellent effect on *H. halys* were α-terpineol and β-caryophyllene. These two compounds occur in rosemary (Lograda et al. 2013), which is the primary active ingredient in the essential oil product that we evaluated. In our field experiments, peppers treated with essential oils had significantly less stink bug injury than the untreated control in two of the five harvests. The reasons for the inconsistency are not known.

Thus, kaolin appears to be an efficacious option for growers seeking a repellent or deterrent to reduce *H. halys* crop damage. Puterka and Glenn (2003) and Puterka et al. (2003) also demonstrated reduced feeding injury by pear psylla, *Cacopsylla pyricola* (Foerster) (Hemiptera: Psyllidae), and glassy-winged sharpshooter, *Homalodisca vitripennis* (Germar) (Hemiptera: Cicadellidae), respectively, with applications of kaolin. Moreover, because kaolin applications may already be used by some fruit growers to reduce sunscald (Glenn and Puterka 2005) and because peppers can also suffer high losses to sun scalding injury (Díaz-Pérez 2014), the use of kaolin may be an economically feasible pest management option for certain cropping systems. More data are needed on its effects on other insects. For instance, Unrue et al. (2000) showed a reduction of lepidopteran damage in apple from kaolin. A few drawbacks are that kaolin can potentially clog spray nozzles or screens, often needs to be reapplied after rain, and the white residue needs to be washed off of produce after harvest. However, this pest management tool is Organic Materials Review Institute-certified and offers organic producers a pest management option for *H. halys*.

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