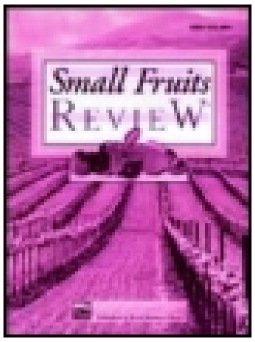

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Effects of Kaolin Clay Application on Flower Bud Development, Fruit Quality and Yield, and Flower Thrips [*Frankliniella* spp. (Thysanoptera: Thripidae)] Populations of Blueberry Plants

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SUMMARY. Three separate studies were conducted to report the effects of kaolin applications (Surround WP) on southern highbush blueberries (*Vaccinium corymbosum* L.) and rabbiteye (*V. ashei* Reade) blueberries. When applied to mature blueberry plants, kaolin clay emulsion dried to form a white reflective film and affected bud development, fruit set and development, plant growth, and fruit yield, but had no effect on fruit quality parameters. When kaolin was applied before fruit set,

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yield was increased with no significant residue left on the fruit. Surround WP consistently reduced the number of flower thrips (*Frankliniella* spp.) within the canopy of rabbiteye blueberry plants by approximately 50%. Kaolin applications were not phytotoxic to blueberry buds, flowers, leaves, or fruit and were harmless to foraging bees.

KEYWORDS. Kaolin, southern highbush blueberry, thrips, fruit yield, fruit quality, crop protectant

INTRODUCTION

Hydrophobic particle film technology was introduced in 1999. The hydrophobic particle film based on the inert clay mineral called kaolin has been formulated as a crop protectant and has a sublethal impact on fungal pathogens and insects (Glenn et al., 1999). Simple dust applications of particle films are not sufficiently durable for long service. For this reason, the hydrophobic kaolin clay particles are pre-mixed with methanol to increase their miscibility in water and surfactants are added (Glenn et al., 2001). This hydrophilic particle film is now marketed as Surround WP. Surround WP, based on a nontoxic kaolin particle and a spreader-sticker made of natural materials, has been officially recognized as "organic" by the Organic Materials Review Institute (ATTRA-a). Kaolin particle film has proven to be very effective in protecting fruit trees from various insect pests, but many horticultural benefits have been reported as well.

Flower thrips including *Frankliniella bispinosa* (Morgan), *F. occidentalis* (Pergande), *F. tritici* (Fitch), *Scirtothrips ruthveni* Shull are emerging as pests of cultivated blueberries in New Jersey and the Southern States. Severe feeding and oviposition injury to flowers and fruit is thought to seriously curtail blueberry yield in certain years (Parker et al., 1995). Both adult and nymphal flower thrips typically take refuge between the crevices that exist between various floral organs and are difficult to kill with conventional contact insecticides.

Kaolin-based emulsions have multiple modes of action that can offer broader protection to blueberry crops from flower thrips and other blueberry pests (Glenn et al., 1999; Knight et al., 2000; Lapointe, 2000;

Puterka et al., 2000; Unruh et al., 2000). Kaolin clay particles adhere to plant surfaces with the aid of wetting agents. These particles form a physical barrier over the flowers, leaves, stems, and fruit. If these particles attach to the waxy cuticles of pest insects they interfere with feeding, as well as cause irritation and desiccation (Glenn et al., 1999; Swamiappan et al., 1976). Also, kaolin has no nutritional value to herbivorous insects and can potentially reduce the digestibility of plant tissue (Howe and Westley, 1988). Induced plant resistance to pest insects is also possible, as plants sprayed with kaolin can become unrecognizable as suitable hosts (Bar-Joseph and Frenkel, 1983; Glenn et al., 1999). Host suitability to flower thrips can diminish with intensification of reflected UV-light (350 to 390 nm) visible to flower thrips (Glenn et al., 1999; 2002; Lewis, 1997; Parker et al., 1995).

Particle film sprays such as kaolin have been recommended to lower the temperature of apple fruit; thereby reducing sunburn and improving red fruit color in situations where temperatures are higher than optimal (Heacox, 1999; Stanley, 1998; Warner, 2000a; Werblow, 1999). Yield was increased in some cases, yet was unaffected in other studies. The increase in yield was reportedly due to a decrease in pre-harvest fruit drop. This also was evident when kaolin particle film was applied to Seckel pear trees (Puterka et al. 2000).

Solar injury was suppressed with spray applications of a reflective, processed-kaolin particle film material on apple [*Malus sylvestris* (L.) Mill var *domestica* (Borkh.) Mansf.]. Glenn et al. (2002) reported that fruit surface temperature was reduced by the application of reflective particles and the amount of temperature reduction was proportional to the amount of particle residue on the fruit surface. It was also noted that the processed-kaolin film material was highly reflective to the ultraviolet wavelengths and this characteristic may be important in reducing solar injury to both fruit and leaves (Glenn et al. 2002).

Much research has been done on the effects of kaolin clay particle films on apple (*Malus* spp.), pear (*Pyrus* spp.), etc., but no research has been reported for blueberry plants. The objectives of this research were: (1) to determine the effects of kaolin clay on blueberry yield, quality, size, development, fruit set, and plant growth; (2) to determine at what stage of flower or fruit development would the application of kaolin clay be the most beneficial; and (3) to determine the impact of kaolin clay application on the populations of flower thrips (genus *Frankliniella*).

MATERIALS AND METHODS

Fruit quality and yield. Mature southern highbush blueberry (*Vaccinium corymbosum* L.) plants grown on Ruston fine sandy loam soil (fine-loamy, siliceous, thermic Typic Paleudult) at the USDA Small Fruits Research Station site in Stone County, Mississippi were used in the following 2 studies. Prior to and throughout the studies, all plants received uniform fertilizer and irrigation rates (Braswell et al., 1991). All treated plants were sprayed with a mixture of 1077 g of kaolin clay (= 1133.95 g Surround WP, Englehard Corporation, Iselin, NJ) and 59 ml of the non-ionic surfactant Silken (Riverside/Terra Corp., Sioux City, Iowa) per 19 L of solution. Treated plants were sprayed using a 12 L pressurized backpack sprayer (SOLO™ Kleinmotoren GmbH, Sindelfingen, Germany). The plants were sprayed until drip and were visually inspected and re-sprayed to ensure complete coverage.

Effects of kaolin clay on bloom development. 'Cooper' blueberry plants established in 1995 were arranged in a randomized complete block design consisting of 9 replications with each replication having 2 treatments (sprayed and unsprayed) and border plants between treatments. Treated plants were sprayed with kaolin on March 8, 2001. Ten buds from each plant were rated according to the blueberry flower bud rating scale (Spiers, 1978) prior to treatment, with the goal of getting 2 of each rating 3-7 on each plant. Tags were attached next to the buds and labeled with the rating and a letter (3a, 3b, etc.). Flower buds were rated 10 days following application, and the number of flowers per bud was recorded. Fruit diameter was measured, and the number of fruit per bud was counted on 3 occasions (April 17, May 23, and May 30). The number of flowers/bud, berries present, and fruit picked was analyzed to assess fruit set. The rate of development and size of the fruit was also recorded. All data was analyzed by ANOVA using SAS (SAS Institute, 1985).

Effects of application time of kaolin clay. 'Magnolia' blueberry plants established in 1994 were arranged in a randomized complete block design consisting of 4 replications with 15 plants (5 treatments and 3 plants per treatment) per replication. The 5 treatments consisted of an unsprayed control and a single spray of kaolin applied at 4 different stages of fruit development; pre-fruit (March 8, 2001; approximately 50% flowering), early fruit set (March 29), mid-maturity (April 17), and pre-harvest (May 3). The volume (length × width × height) of the plant size was obtained prior to treatments. Fruit was harvested from the middle plant in each block when ripe and the yield was measured. The harvesting dates were May 14, May 23, May 31, and June 7, 2001.

On each harvesting date, randomly selected berries were measured for chemical analysis, compression, and turbidity (residue). Thirty berries from each plant were swirled in 100 ml of distilled water for 1 min. to remove the residue from the berries. The water with residue was tested for turbidity using a Perkin-Elmer Lambda 3B UV/VIS spectrophotometer. Standards of 0, 10, and 100 ppm of kaolin clay (Surround WP) were measured with the spectrophotometer prior to measuring the water with unknown amounts of residues. The standards were used to set up a linear regression and calculate the amount of kaolin clay residue left on the berries in ppm. A 30 g sample of berries was homogenized 1 min with a Waring blender. Soluble solids concentration (SS) of the homogenate was measured by filtering homogenate through 2 layers of cheesecloth and measuring the juice with a (Bausch and Laumb) hand held refractometer. Total solids (TS) were obtained by drying a 10 g aliquot of homogenate in a forced air drying oven at 72°F for 24 h. A 10 g aliquot diluted to 100 ml with distilled water was used for pH measurement.

Compression force was measured with a QTS 25 (Stevens Mechtric) texture press using a spherical probe. For each treatment and replication 10 berries were compressed. Compression force was applied parallel to the stem-calyx axis until 150 g of pressure was applied. Modulus (g/s) and deformation at peak load (mm) were recorded.

After the final harvest, the volume of the plants was calculated from measuring the height and a cross-sectional width (length × width × height). Growth was calculated against preliminary measurements and was analyzed with ANOVA using SAS (SAS Institute, 1985). Yield and chemistry data were analyzed with GLM using SAS.

Flower thrips populations. Blueberry host plants were established at the USDA-ARS Small Fruits Research Station located in Poplarville, Mississippi. Three rabbiteye blueberry (*V. ashei* Reade) cultivars were used: ‘Delite’, ‘Tifblue’, and ‘Woodard’. Plants were established in 1988 in a Ruston fine sandy loam soil, and were planted according to a 3 × 3 Latin square. There were 6 replications, 2 treatments (kaolin and unsprayed), and 9 plants per experimental plot (total N = 108 plants). The application was a mixture of 1077 g of kaolin (= 1134 g Surround WP, Engelhard Corporation, Iselin, NJ) and 59 ml of a non-ionic surfactant (Silkin, Riverside/Terra Corp., Sioux City, IA) per 5 gallons of water. Therefore, each blueberry bush received about 20 g kaolin and control plants went unsprayed (0 g kaolin). Three applications were repeatedly made to the same plants during bloom (March 7, 2001), post-bloom (April 20), and pre-harvest (May 17). Liquid applications were applied with a pressurized 12 L backpack sprayer (SOLO™ Kleinmotoren GmbH, Sindelfingen, Germany). The plants were sprayed until drip and were visually inspected and re-sprayed to ensure complete coverage.

Yellow Pherocon AM sticky traps (23 cm × 28 cm: Tréce Inc. Salinas, CA) were placed on the center plant in each experimental block in the middle of the canopy, on the same day of application after the kaolin had completely dried. The 36 sticky traps were collected exactly one week after making the kaolin applications. Thrips abundance was estimated by counting the total number of thrips in five randomly chosen quadrants on a 3 × 5 counting grid. Multiplying this tally by 3 and adding the number of thrips that fell outside the boundaries of the grid gave an estimate of the total number of thrips per trap. Thrips abundance data were analyzed using a 3 × 3 factorial ANOVA and sequential sums of squares for calculating F-values (SAS Institute, 1985).

RESULTS AND DISCUSSION

Bud development. The number of flowers/bud, berries present, and berries picked were significantly greater for the plants treated with H kaolin (Table 1). Therefore, fruit set was increased with the application of Surround. This is in accordance with previous studies on apples and pears (Glenn et al., 1999; Glenn et al., 2001; Puterka et al., 2000). The rate of bud development was slower for the treated plants, possibly due to lowered heat stress and lowered direct photosynthesis. Increased fruit set with the application of kaolin could be due to insect control or horticultural benefits such as reduced heat stress and increased net photosynthesis (ATTRA-b). The berry size was smaller for the treated plants. Previous studies on apples and pears found fruit size to be equal or increased with the application of kaolin particle films (Glenn et al., 1999; Glenn et al., 2001; Puterka et al., 2000). In this study, the decrease in size correlates with the increase in fruit set. When there is an increase in fruit set there are fewer nutrients available per berry. Also, reductions in fruit size could possibly be due to an increase in the amount of reflected light (Glenn et al., 1999; Schupp et al., 2002). When fruit trees were not exhibiting heat stress, Glenn et al. (2001) showed that kaolin sprays reduced CO_2 assimilation and resulted in no size increase. Surround was found to reduce fruit size under environmental conditions where light

TABLE 1. Impact of kaolin on fruit set, development, and size of 'Cooper' southern highbush blueberry fruit.

Treatment	Number of flowers/bud	Floral bud development[z] rating	Berries/bud[y]		Berries/bud[x]	
			Number	Size (mm)	Number	Size (mm)
Spray	5.72 a[w]	6.30 b	5.36 a	1.03 b	3.45 a	1.61 b
No spray	4.86 b	6.45 a	4.44 b	1.07 a	1.90 b	1.70 a

[z] Floral bud development scales from Spiers (1978) 10 days after kaolin treatment.
[y] Unharvested berries on bush, 17 April 2001.
[x] Harvested berries, 30 May 2001.
[w] Means separation within columns at $P \leq 0.05$ level.

was more likely to be limiting to CO_2 assimilation than was high temperature (Schupp et al., 2002).

Effects of application time. The soluble solids, total solids, pH, and compression measurements were not significantly different for the treated and untreated plants (Table 2). These results support previous studies where kaolin sprays did not affect fruit quality (Glenn et al., 1999; Glenn et al., 2001; Puterka et al., 2000; Schupp et al., 2002). Turbidity (residue on fruit) measurements increased linearly from the control to the last date kaolin applications were made. However, plants treated during the pre-fruit (~50% bloom) stage were not significantly different from control plants in the amount of residue on the fruit (Table 2). The yield for the plants sprayed during the pre-fruit stage was significantly greater than the unsprayed and other treatments (Figure 1). Similar yield results were found when kaolin particle films were applied to apples, peaches, and pears (Glenn et al., 1999; Glenn et al., 2001; Puterka et al., 2000).

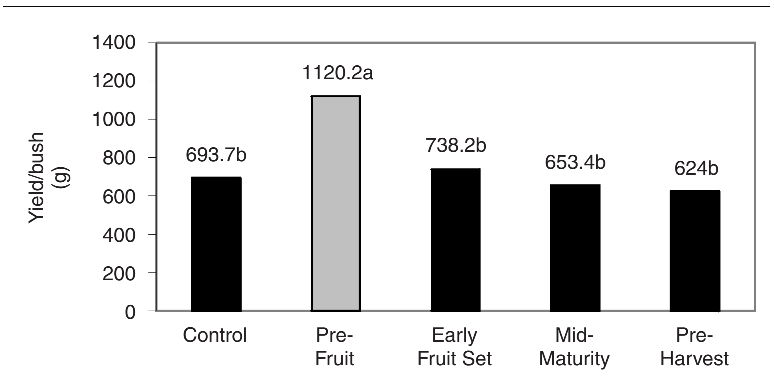
Plant growth increased with the application of kaolin (Figure 2). The earlier applications achieved more growth than the later applications. The control plants had the least amount of growth. Previous studies have found no reduction in shoot growth when applied to fruit trees, but have not observed increased growth (Glenn et al., 1999; Puterka et al., 2000). Increased plant growth could be due to kaolin particles protecting the plants from heat stress and insect pests. Reducing the heat load possibly increased the net photosynthesis and resulted in more plant growth. No phytotoxicity was detected from the application of kaolin particle film possibly because of the decreased particle size ($\leq$ 2 µm) that allowed for gas exchange. Generic kaolin (1.6-4.8 µm) acts as an antitranspirant and can result in phytotoxicity (Eveling and Eisa, 1976).

TABLE 2. Impact of kaolin on fruit quality characteristics of 'Magnolia' southern highbush blueberry.

Application stage	Soluble solids (Brix)	Total Solids (%)	pH	Turbidity	Modulus (g/s)	Deformation (mm)
Control	13.34 a[z]	14.40 a	3.28 a	12.86 d	20.73 a	1.96 a
Pre-fruit	13.33 a	14.58 a	3.24 a	13.27 d	20.37 a	1.91 a
Early fruit set	13.61 a	14.60 a	3.27 a	22.64 c	21.52 a	1.80 a
Mid-maturity	13.43 a	14.51 a	3.31 a	35.25 b	21.34 a	1.87 a
Pre-harvest	13.29 a	14.43 a	3.23 a	61.38 a	21.41 a	1.81 a

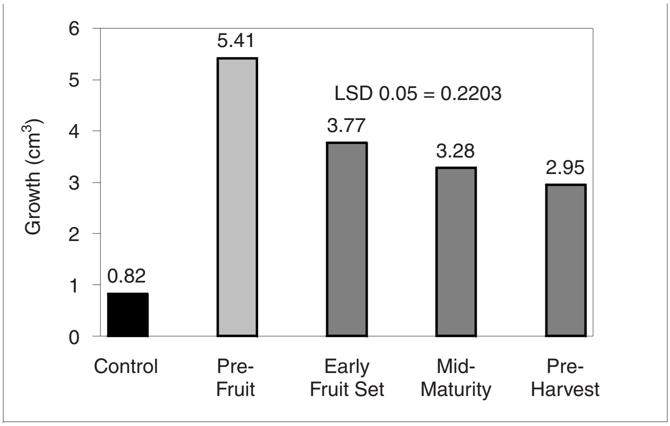
[z] Means separation within columns at $P \leq 0.05$ level.

FIGURE 1. Impact of kaolin particle film on the average yield of 'Magnolia' southern highbush blueberry plants. Means by Duncan's Multiple Range Test ($P \leq 0.05$).



Flower thrips population. Thrips populations in the experimental rabbiteye blueberry field increased rapidly from mid-bloom (7 March 2001) to the onset of harvest (17 May 2001). Aerial applications containing kaolin reduced the abundance of flower thrips associated with *V. ashei* bushes by about 50% (Table 3, Figure 3). No interaction was observed between cultivar and treatment, showing that the efficacy of kaolin to reduce thrips abundance was consistent and not seriously impeded by minor cultivar differences (Table 3). The effectiveness of kaolin as a deterrent to adult thrips increased on those application dates

FIGURE 2. Impact of kaolin clay particle film on plant growth of 'Magnolia' southern highbush blueberry plants.



when thrips counts were the highest, suggesting that the mode of action for Surround WP is to some extent density-dependent.

CONCLUSIONS AND GSROWER BENEFITS

Fruit quality and yield. These results indicate that an application of kaolin clay particle film at pre-fruit (50% bloom) can provide horticultural benefits to blueberry plants. Yield enhancement can be obtained without any significant residue on the berries when applied before fruit set. Later single applications were not more beneficial and a kaolin residue, although organic, was evident on berries. Kaolin clay can be used to increase fruit set without affecting fruit quality. The size of the fruit was decreased, probably because of the increased number of fruit. The application of kaolin can promote growth of blueberry plants without affecting pollination.

Flower thrips populations. Kaolin applications invariably reduced the number of adult flower thrips associated with three cultivars of rabbiteye blueberry by about 50%. The efficacy of kaolin increased as adult thrips became more numerous. This demonstrated that kaolin might sufficiently alter host suitability, forcing larger numbers of thrips to move to adjacent, unsprayed bushes. Kaolin treatments broadcast

TABLE 3. Summary of ANOVA results for three experimental factors (Cultivar, Treatment and Application Date) as well as interactions affecting the abundance of flower thrips (*Frankliniella* spp.) at an experimental rabbiteye blueberry planting on the USDA-ARS Small Fruit Research Station, Poplarville, Mississippi.

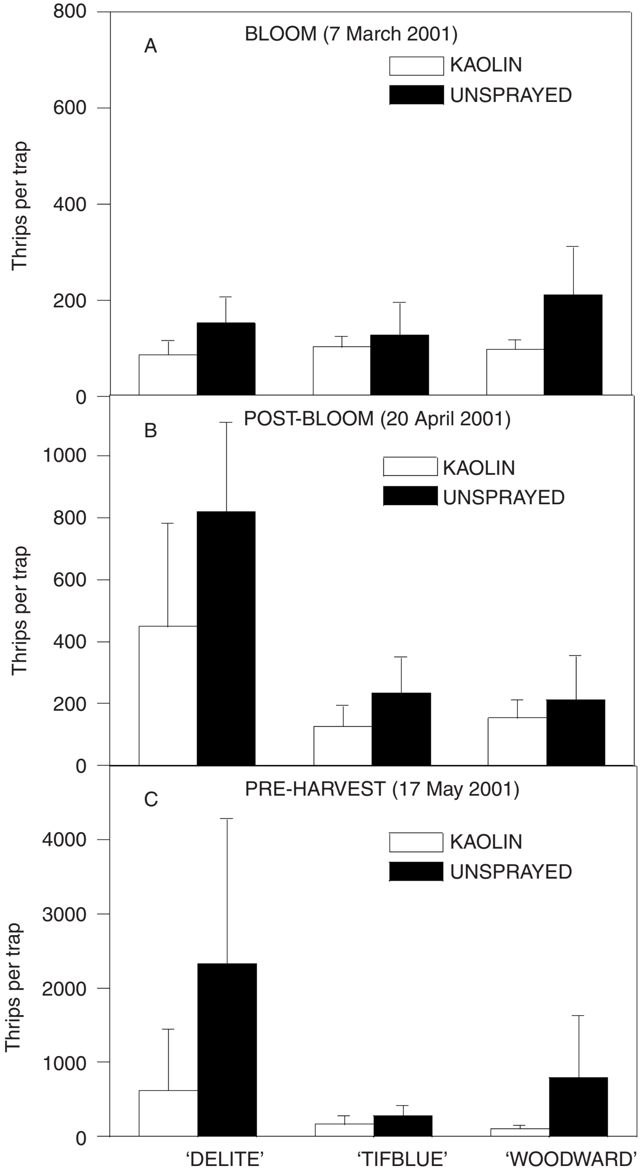
Source of Variation	df	F	P
Cultivar	2	11.13	< 0.0001
Treatment	1	11.56	0.0010
Cultivar × Treatment	2	3.09	0.0503
Application Date	2	10.40	< 0.0001
Cultivar × Application Date	4	4.57	0.0021
Treatment × Application Date	2	5.11	0.0079
Cultivar × Treatment × Application Date	4	1.82	0.1315
Error	90		
Total	107		

over a much wider area could effectively control flower thrips in rabbiteye blueberry fields, especially around peak bloom and early fruiting when damage is more severe (Polavarapu, 2001).

These preliminary results clearly demonstrate that kaolin particle barriers can alter the foraging patterns of adult thrips within patches of flowering and fruiting blueberries. Additional studies are needed to verify the more direct effects of kaolin on thrips oviposition, feeding behavior and survival on blueberry host plants. Kaolin formulated as Surround WP mixed with a non-ionic surfactant was not phytotoxic to blueberry plants and had no adverse impact on pollinator activity (Sampson et al., unpublished data) and yield.

The Food Quality Protection Act (FQPA) and other regulations are encouraging the discovery, development, and implementation of reduced-risk alternatives to the toxic pesticides currently in use on fruit crops. A crop protectant like kaolin-based emulsions can become an increasingly important element of blueberry integrated pest management (IPM). Our results show kaolin clay particle films to be an effective method for reducing thrips populations associated with rabbiteye blueberry plants. Kaolin that is not amended with prohibited substances can also be a viable method of crop protection for certified organic farmers.

FIGURE 3. The impact of kaolin applications on the seasonal abundance of adult flower thrips associated with three varieties of rabbiteye blueberry. Bars represent mean ± 1 SD.



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