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A Kaolin-based Particle Film Suppresses Certain Insect and Fungal Pests while Reducing Heat Stress in Apples

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Abstract

The application of non-toxic particle films to suppress arthropod pests and diseases in crop plants is a promising recent development in horticulture. Experiments were conducted in two orchards in southwest Missouri to evaluate a specific particle film's effectiveness against such pests in apples [*Malus sylvestris* (L.) Mill. var. *domestica* (Borkh) Manst.]. A newly-developed kaolin-based product, Surround WP (Engelhard Corp., Iselin, NJ), was applied at five different rates and frequencies throughout two growing seasons. The product was successful at suppressing plum curculio (*Conotrachelus nenuphar* Herbst) damage to fruits, red-banded leafroller (*Argyrotaenia velutinana* Walker) damage to leaves (but not consistently to fruits), flyspeck (*Zygophiala jamaicensis* Mason) and sooty blotch [*Gloeodes pomigena* (Schwein.) Colby] diseases on fruits, and a *Phoma* leaf spot (*Phoma sp.*), but was not consistently effective against cedar apple rust (*Gymnosporangium juniperi-virginianae* Schwein). Overall grade of apple was improved with particle film applications. Generally, higher rates and more frequent applications resulted in better pest suppression. The particle film coating also reduced plant stress during extreme temperature conditions. Results suggest that kaolin-based particle films have potential applications in integrated management of apple pests, while providing some physiological benefits to the plants.

Introduction

Particle film technology is emerging as a new, important tool in the management of agricultural and horticultural pests. Applications of non-toxic kaolin-based particle films to leaves and fruits can form a protective barrier capable of suppressing certain arthropod pests and fungal diseases (4). Unruh et al. (13) determined that particle films of kaolin and adjuvants suppressed codling moth (*Cydia pomonella* L.) larval walking speed, fruit discovery rate, larval fruit penetration rate, and female oviposition rate on apples in the laboratory, while fruit infestation rates were reduced by particle film treatments in apple and pear (*Pyrus communis* L.) orchards. Kaolin particle films also reduced codling moth fruit injury to apples in a study by Knight (6). Knight et al. (7) likewise found that a kaolin-based particle film significantly reduced female longevity,

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mating success, and oviposition in the oblique-banded leafroller (*Choristoneura rosaceana* Harris) in apples. Shoot infestation was also reduced by particle film application before bud-break. Oviposition by the root weevil (*Diaprepes abbreviatus* L.) was completely suppressed in orange [*Citrus sinensis* (L.) Osbeck] while feeding by adult weevils was reduced with a hydrophilic kaolin-based particle film (8). In pear, Puterka et al. (11) reduced pear psylla (*Cacopsylla pyricola* Foerster) egg, nymph, and adult numbers, and pear rust mite (*Epitrimerus pyri* Nalepa) damage with both hydrophobic and hydrophilic particle films, while yields were nearly doubled. They suggest that hydrophobic films may be required for control of many diseases but found that both hydrophilic and hydrophobic films reduced *Fabraea* leaf spot (*Fabraea maculata* Atkinson) in pear. Ehret et al. (1) reduced severity of powdery mildew [*Sphaerotheca fuliginea* (Schlech. Fr.) Poll.] on cucumber (*Cucumis sativus* L.) and powdery mildew [*Uncinula necator* (Schwein.) Burrill] on grape (*Vitis vinifera* L.) with foliar sprays of a nonswelling chlorite mica clay. Marco et al. (10) also reported suppression of powdery mildew (*S. fuliginea*) on squash (*Cucurbita pepo* L.) with various clay formulations.

Particle films are also capable of providing physiological benefits to crop plants. Glenn et al. (3) demonstrated that kaolin-based particle films can lower canopy temperature, thereby reducing heat stress to leaves and increasing C assimilation, often resulting in increased yield in apples. Further studies (2) documented reduced apple fruit temperature and solar injury with application of a processed-kaolin particle film; the authors hypothesizing that the product's reflectiveness to UV wavelengths is at least partly responsible for this effect. Solar injury to apple fruits was also reduced by particle films in a study by Schupp et al. (12). In cotton (*Gossypium hirsutum* L.), application of kaolin-based particle films reduced canopy temperatures while increasing leaf transpiration rates (9), and in grapefruit (*Citrus paradisi* L.), kaolin particle films increased photosynthesis and water use efficiency (5).

Surround WP contains a hydrophilic kaolin mineral particle that is uniform, sprayable, non-abrasive, rain-fast, and of optimum size for insect adhesion and irritation while permitting the transmission of photosynthetically-active radiation. The objective of this study was to evaluate different rates and frequencies of Surround WP particle film applications in: 1) suppressing some important apple insect pests and fungal diseases of the Midwest, 2) determining the product's effect on fruit grade and yield, and 3) confirming its ability to reduce plant stress under Midwest conditions.

Materials and Methods

The study involved two apple orchards, both planted in 1991 at the University of Missouri's Southwest Research Center at Mt. Vernon, in USDA Hardiness Zone 6 (37° 4' lat, 93° 53' long, and 378 m alt). The soil is a prairie-derived Keeno cherty silt loam (loamy-skeletal, siliceous, mesic Mollic Fragiudalf) that is moderately well-drained with a 3% slope. Rainfall during the two years of the study (2000, 2001) was 953 and 990mm, respectively, both well below the mean annual rainfall of 1,106 mm. Maximum temperatures for 2000 and 2001 were 41 and 38°C, respectively, while minimum temperatures were -23 and -20°C.

Orchard 1 consisted of 90 trellised dwarf 'Liberty' and 'Jonafree' apple trees on 'Mark' rootstock, spaced 1.5 m apart in three rows. The orchard was set up in linear plots of three trees per cultivar, alternating cultivars within the row, resulting in 15 plots of three trees per cultivar. Three replications of five treatments were randomly assigned to each cultivar's 15 plots. Treatments were: 56 kg/ha Surround WP once per week (56W), 56 kg/ha every two weeks (56Bi), 28 kg/ha once per week (28W), 28 kg/ha every two weeks (28 Bi), and untreated control. Data were collected only from the middle tree of each three-tree plot to avoid border effects from neighboring closely-spaced plots. Orchard 2 contained 20 semi-dwarf trees, ten each of 'Ultragold' and 'Jonagold' on 'M.7' rootstock, planted 4.0 m apart in two rows and alternating cultivars within the row. Each tree served as a plot. Two replications each of the above five treatments were randomly assigned to each cultivar's ten plots.

Dormant oil was applied pre-bloom both years. No other pesticides were used other than the experimental materials. Irrigation water was applied as needed through a drip system. Weeds were controlled by cultivation. Trees were fertilized with a 3-1-5 alfalfa-based fertilizer (Bradfield Industries, Springfield, MO), yielding approximately 71 g N per tree per year. Applications of Surround WP treatments began at petal fall (25 Apr 2000, 26 Apr 2001) and continued at designated intervals until about one week before harvest (1 Aug 2000, 5 Aug 2001). Trees were hand-sprayed with a tractor-mounted pto-driven sprayer at 150 psi pressure or greater, thoroughly covering both top and bottom of foliage and fruits.

Insect traps were used to monitor populations of several serious apple insect pests common to the region to correlate damage, or lack thereof, with the known presence of certain insect species. Ten appropriate pheromone-based sticky insect traps (Trécé, Inc. Salinas, CA) each for codling moth, oriental fruit moth (*Grapholitha molesta* Busck), red-banded leafroller, and San Jose scale (*Quadraspidiotus perniciosus* Comstock) were placed throughout the two orchards and refreshed every four weeks during the growing season. Plum curculio were monitored via two "Tedders Traps" (Gempler's, Belleville, WI). Trapped insects were removed and counted weekly to document insect population patterns throughout the seasons.

Detailed data on insect damage and fungal disease on both leaves and fruit were collected periodically throughout the two growing seasons. Most fruit data, however, were collected upon harvest (7-11 Aug 2000, 10-13 Aug 2001). Between 50 and 100 apple fruits per plot were examined for insect and disease damage with a general target of 50 fruits. If a plot had less than 50 fruits, all were examined. Individual fruits were first graded, with "1" being a near-perfect marketable apple, "2" being an apple of good quality suitable for cider, and "3" an unusable apple. Fruits were then scored positive or negative for the superficial fungal diseases sooty blotch and flyspeck before being cut open and individually examined to ascertain what type of insect damage, if any, had occurred. Fruits were scored either positive or negative for damage from plum curculio, codling moth, oriental fruit moth, red-banded leafroller (or leafroller complex), and San Jose scale (2001 only). Fruit yield per plot was also documented. Final leaf data were collected in September both years to document what type of damage had accumulated throughout the growing season. Leaves were examined for the fungal diseases cedar apple rust and a *Phoma* leaf spot, and for surface-feeding damage from red-banded leafroller (or leafroller complex) (2001 only). For each condition, 100 leaves from within each plot were individually and randomly examined on multiple occasions. Leaves were scored as either affected or not for each pest being evaluated.

The data were analyzed separately for each orchard - year combination. Orchards were not pooled because each contained different cultivars; years were not pooled because of unequal variances ($p \leq 0.05$). The resultant analysis was a completely randomized 2 by 5 factorial arrangement of treatments (2 cultivars, 5 treatments) for each orchard - year. In most cases, cultivar by treatment interactions were not significant, thus mean differences were determined for treatment alone using Fisher's Least Significant Difference test ($p \leq 0.05$). Additional contrasts were performed for testing differences in treatment rate only, treatment frequency only, and treated versus untreated trees. Differences attributed to cultivar alone were not considered relevant to the study and are not discussed.

Data on heat stress and leaf temperature were measured with a LI-6400 Portable Photosynthesis System (LI-COR Biosciences, Lincoln, NE). We generally tried to perform these measurements on very hot, windy, and dry days when the plants would likely be under severe stress. Five leaves per treated tree (plot) were measured in either Orchard 1 or Orchard 2 on nine occasions. Similar, average-appearing leaves at between 1 and 2 m height on the plant were measured. The following data were recorded: photosynthesis rate (μmol CO_2 m^{-2} s^{-1}), stomatal conductance (mmol H_2O m^{-2} s^{-1}), transpiration rate (μmol H_2O m^{-2} s^{-1}), air temperature (°C), and leaf temperature (°C). Each data set was analyzed separately. Plant physiological differences among treatments were determined by comparing least square means using Fisher's Least Significant Difference test ($p \leq 0.05$). Additional contrasts were performed to compare treated versus untreated trees.

Results and Discussion

Insect traps revealed low populations of codling moth and oriental fruit moth during both growing seasons; therefore we were unable to obtain reliable data on the efficacy of Surround WP against those two species. San Jose scale was present but not in economically-important numbers. Plum curculio was abundant both years with large numbers of adults trapped in mid-May and late July. Red-banded leafroller populations were also substantial both years with large peaks of adults trapped in mid-June followed by smaller peaks in late July (insect population data not shown). These latter two insect species were therefore the most thoroughly evaluated. Because we could not be 100% certain that all the various *Tortricidae* leafroller larvae that may have been present were indeed red-banded leafroller, we hereafter refer to this insect group as "leafroller complex". Cedar apple rust, *Phoma* leaf spot, flyspeck, and sooty blotch diseases were abundant both seasons.

Both cultivars in Orchard 1, 'Liberty' and 'Jonafree', produced fruit in both 2000 and 2001 while neither of the cultivars in Orchard 2, 'Ultragold' and 'Jonagold', produced fruit either year. Therefore, only leaf data are available from Orchard 2. Our results and statistical analyses show that Surround WP was able to significantly ($p \leq 0.05$) suppress a variety of insect and fungal pests while improving fruit grade. A portion of these data is presented in Tables 1 through 6.

Table 1. Mean percentage of apple fruits infested with plum curculio.

Cultivar	Control	28Bi[z]	28W	56Bi	56W
2000					
Jonafree	71 a[y]	37 b	31 b	6 c	16 bc
Liberty	65 a	20 b	20 b	21 b	15 b
2001					
Jonafree	46 a	46 a	6 b	13 b	4 b
Liberty	81 a	76 a	30 b	32 b	22 b

[z] 28Bi = 28 kg/ha Surround WP applied every two weeks
28W = 28 kg/ha Surround WP applied weekly
56Bi = 56 kg/ha Surround WP applied every two weeks
56W = 56 kg/ha Surround WP applied weekly
[y] Means followed by different letters within a row are significantly different according to Fisher's LSD test ($p \leq 0.05$)

Table 2. Mean percentage of apple leaves damaged by red-banded leafroller and/or leafroller complex, 2001.

Cultivar	Control	28Bi[z]	28W	56Bi	56W
Jonafree	36 a[y]	4 b	2 b	2 b	1 b
Liberty	32 a	5 b	2 b	2 b	1 b
Jonagold	22 a	4 b	1 b	1 b	1 b
Ultragold	24 a	3 b	2 b	3 b	1 b

[z] 28Bi = 28 kg/ha Surround WP applied every two weeks
28W = 28 kg/ha Surround WP applied weekly
56Bi = 56 kg/ha Surround WP applied every two weeks
56W = 56 kg/ha Surround WP applied weekly
[y] Means followed by different letters within a row are significantly different according to Fisher's LSD test ($p \leq 0.05$)

Plum curculio was significantly suppressed by Surround WP in both 'Liberty' and 'Jonafree' in 2000 and 2001 (Table 1). Most Surround WP treatments alone provided substantial protection from plum curculio compared with control, with the higher and more frequent applications generally performing best. Cultivar by treatment interactions were not significant. Linear contrasts detected a significant advantage of treatment rate over frequency in 2000 but this pattern was not consistent in 2001. Suppression of leafroller complex damage to fruit was not consistent (data not shown), while larval leaf feeding was reduced to 5% of leaves or less with all Surround WP treatments among all four cultivars evaluated (Table 2). No differences in leaf feeding damage were detected among any of the treated plots, but all had significantly less damage than untreated plots. A significant cultivar by treatment interaction was revealed in the statistical analysis for leafroller complex, with 'Jonafree' and 'Liberty' responding better to treatment than 'Jonagold' and 'Ultragold'. Suppression of San Jose scale was not consistent (data not shown), however this insect was not abundant and damage to fruits did not exceed an economically-important threshold.

Surround WP significantly suppressed both flyspeck and sooty blotch on 'Jonafree' fruit in 2000 and virtually controlled both diseases on 'Jonafree' in

Table 3. Mean percentage of apple fruits infected with flyspeck and sooty blotch.

Cultivar	Control	28Bi[z]	28W	56Bi	56W
		Flyspeck			
2000					
Jonafree	91 a[y]	51 b	45 b	55 b	28 b
Liberty	89 a	97 a	71 a	87 a	65 a
2001					
Jonafree	63 a	0 b	0 b	3 b	0 b
Liberty	29 a	19 a	15 a	7 a	4 a
		Sooty blotch			
2000					
Jonafree	88 a	58 bc	42 bc	62 b	38 c
Liberty	90 a	90 a	77 a	72 a	73 a
2001					
Jonafree	25 a	1 b	0 b	1 b	0 b
Liberty	33 a	3 b	13 ab	17 ab	2 b

[z] 28Bi = 28 kg/ha Surround WP applied every two weeks
28W = 28 kg/ha Surround WP applied weekly
56Bi = 56 kg/ha Surround WP applied every two weeks
56W = 56 kg/ha Surround WP applied weekly

[y] Means followed by different letters within a row (and within a disease) are significantly different according to Fisher's LSD test ($p \leq 0.05$)

2001 (Table 3). With 'Liberty', flyspeck was not significantly suppressed either year although a trend toward less disease with higher and more frequent treatments was indicated. Sooty blotch on 'Liberty' was not significantly affected by Surround WP treatments in 2000, but was largely suppressed in 2001, most notably by the highest and most frequent (56W) treatment. Although significant differences were detected between cultivars with these two diseases, specific cultivar by treatment interactions were not significant. Cedar apple rust was significantly higher in untreated trees compared with all treated trees for both 'Jonafree' and 'Jonagold' in 2000 (Table 4). No differences were measured, however, with 'Ultragold' in 2000. In 2001, no consistent or significant differences in rust infection were detected among any of the treatments for 'Jonafree' and 'Ultragold', whereas with 'Jonagold', the 56Bi treatment had more rust than control plots. 'Liberty' is resistant to cedar apple rust and was not evaluated. This inconsistency between years is difficult to explain, but was perhaps due to differences in weather conditions, cultivar susceptibility, and virulence of the pathogen from one year to the other. *Phoma* leaf spot was evaluated only in 2001. Control of this leaf disease was highly significant with all Surround WP treatments among all four cultivars except Jonagold 28Bi and 28W (Table 5).

Grade of apple fruits was generally improved by Surround WP treatments (Table 6). Not a single untreated apple was rated Grade 1 either year. Except for 'Liberty' in 2000, significant improvements in fruit grade were achieved with the higher and more frequent applications of Surround WP. For Grades 2 and 3 (data not shown), significant

Table 4. Mean percentage of apple leaves infected with cedar apple rust.

Cultivar	Control	28Bi[z]	28W	56Bi	56W
2000					
Jonafree	41 a[y]	11 b	6 b	2 b	5 b
Jonagold	5 a	2 b	3 b	2 b	3 b
Ultragold	3 a	3 a	4 a	2 a	3 a
2001					
Jonafree[x]	12 a	11 a	11 a	15 a	13 a
Jonagold	6 b	11 ab	7 b	17 a	7 b
Ultragold	16 a	13 a	11 a	8 a	12 a

[z] 28Bi = 28 kg/ha Surround WP applied every two weeks
28W = 28 kg/ha Surround WP applied weekly
56Bi = 56 kg/ha Surround WP applied every two weeks
56W = 56 kg/ha Surround WP applied weekly

[y] Means followed by different letters within a row are significantly different according to Fisher's LSD test ($p \leq 0.05$)

[x] Mean of three late-summer samplings; no differences among any treatments in any sampling ($p \leq 0.05$)

differences were measured between untreated apples and all of the Surround WP treatments, regardless of rate or frequency. Cultivar by treatment interactions were also important for determining Grade 1 fruits, with 'Jonafree' tending to respond more to Surround WP treatments than 'Liberty'. Fruit yield for 'Liberty' and 'Jonafree' was not affected by treatment either year (data not shown).

Several dry, very hot, and windy days occurred during the 2001 growing season, allowing us to test the efficacy of Surround WP in protecting the trees from stress. Leaf gas exchange measurements were obtained on nine occasions between July 20 and Aug. 21 using the LI-6400 Portable Photosynthesis System. The trees were well-irrigated, so would not have been under extreme water stress. However, mid to late summer temperatures and pan evaporation remained very high, creating a potentially stressful situation for the trees. Mean air temperatures recorded by the LI-6400 during each of the measurement periods (generally about 2.5 h at mid-day) ranged from 34.4 to 38.6°C. Because little

Table 5. Mean percentage of apple leaves infected with a *Phoma* leaf spot, 2001.

Cultivar	Control	28Bi[z]	28W	56Bi	56W
Jonafree	19 a[y]	3 b	1 b	2 b	0 b
Liberty	20 a	2 b	2 b	4 b	1 b
Ultragold	23 a	9 b	10 b	10 b	4 b
Jonagold	14 a	6 ab	10 ab	3 b	5 b

[z] 28Bi = 28 kg/ha Surround WP applied every two weeks
28W = 28 kg/ha Surround WP applied weekly
56Bi = 56 kg/ha Surround WP applied every two weeks
56W = 56 kg/ha Surround WP applied weekly
[y] Means followed by different letters within a row are significantly different according to Fisher's LSD test ($p \leq 0.05$)

Table 6. Mean percentage of Grade 1 apple fruits.

Cultivar	Control	28Bi[z]	28W	56Bi	56W
2000					
Jonafree	0 b[y]	3 b	5 b	4 b	19 a
Liberty	0 a	1 a	1 a	0 a	5 a
2001					
Jonafree	0 d	7 d	43 b	32 c	54 a
Liberty	0 b	0 b	13 a	20 a	21 a

[z] 28Bi = 28 kg/ha Surround WP applied every two weeks
28W = 28 kg/ha Surround WP applied weekly
56Bi = 56 kg/ha Surround WP applied every two weeks
56W = 56 kg/ha Surround WP applied weekly
[y] Means followed by different letters within a row are significantly different according to Fisher's LSD test ($p \leq 0.05$)

rain occurred during this sampling period to wash the particle-film coatings from the leaves, a good, uniform coating was present during all measurement periods regardless of when the last Surround WP application had been made.

Of the nine measurement periods, only July 20 and August 21 had significant differences in plant physiological factors (Table 7). These were the two hottest days as evaluated by both air and leaf temperatures. In general, stomatal conductance, transpiration, and photosynthesis were higher in the Surround WP-treated leaves compared with untreated leaves on these two very stressful days. The various Surround WP application rates and frequencies made little difference in plant stress response, perhaps a result of the lack of rain and consequent build-up of a good particle film coating on all leaf surfaces regardless of treatment. These plant physiological data concur with Glenn et al. (3) in that Surround WP coatings appear able to reduce heat stress in apples under extreme conditions.

During two seasons of testing with four cultivars, the Surround WP product was effective in suppressing a variety of important insect pests and fungal diseases in apples, while improving the overall quality or grade of fruit. The particle film coatings also reduced plant stress under extreme heat situations. As far as making specific application recommendations to orchardists, it seems evident that in most

Table 7. Mean apple plant physiological data recorded on the two most stressful sampling days, 2001.

Treatment	Photo[z]	Cond	Transp	Leaf temp
20 July (Jonafree and Liberty pooled)				
Control	8.6 b[y]	40.5 c	2.39 b	38.4 ab
28Bi[x]	11.6 ab	55.9 abc	3.30 ab	39.2 a
28W	11.2 ab	55.7 ac	3.24 ab	38.8 a
56Bi	15.3 a	76.5 a	3.91 a	36.5 b
56W	14.7 a	64.6 ab	3.68 a	39.0 a
21 Aug. (Jonagold and Ultragold pooled)				
Control	3.9 b	27.0 b	1.35 b	40.1 a
28Bi	6.4 a	53.0 a	2.41 a	39.2 ab
28W	5.1 ab	49.9 a	2.15 a	37.8 b
56Bi	5.2 ab	60.8 a	2.76 a	39.4 ab
56W	6.1 ab	57.0 a	2.64 a	39.2 ab

[z] Photo = photosynthesis rate (µmol CO_2 m^{-2} s^{-1})
Cond = stomatal conductance (mmol H_2O m^{-2} s^{-1})
Transp = transpiration rate (µmol H_2O m^{-2} s^{-1})
Leaf temp = leaf temperature (°C).

[y] Means followed by different letters within a column and within dates are significantly different according to Fisher's LSD test ($p \leq 0.05$)

[x] 28Bi = 28 kg/ha Surround WP applied every two weeks
28W = 28 kg/ha Surround WP applied weekly
56Bi = 56 kg/ha Surround WP applied every two weeks
56W = 56 kg/ha Surround WP applied weekly

cases and with most pests, the higher the rate and the more frequent the application of Surround WP, the more effective is pest control. Our highest and most frequent rates of 56 kg/ha sprayed weekly generally resulted in the most undamaged leaves and fruits in the orchards. Because a strong and persistent coating seems to be most successful, we would recommend orchardists maintain a heavy, consistent film on their trees and fruit at all times that a particular targeted pest is present.

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Crop Load Affects Seasonal Pattern of Vegetative Growth and Competition with Reproductive Sinks in Peach

For an entire growing season, the authors studied the leaf, wood, and stem growth of four-year-old peach trees carrying no crop, a commercial crop, or a heavy crop. Leaf, wood, and stem growth was suppressed on cropping trees compared to defruited trees. Leaf biomass growth was suppressed by the presence of fruit in Stages I and II, but not in Stage III. The presence of fruit suppressed growth of wood biomass in all stages of fruit growth. Total above ground biomass production was similar in all three treatments. From: Berman, M. E., and T.M. Dejong. 2003. J. Hort. Sci. Biotech 78:303-309.