The Effect of Synthetic Surfactants on Disease Severity of White Rust on Spinach

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ABSTRACT

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White rust, caused by *Albugo occidentalis*, is an economically important disease of spinach (*Spinacia oleracea*). Although cultural practices and partial host resistance are used for disease management, control strategies often rely on fungicides. An alternative approach, the use of ionic (cationic or anionic) and nonionic surfactants, was evaluated for its effect on white rust in greenhouse and field experiments. Surfactant treatments were compared with a water control and two commercial fungicides, azoxystrobin (Quadris) and 1,2,3-benzothiadiazole-7-carbothioic acid *S*-methyl ester (Actigard). Greenhouse plants were treated with a single surfactant application followed by inoculation with sporangia. Disease severity was rated on leaves 8 to 12 days after inoculation. Field tests were conducted in Arkansas and Texas and received three to five surfactant applications during the season. Disease severity was determined at the end of the growing season. In greenhouse and field tests, all surfactant treatments showed significant reductions in white rust severity compared with water controls. The surfactants Naiad and sodium dodecyl sulfate (SDS) were highly effective and comparable to fungicides in reducing white rust severity. In a laboratory assay, microscopic examination revealed that most of the surfactants at low concentrations caused rapid (<2 min) zoospore lysis.

Additional keywords: oomycete

White rust, caused by *Albugo occidentalis* G.W. Wils., is one of the most economically important diseases of spinach in the central and eastern United States (4). It is managed by the use of cultural practices, disease resistance, and fungicides. Brandenberger et al. (1) found that some commercial spinach lines had horizontal resistance. However, even with horizontal resistance, white rust can still cause significant yield losses under conditions favorable for disease development. Consequently, commercial disease management relies on fungicides for controlling white rust. In some cases, a combination of horizontal resistance and fungicides has proven to be effective (5).

A. occidentalis has a similar life and disease cycle to the more thoroughly studied *A. candida*, with zoospores as the infecting propagule. Zoospores, which lack a cell wall, encyst and then germinate to infect leaves. A novel approach for controlling zoosporic plant pathogens involves the use of synthetic or biologically produced surfactants. This approach was first discovered when a surfactant, an inert ingredient in a fungicide formulation, proved to be as effective as the fungicide (22–25). Syn-

thetic surfactants are used as adjuvants to decrease the surface tension of water and to increase the contact between the active ingredient and the plant surface. Surfactants are also produced by microorganisms, including fungi and bacteria, and are known as biosurfactants (9,14). The functions of biosurfactants are not fully understood and may vary from organism to organism. Several roles for biosurfactants have been proposed, including increasing biodegradation of slightly soluble organic carbon sources (11), aiding in attachment and detachment of bacteria to surfaces (14), serving as antibacterial defense mechanisms (14), serving as a virulence factor in the pathogenesis of specific microorganisms to both plants (3,8) and animals (13), aiding in the colonization of leaf surfaces (2), and facilitating metal uptake (7,11).

A number of studies have shown the effectiveness of surfactants as practical control agents for root-infecting zoosporic plant pathogens. Surfactants can control diseases caused by zoosporic oomycete pathogens, including *Pythium aphanidermatum* on cucumbers (20,21), *Phytophthora capsici* on peppers (16,18,21), *Plasmopara lactucae-radicis* on lettuce (15,17), and *Phytophthora parasitica* on citrus (10). Zoospore lysis has been proposed as the mechanism by which surfactants reduce infection by oomycetes (6,12,15,17,19). Surfactants are thought to intercalate into the plasma membrane and cause the zoospore to rupture (17).

The objective of the current research was to evaluate the effectiveness of several

commercial synthetic surfactants to control white rust on spinach, caused by *A. occidentalis*. Efficacy studies were conducted under greenhouse and field conditions. Laboratory experiments also were conducted to evaluate the direct effect of surfactants on zoospores.

MATERIALS AND METHODS

Various ionic (cationic and anionic) and nonionic synthetic surfactants were tested for their efficacy to control spinach white rust (Table 1). These included commercial products frequently used as pesticide adjuvants as spreaders and stickers. Three other surfactants, sodium dodecyl sulfate (SDS), Triton X-100, and Naiad, also were used. Naiad is used to treat hydrophobic soils in turf (Jim Karrick, Naiad Company, *personal communication*), and SDS and Triton X-100 are commonly used industrial surfactants. Concentrations of surfactants used were initially based on commercial recommendations. In some cases, concentrations were adjusted to reduce phytotoxicity on spinach observed in preliminary experiments.

Inoculum production. An isolate of *A. occidentalis* was originally recovered from diseased spinach leaves collected in Kibler, AR, in the fall of 1998. For each greenhouse experiment, fresh inoculum was produced on the white rust susceptible cv. St. Helens. The plants were grown in 25 × 50 cm plastic trays filled with Redi-Earth potting mix (Scotts-Sierra, Marysville, OH). Approximately 15 seeds were planted per row with 10 rows per flat. Plants were grown in a greenhouse with day and night temperatures of approximately 27°C and 21°C, respectively, and fertilized weekly with an all-purpose fertilizer (Peters, 20-20-20) at 10 g/liter. Plants were inoculated 2 to 3 weeks after planting and sporangia collected after 10 days by vigorously shaking leaves with sori in cold (4°C) water. The sporangial suspension was adjusted to 1 × 10⁶ sporangia per ml and used to inoculate spinach plants of cv. St. Helens. Inoculum was applied with an air compressor (GAST, model 0322-V4B-G18DX, Benton Harbor, MI) calibrated at 0.9 kg/cm² (5 psi). Plants were sprayed to runoff.

Greenhouse tests. Seed of St. Helens was sown in 10-cm-diameter plastic pots filled with Redi-Earth potting mix and grown as previously described. Plants were thinned to five plants per pot and grown for 2 to 3 weeks prior to treatment. Plants were inoculated at the two- to four-true-

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leaf stage within 30 min after application of surfactant treatments. After inoculation, plants were incubated in an upright dew chamber (Percival) maintained at 18°C and 100% relative humidity for 48 h. The plants were then transferred to a growth chamber (Conviron) maintained at 20°C with a 12-h light (77,500 lm/m²)/12 h dark cycle provided by cool-white fluorescent bulbs and incandescent bulbs. Plants were observed daily and scored for disease severity 8 to 12 days after inoculation.

Surfactant treatments. Prior to inoculation, plants were treated with one of the surfactants. Approximately 40 ml of each surfactant treatment was applied to 25 test plants in each treatment with an air compressor. Within 30 min of surfactant application, the plants were inoculated with a sporangial suspension of *A. occidentalis* (1 × 10⁶ sporangia per ml). A water treatment was used as a control. A commercial fungicide, azoxystrobin (Quadris, Syngenta,

Greensboro, NC; 0.25 ml/liter) also was included.

Disease ratings. Disease severity was rated on the basis of percent leaf area covered with white rust pustules between 8 and 12 days after inoculation. The first (oldest) two to four true leaves on each plant were rated. Disease was rated on a scale of 0 to 6 (Fig. 1), as previously described, in which 0 = no signs of infection; 1 = <10% of leaf area with pustules; 2 = 11 to 25%; 3 = 26 to 50%; 4 = 51 to 75%; 5 = 76 to 90%; 6 = >90%. Phytotoxicity was evaluated on a 0 to 3 scale in which 0 = no visible damage, 1 = ≤10% of leaf area with water-soaking or necrosis, 2 = >11 to 50% of leaf area with water-soaking or necrosis, and 3 = >50% of leaf area with water-soaking or necrosis.

Experimental design. Five pots (replications) with five plants per pot were used for each treatment. The disease rating for each treatment was an average of 10 to 20

leaves from each replication. Pots were inoculated and incubated in a completely randomized design. Greenhouse tests were conducted three times. White rust disease ratings among treatments were compared using an analysis of variance ($P = 0.05$). An LSD means separation test was performed following a significant F test with the statistical analysis program JMP (SAS Institute, Cary, NC).

Arkansas field tests. Surfactants were evaluated in three field experiments in Arkansas (Spring-1999, Fall-1999, and Spring-2000) at the Vegetable Substation, Kibler. The tests were planted on 17 February and 23 September 1999, and 18 January 2000 following commercial practices. Alternating beds of cvs. St. Helens (susceptible) and F380 (partial resistance) were used. Each bed (1.4 m wide × 60 m long) was planted with seven rows (approximately 0.23 m between rows) with approximately 35 plants per meter of row. Each plot was 4.5 or 6 m of bed depending on the test. For the Fall-1999 and Spring-2000 tests, a bed of the highly susceptible cv. Avon was planted between beds of St. Helens and F380 to serve as spreader plots.

Due to low disease pressure observed in the Spring-1999 test at Kibler, the Fall-1999 test was inoculated once with *A. occidentalis* using a SOLO hand pump backpack sprayer. Inoculum produced in the greenhouse (2.7 × 10⁵ sporangia per ml) was sprayed uniformly over the plots on 5 November. In the Spring-2000 test, only the spreader plots of Avon were inoculated once on 30 March. Field inoculations were performed in the evening (at 1800 h) to take advantage of dew formation and to promote infection.

Surfactant treatments. Seven surfactant treatments were used in addition to a water control and two fungicides, azoxystrobin (Quadris) and 1,2,3-benzothiadiazole-7-carbothioic acid *S*-methyl ester (Actigard), for the three field tests. The field plots received 3, 5, or 4 treatments for the Spring-1999, Fall-1999, and Spring-2000 tests, respectively. For the Spring-1999 test, treatments were applied on 14, 21, and 28 April. For the Fall-1999 test, treatments were applied on 13 and 27 October and 10, 19, and 24 November. For the Spring-2000 test, treatments were applied on 14, 20, and 28 March and 4 April. A total of 2 liters of water was used per replication (approximately 0.25 to 0.33 liters/m²). Applications were made using a backpack CO₂ sprayer.

Sampling and disease rating. For the Spring-1999, Fall-1999, and Spring-2000 tests, disease was rated on 28 April, 7 December, and 6 April, corresponding to 70, 75, and 78 days after planting, respectively. Thirty leaves were collected at random from each plot, avoiding leaves near the growing point that were not fully expanded and older senescing leaves. Only plants in the center five rows of each plot were

Table 1. List of materials tested for activity against the white rust pathogen, *Albugo occidentalis*

Trade name	Active ingredient(s)	% Active ingredient	Manufacturer
Nonionic			
Activate plus	Alkylaryl polyethylene glycols, free fatty acids and IPA	90	Terra
Agridex	Proprietary blend of heavy range paraffin base petroleum oils, Polyol fatty acids esters, Polyethoxylated derivatives	99	Helena
Dyne-Amic	Proprietary blend of polyalkylene oxide, polydimethylsiloxane, polyoxypropylene-polyoxyethylene	100	Helena
Kinetic	Proprietary blend of polyalkylene oxide, polydimethylsiloxane, polyoxypropylene-polyoxyethylene	99	Helena
Latron AG98	Alkylaryl polyoxyethylene glycols	80	Rohm and Hass
Latron CS7	Blend of alkylaryl polyethoxylate and sodium salt of alkylsulfonated alkylate	60	Rohm and Hass
Penetrator plus	Proprietary blend of light to midrange paraffin oil, Polyol fatty acid esters, Polyethoxylated esters, Ethoxylated alkyl aryl phosphate esters	97	Helena
Triton X-100	<i>t</i> -Octylphenoxypolyethoxyethanol	97	Sigma
Naiad	2-Hydroxyethyl ammonium alkyl benzene sulfonate, alkyl phenoxy poly (ethylene oxy) ethanol, DI (2-hydroxy ethyl) ammonium <i>cis</i> -9-octadecadonate octyl alkylamide	16	Naiad
Ionic			
10% SDS	Sodium dodecyl sulfate	95	Sigma
Fungicides			
Quadris	Azoxystrobin	23	Syngenta
Actigard	1,2,3-Benzothiadiazole-7-carbothioic acid <i>S</i> -methyl ester	50	Syngenta

Fig. 1. White rust field severity rating scale 0 to 6, where 0 = no signs on leaf area, 1 = <10% leaf area with signs, 2 = 10 to 25%, 3 = 25 to 50%, 4 = 50 to 75%, 5 = 75 to 90%, 6 = 90 to 100%.

sampled. All 30 leaves were scored for disease severity using the 0 to 6 scale described above. Disease incidence was determined based on the number of leaves with a rating ≥ 1 . Five or six whole plants also were sampled at random from within each plot. Fully expanded mature leaves (approximately six leaves per plant) were scored for disease severity and disease incidence. Phytotoxicity also was rated for both leaf and whole plant samples.

Texas field tests. Two over-winter field tests, Fall/Spring-1998 and Fall/Spring-1999, were conducted at the Del Monte Experiment Station in Crystal City, TX. These tests were planted on 31 October and 30 September, respectively, and were rated 97 and 135 days after planting, respectively. The highly susceptible cv. Cascade was used. Field plots were planted following commercial production practices with two rows of plants per 1.0-m-wide bed and a plant spacing of 35 plants per meter of row. Each treatment consisted of 3.5- or 12-m-long plots, for the Fall/Spring-1998 or Fall/Spring-1999 experiments, respectively. Each treatment was replicated four times.

Surfactant treatments. Nine or 10 different surfactant treatments, a water control, and one or two fungicides were used depending on the test. One of the surfactant treatments (Naiad) was used in combination with Ridomil (Metalaxyl, Syngenta) at 2.8 kg/ha, which was applied once, in-furrow, at planting. Plots received five or four surfactant applications for the Spring/Fall-1998 or Spring/Fall-1999, respectively. Surfactants were applied on 1, 9, 12, and 15 December and 8 January for Spring/Fall-1998. For the Spring/Fall-1999 test, surfactants were applied on 20 and 28 December and 12 and 19 January. A total of 8 liters was applied for all four replications of each treatment (approximately 0.2 to 0.5 liters/m²).

Field sampling and disease rating. Sampling at Crystal City for the

Fall/Spring-1998 and Fall/Spring-1999 plot was done on 4 February and 11 February, corresponding to 97 and 135 days after planting, respectively. For the Fall/Spring 1998 test, 10 plants were selected at random, and one lower (older) leaf and two upper (younger) leaves were scored for disease incidence and severity. For the Fall/Spring 1999 test, 30 leaves per plot were collected at random, avoiding older senescing leaves and leaves near the growing points that were not fully expanded. Ten whole-plant samples also were collected at random from plots during the Fall/Spring-1999 test. Fully expanded mature leaves (approximately six leaves per plant) were then scored for disease severity and disease incidence as previously described. Phytotoxicity also was rated for both leaf and plant samples.

Design for field experiments. The three tests at Kibler, AR, each consisted of a split-plot design with cultivar as the main plot and surfactant as a subplot. Each subplot was a bed 1.4 m wide by 4.5 to 6 m long depending on the test. At the Crystal City, TX, experiments, a randomized complete block design was used. Each bed was 0.3 m wide by 3.5 to 12 m long, depending on the test.

Statistical analyses for field experiments. White rust disease incidence and severity ratings were compared using analysis of variance followed by an LSD means separation test ($P = 0.05$) with the statistical analysis program SAS 7.0 (SAS Institute). For Kibler experiments, data collected for each cultivar were analyzed as two separate randomized complete block designs due to unequal variance between the two cultivars.

Zoospore lysis. A zoospore lysis test was conducted to determine the effect of surfactants on the zoospores of *A. occidentalis*. Leaves were collected from heavily diseased, greenhouse-grown spinach, held over empty petri dishes, and tapped to dislodge sporangia. Chilled (4°C) deion-

ized water (5 ml) was added to the petri dishes, which were incubated at room temperature for 30 min. The cold-water shock resulted in zoospore release after approximately 30 min. Motile zoospores were observed with a compound microscope at $\times 400$. For the surfactant treatments, 10 μ l of the zoospore suspension containing >100 zoospores was placed in a glass-cavity microscope slide for observation; surfactants then were added to the drop containing zoospores. The surfactants were used at 1:2, 1:10, and 1:20 dilutions of the concentrations used in the greenhouse and field experiments. Dilutions were made by adding 10, 1, or 0.5 μ l of each of the stock materials to the zoospore suspension. A stopwatch was used to record elapsed time for zoospores to lyse. Each treatment was replicated three times and the experiment was conducted twice.

RESULTS

Greenhouse tests. The mean disease severity for the control treatment was high (range 4.9 to 5.6) in all three tests. A single application of the eight surfactants caused a significant reduction in white rust severity in all three tests (Table 2). Across all three tests, SDS and Naiad consistently had the lowest mean disease severity among the surfactants. Quadris fungicide consistently gave the lowest mean disease rating (range 0.0 to 0.2) among the treatments; however, the mean disease severities for the SDS and Naiad treatments were not significantly different from Quadris in two of the three tests (Table 2). Some variability existed from test to test, and very minor phytotoxicity was observed with some of the surfactants.

Kibler field tests. Disease pressure varied considerably for the three field tests conducted in Arkansas. St. Helens consistently had higher disease severity than the partially resistant cv. F380 (Table 3). St. Helens, had disease incidence and severity of 56 to 96% and 1.2 to 3.2, respectively,

Table 2. Effect of surfactants on white rust (*Albugo occidentalis*) severity on spinach in greenhouse tests and their phytotoxicity

Treatment	Concentration ^a	Disease severity ^v tests			Phytotoxicity rating ^w tests		
		Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Control (H ₂ O)		4.9 a ^x	5.6 a	5.4 a	0	0	0
Latron AG98	2.0	3.4 b	...	...	0	...	...
Latron CS7	2.0	3.3 b	0.9 cd	2.0 c	0	0	0
Dyne-Amic	20.0	2.4 c	2.4 b	0.9 cd	0	1	0
Kinetic	2.0	1.9 c	1.5 c	1.0 cd	0	1	1
Agridex	20.0	1.0 d	0.5 de	3.4 b	0	0	0
Triton X-100	2.0	0.5 de	1.0 cd	3.1 b	0	0	0
10% SDS	20.0	0.2 e	1.2 c	0.6 d	0	0	0
Naiad	25.0	...	0.0 e	0.2 d	-	0	0
Quadris ^z	1.0	0.2 e	0.0 e	0.0 d	0	0	0

^a All concentrations are in ml of product per liter unless otherwise noted.

^v The first two to four true leaves from each experimental unit (replication) for each treatment were scored for white rust disease severity on a scale of 0 to 6, where 0 = no signs on leaf area, 1 = $<10\%$ leaf area with signs, 2 = 10 to 25%, 3 = 25 to 50%, 4 = 50 to 75%, 5 = 75 to 90%, 6 = 90 to 100%.

^w Phytotoxicity: 0 = no burn, 1 = $<10\%$ water-soaking or necrosis, 2 = 11 to 50%, 3 = $>50\%$.

^x Means followed by the same letter within a column are not significantly different ($P = 0.05$) using a protected LSD means separation test.

^y Not tested.

^z Fungicide control.

whereas F380 had 25 to 64% and 0.6 to 1.0, respectively (Table 3).

The water control numerically had the highest disease incidence and mean disease severity in both cultivars. In most cases, the surfactants and fungicides reduced white rust severity when compared with the water control (Table 3). In two (Spring-1999 and Spring-2000) of the three tests, surfactants caused a significant reduction in disease severity on St. Helens. Except for Triton X-100 in the Spring-1999 test, this reduction was evident on F380 as well. Under field conditions, several surfactant treatments were not significantly different from Quadris on both cultivars in at least one test. Naiad surfactant was not significantly different than Quadris fungicide in all three tests.

Disease incidence and severity based on whole-plant samples were similar to results from leaf samples (data not shown). The

water control typically had the highest disease incidence and severity, ranging from 74 to 82% and 1.9 to 3.0, respectively, on St. Helens. The majority of surfactants and fungicides reduced disease incidence and disease severity, and most surfactants performed similarly from one field test to the next.

Some of the surfactant treatments were phytotoxic (data not shown). Symptoms, including water-soaking and necrotic areas around leaf margins, were regularly observed on both cultivars. Agridex and Penetrator plus were moderately phytotoxic at the concentrations used. Mild phytotoxicity was observed for Dyne-Amic. Actigard caused some leaf tip curling and yellowing.

Texas field tests. Disease incidence and severity varied between the two tests on the susceptible spinach cv. Cascade. White rust pressure during the Spring/Fall-1998

experiment was much higher than that during Spring/Fall-1999 (Table 4). For water controls, disease incidence and mean disease severity for the Spring/Fall-1998 test were 94% and 2.4, respectively. For the Spring/Fall-1999, disease incidence and disease severity were 54% and 0.8, respectively.

Depending on the test, some surfactants and fungicides reduced white rust incidence and severity when compared with the water control. In the Spring/Fall-1998 test, only Actigard and Quadris significantly reduced both disease incidence and severity. Although disease pressure was low for the Spring/Fall-1999 test, all surfactants tested significantly reduced disease incidence and severity. For the Spring/Fall-1999 test, no surfactant treatment was significantly different than Quadris fungicide. Naiad and Naiad combined with metalaxyl applied at planting were the most effective treatments.

Sampling on a whole-plant basis was carried out only for the Spring/Fall-1999 test, and results were very similar to those observed for leaf samples (Table 4). The water control had the highest mean disease incidence and severity, and all surfactants reduced disease severity. None of the surfactants were significantly different from Quadris fungicide.

Zoospore lysis. Zoospores were released from sporangia 30 min after the cold water shock. Zoospores in the water control remained motile for >120 min before encysting and germinating. Most of the surfactant treatments caused rapid zoospore lysis (<300 s). Naiad, Latron CS7, Activate plus, Triton X-100, and 10% SDS caused rapid zoospore lysis at the 1:2, 1:10, and 1:20 dilutions (Table 5). The fungicide Quadris caused zoospores to stop swimming in less than 60 s at all concentrations, but zoospore lysis was not observed. Kinetic and Agridex surfactants and Actigard did not cause zoospore lysis after 300 s of observation. Dyne-Amic and Penetrator plus surfactants formed an emulsion in the zoospore suspension and zoospores could not be observed with the microscope.

DISCUSSION

All of the surfactants examined were effective in reducing white rust incidence and severity on spinach in both greenhouse and field experiments. These data are consistent with reports by Stanghellini and Miller (17) in which surfactants reduced diseases caused by several zoosporic plant pathogens. All surfactants and the azoxystrobin (Quadris) tested in the greenhouse significantly reduced white rust severity when compared with the water control. Most of the field experiments gave similar results to those results found in the greenhouse. Most of the surfactants and fungicides reduced disease incidence and severity in field tests.

Table 3. Effect of surfactants on white rust (*Albugo occidentalis*) severity of spinach leaves at Kibler Experiment Station, Kibler, AR

		Spinach cultivar				
Time	Treatments	Concentration ^w	St. Helens		F 380	
			Disease severity ^x	Disease incidence (%)	Disease severity	Disease incidence (%)
Spring-1999						
	Control (H ₂ O)		1.2 a ^y	56 a	0.7 a	53 a
	Kinetic	2.0	0.7 b	47 a	0.3 cd	26 b
	Triton X-100	2.0	0.7 b	42 a	0.7 ab	53 a
	Latron CS7	2.0	0.6 bc	49 a	0.4 bc	34 ab
	Agridex	20.0	0.2 ef	15 dc	0.3 cde	23 b
	10% SDS	20.0	0.6 bcd	44 a	0.4 de	9 c
	Dyne-Amic	20.0	0.3 cdef	21 c	0.1 de	7 c
	Actigard ^z	7.5 g/liter	0.4 bcde	40 ab	0.0 e	2 c
	Naiad	25.0	0.2 def	23 bc	0.0 e	1 c
	Quadris ^z	1.0	0.0 f	3 d	0.0 e	2 c
Fall-1999						
	Control (H ₂ O)		1.4 a	72 a	0.6 a	25 a
	Kinetic	2.0	1.0 ab	57 ab	0.3 abc	20 a
	Activate plus	12.5	1.1 ab	59 ab	0.3 abc	18 a
	Latron CS7	2.0	0.9 bc	51 bc	0.4 ab	30 a
	Agridex	20.0	0.2 d	17 d	0.1 bc	4 b
	10% SDS	20.0	1.1 ab	55 b	0.4 abc	20 a
	Dyne-Amic	20.0	0.9 bc	54 b	0.3 abc	17 a
	Actigard ^z	7.5 g/liter	0.6 c	36 c	0.0 c	3 b
	Naiad	25.0	0.9 bc	45 bc	0.5 a	24 a
	Quadris ^z	1.0	1.0 b	54 b	0.4 abc	18 a
Spring-2000						
	Control (H ₂ O)		3.2 a	96 a	1.0 a	64 a
	Kinetic	2.0	2.0 b	88 abc	0.6 b	52 a
	Latron CS7	2.0	1.9 bc	92 ab	0.6 b	47 ab
	Penetrator plus	2.0	1.6 bcd	85 bcd	0.2 cd	22 cd
	Agridex	20.0	1.5 cd	79 bcde	0.3 c	31 c
	10% SDS	20.0	1.4 d	74 cde	0.3 c	31 bc
	Dyne-Amic	20.0	1.2 d	70 de	0.1 cde	12 de
	Actigard ^z	7.5 g/liter	1.2 d	65 e	0.0 de	3 ef
	Naiad	25.0	0.1 e	12 f	0.0 e	1 f
	Quadris ^z	1.0	0.0 e	5 f	0.0 e	0 f

^w All concentrations are in ml of product per liter unless otherwise noted.

^x Thirty random leaf samples were collected from each of four replications and scored for disease severity on a scale of 0 to 6, where 0 = no signs on leaf area, 1 = <10% leaf area with signs, 2 = 10 to 25%, 3 = 25 to 50%, 4 = 50 to 75%, 5 = 75 to 90%, 6 = 90 to 100%. Disease incidence = percent leaves with rating ≥1.

^y Means followed by the same letter within a column for a given test are not significantly different ($P = 0.05$) using a protected LSD means separation test. Percentages for disease incidence were analyzed after arcsine transformation. Data for each cultivar were analyzed as two separate randomized complete block designs (RCBD) due to unequal variance.

^z Fungicides.

Several surfactants were comparable to the azoxystrobin (Quadris) fungicide in reducing disease incidence and severity. Naiad was as effective in most cases as Quadris. SDS proved to be very effective as well. Both surfactants showed little or no phytotoxicity at the concentrations used. Agridex, a surfactant containing a mixture

of paraffin-based petroleum based oil, was effective in reducing disease, but was phytotoxic.

A clear difference in susceptibility existed between the two cvs., St. Helens and F380, tested at Kibler, AR. Disease incidence and disease severity were much lower for the partially resistant cv. F380

for every field test, which is consistent with reports by Brandenberger et al. (1).

The surfactants examined had a direct effect on zoospore lysis, and these data are consistent with previous reports (6,16,17,18,20,21). The time required for zoospore lysis by the various surfactants was consistent with their performance under greenhouse and field conditions. Due to its unique mode of action, Quadris (an ATP/respiration inhibitor) caused zoospores to become immobile but did not cause them to lyse.

The efficacy of surfactants as an alternative method for disease management of zoosporic plant pathogens has been demonstrated (6,15–18,20–25). In this study, the use of commercially available surfactants to reduce white rust of spinach was demonstrated and may have potential as an effective tool in disease management as fungicides become increasingly more restricted. The use of surfactants combined with partial resistance or alternating with fungicides might lead to reduction in fungicide use on spinach. However, the use of surfactants for disease management should continue to be investigated taking into account the cost of the materials, the volumes needed to get adequate coverage, and frequency of application. With lower health risks than fungicides, surfactants could be a good alternative for disease management.

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Table 4. Effect of surfactants on white rust (*Albugo occidentalis*) severity on spinach at Del Monte experiment station Crystal City, TX

Time	Treatments	Concentration ^v	Leaves ^u		Plants ^u	
			Disease severity	Disease incidence (%)	Disease severity	Disease incidence (%)
Spring/Fall-1998						
	Control (H ₂ O)		2.4 ab ^w	93 ab	... ^x	...
	Kinetic	2.0	2.9 a	98 a	...	...
	Triton X-100	2.0	2.5 ab	89 abc	...	...
	Latron AG98	20.0	2.3 b	92 abc	...	...
	Latron CS7	2.0	2.3 b	88 bcd	...	...
	Agridex	20.0	2.5 ab	93 ab	...	...
	10% SDS	20.0	2.0 bc	87 bcd	...	...
	Dyne-Amic	20.0	2.5 ab	96 a	...	...
	Actigard ^y	7.5 g	1.7 c	82 cd	...	...
	Quadris ^y	1.0	1.5 c	80 d	...	...
Spring/Fall-1999						
	Control (H ₂ O)		0.8 a	54 a	1.0 a	68 a
	Activate plus	12.5	0.3 cd	25 cd	0.3 c	33 bc
	Latron CS7	2.0	0.5 b	46 ab	0.5 bc	45 bc
	Agridex	20.0	0.5 b	45 ab	0.7 b	52 ab
	10% SDS	20.0	0.4 bc	38 bc	0.5 bc	48 bc
	Dyne-Amic	20.0	0.5 bc	38 bc	0.5 bc	48 bc
	Naiad	25.0	0.3 cd	25 cd	0.5 bc	41 bc
	Quadris ^y	1.0	0.3 bcd	32 bcd	0.3 c	28 c
	Naiad plus	25.0/	0.2 cd	18 d	0.4 c	35 bc
	Ridomil ^{y,z}	2.8 kg/ha				

^u For the leaf sampling, 30 arbitrary leaf samples were collected from each of four replications and scored for disease severity on a scale of 0 to 6, where 0 = no signs on leaf area, 1 = <10% leaf area with signs, 2 = 10 to 25%, 3 = 25 to 50%, 4 = 50 to 75%, 5 = 75 to 90%, 6 = 90 to 100%. For the plant sampling, five plant samples were selected arbitrarily, and the first six true leaves were scored for disease severity using the same rating scale as mentioned above. Disease incidence = percentage of leaves with rating ≥1.

^v All concentrations are in ml of product per liter unless otherwise noted.

^w Means followed by the same letter within a column are not significantly different ($P = 0.05$) using a protected LSD means separation test. Percentages for disease incidence were analyzed after arcsine transformation.

^x Not tested.

^y Fungicides.

^z Ridomil was applied in furrow prior to planting.

Table 5. Time for zoospores of *Albugo occidentalis* to lyse after exposure to various surfactants

Treatments ^w	Time to lysis (s) ^v					
	Test 1			Test 2		
	1:2 ^x	1:10	1:20	1:2	1:10	1:20
Control (H ₂ O)	>120 min			>120 min		
Naiad	5	8	12	5	14	18
Latron CS7	10	19	43	8	27	68
Activate plus	12	18	50	7	37	80
Triton X-100	18	26	122	12	37	159
10% SDS	33	150	233	13	106	280
Quadris ^y	NL ^z			NL ^z		
Kinetic	>300			>300		
Actigard ^y	>300			>300		
Agridex	>300			>300		

^v Numbers are the mean of three replications for two tests.

^w Each surfactant was added to approximately 10 µl of water containing zoospores while being observed under a compound microscope at ×400.

^x Dilutions of concentrations used in greenhouse and field tests.

^y Fungicides.

^z NL = no lysis. Zoospores stopped swimming at 21, 24, and 28 s for test 1, and at 25, 30, and 40 s for test 2 for the three dilutions, respectively.

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