Activity of Plant Oils on Diseases Caused by *Podosphaera leucotricha*, *Venturia inaequalis*, and *Albugo occidentalis*

J. NORTHOVER and K. E. SCHNEIDER, Agriculture Canada, Research Station, Box 6000, Vineland Station, Ontario, Canada L0R 2E0

ABSTRACT

Northover, J., and Schneider, K. E. 1993. Activity of plant oils on diseases caused by *Podosphaera leucotricha, Venturia inaequalis*, and *Albugo occidentalis*. Plant Dis. 77:152-157.

The efficacies of several plant oils were assessed with potted seedlings of apple or spinach under controlled conditions, and two oils were orchard-tested. Sunflower, olive, canola, corn, soybean, and grapeseed oils were equally effective in providing over 99% control of *Podosphaera leucotricha* when applied to apple foliage 1 day before or 1 day after inoculation. Mechanically emulsified canola oil was comparable to dinocap and gave 99% control of *P. leucotricha* when applied 1, 2, 4, and 7 days after inoculation. The six oils showed only slight prophylactic activity against *Venturia inaequalis* under controlled conditions. A total of 10 applications of canola or soybean oil emulsified with Agral 90 and applied under orchard conditions reduced foliar and fruit infection by *V. inaequalis* by 66 and 81%, respectively. However, this level of control was not different from that of the Agral 90 surfactant alone and was inferior to that provided by captan. Peanut and safflower oils and the previous six oils were nonfungicidal to *Albugo occidentalis*. Refined glyceridic plant oils showed similar activities despite differences in their oleic and linoleic acid compositions.

Additional keywords: apple powdery mildew, apple scab, chlorothalonil, environmentally safe fungicide, organic fungicide, vegetable oil, white rust

The efficacy of oils for the control of fungal diseases of plants has been reviewed by Calpouzos (1,2). Mineral oils, of petroleum origin, have received the most attention because of their insecticidal and acaricidal activity (9) and their earlier use as low-volume carriers or adjuvants for copper fungicides (1,2). Mineral oil has been commercially and extensively used for the control of Sigatoka leafspot disease (caused by *Mycosphaerella musicola* J. L. Mulder in J. L. Mulder & Stover) of banana (1-3). A number of essential oils, so named because of their essence, flavor, or perfume, have microbiological activity (14). However, relatively few studies have been conducted with plant oils, obtained mostly from the seeds of field crops. Mineral oils are primarily paraffinic in composition, and essential oils have terpenoid, aldehydic, or esteric structures. In contrast, plant oils resemble animal and fish oils by being "fatty" acid esters of glycerol, or glyceridic oils. Glyceridic oils are usually trisubstituted, and most usually with long-chain C_{18} acids. If saturated acids such as palmitic ($C_{16:0}$) or stearic ($C_{18:0}$) predominate, the products are solids at 25 C and are termed fats (tallow, coconut butter). If monounsaturated oleic acid ($C_{18:1}$) or diunsaturated linoleic acid ($C_{18:2}$) predominate, the products are liquids at 25 C and are oils.

The early research on plant oils by Martin and Salmon (12,13) showed that several emulsified oils acted therapeutically by inactivating lesions of the powdery mildew (caused by *Sphaerotheca macularis* (Wallr.:Fr.) Lind) of hop. In contrast, surfactant-emulsified neem oil was more effective as a prophylactic treatment, giving excellent protection of bean plants against bean rust (*Uromyces appendiculatus* (Pers.:Pers.) Unger) (10). Clayton et al (4) used multiple-spray programs to protect tobacco seedlings from blue mold (caused by *Peronospora tabacina* D. B. Adam) and found that plant oils with high proportions of linoleic acid ($C_{18:2}$) or other polyunsaturated acids were fungicidal, whereas oils with high proportions of the monounsaturated oleic acid ($C_{18:1}$) were nonfungicidal.

The prospect of using plant oils as fungicides is very appealing, because refined oils are now readily available and safe for human consumption and are used in baked goods, salad dressings, and deep-frying. Their use as natural alter-

Accepted for publication 12 October 1992.

natives to synthetic fungicides would be especially attractive to home gardeners and producers of organically grown produce.

The present work was undertaken to examine the activity of several glyceridic plant oils against three foliar diseases, namely, apple powdery mildew (caused by *Podosphaera leucotricha* (Ellis & Everh.) E. S. Salmon), apple scab (caused by *Venturia inaequalis* (Cooke) G. Wint.), and spinach white rust (caused by *Albugo occidentalis* G. W. Wils.). Furthermore, we wished to test the hypothesis, advanced by Clayton et al (4), that plant oils high in linoleic acid are more fungicidal than those low in linoleic acid. The prophylactic and therapeutic activities of several oils against apple powdery mildew were compared. Preliminary reports of this research and related studies to control brown rot (caused by *Monilinia fructicola* (G. Wint.) Honey) of peach and powdery mildew (caused by *Sphaerotheca fuliginea* (Schlechtend.:Fr.) Pollacci) of greenhouse cucumber have been published (16,17,19).

MATERIALS AND METHODS

Apple powdery mildew experiments. Three experiments were conducted with potted apple seedlings in their first and/or second growth cycles. Seeds were obtained from open-pollinated apples, *Malus domestica* Borkh. 'McIntosh,' stratified in steam-pasteurized potting mix at 1 C for 6–8 wk. Individual seedlings were transplanted and raised in potting mix in clay pots, 13.6 cm in diameter, in a greenhouse at 20–25 C with 16-hr photoperiods, until the plants were 25–50 cm high and suitable for use in the three reported experiments.

In experiment 1, we examined the therapeutic efficacy of four surfactants, used both alone and combined with canola oil, applied to greenhouse-grown plants naturally infected by powdery mildew. A total of 50 moderately infected plants, each with 25 leaves counted basipetally from the youngest unfolded leaf, were assigned as five replicates to each of 10 treatments. The latter consisted of a reverse osmosis (RO) water check and RO water solutions of four surfactants (0.25 g per 0.99975 L of water): Agral 90 (90% nonylphenoxy polyethoxy ethanol), Tween 20, Triton B 1956 (phthalic glycerol alkyl resin, modified), and Triton XR (70% octylphenoxypolyethoxy-9-ethanol). Four additional treatments consisted of each surfactant (0.25 g) mixed as a solution with 9.75 g of canola oil and emulsified with slight agitation in 0.990 L of RO water. A check of canola oil in water was mechanically emulsified for 1 min at an intermediate setting of a homogenizer (Brinkmann Instruments, Rexdale, ON, Canada). The emulsions were applied to plants to the point of droplet coalescence, with a compressed-air paint spray gun operated at 300 kPa. The treated plants were randomly arranged on a greenhouse bench and incubated at 20–25 C with 16-hr photoperiods. Powdery mildew severity on each leaf was assessed 1 day before and 7 days after treatment, using a scale as described below (see Disease assessment).

In experiment 2, the prophylactic and therapeutic activities of three low-linoleic acid oils (sunflower, olive, and canola) and three high-linoleic acid oils (corn, soybean, and grapeseed) were contrasted with that of dinocap against a water check. All the oils used in this study were samples of products used commercially in salad dressings, deep-frying, and many other food preparation processes. They were refined, bleached, and decolorized, with a clear appearance and bland flavor. They were supplied under nitrogen with a maximum peroxide value of 0.5–1.0 meq/kg and maximum free acid (as oleic equivalent) of 0.05–0.5%. The linoleic acid and oleic acid compositions of these oils and the ratios of these compositions are given in Table 1. The oils were mechanically emulsified as previously described, and dinocap (0.09 g a.i./L) was suspended with slight agitation.

The prophylactic treatments were sprayed on half of the plants 1 day before inoculation, and the remaining plants were sprayed therapeutically 1 day after inoculation. Five plants (replicates) were used per treatment, in a completely randomized design, and the three youngest unfolded leaves were treated and inoculated. The inoculum was prepared from heavily mildewed apple seedlings housed separately from those grown disease-free for experimentation. A sterile solution of Tween 20 (0.5 g/L) was used to wash spores from infected leaves and to minimize spore aggregation. The suspension was coarse-filtered, measured with a hemacytometer, adjusted to 2×10^5 conidia per milliliter, and applied with a glass compressed-air atomizer to the upper leaf surfaces. Inoculated plants were kept damp in a dark mist room at 22 C for 20 hr and then incubated in a growth room at 25 C and 80% relative humidity (RH), with a 16-hr photoperiod of fluorescent light of 300 $\mu E \cdot s^{-1} \cdot m^{-2}$, measured at 400–700 nm with a LI-190SB quantum sensor (Li-Cor, Lincoln, NE). The terminal three leaves were individually evaluated 13 days after inoculation for the percentage of leaf area covered with powdery mildew, using the scale described below (see Disease assessment). This experiment was conducted twice.

In experiment 3, the therapeutic activity of canola oil applied 1, 2, 4, and 7 days after inoculation was more fully examined. Dinocap and a water check served as comparative treatments. The terminal three unfolded leaves were marked at the time of inoculation (day 0) on each of the five replicate plants per treatment. The plants were inoculated and incubated as in experiment 2, and the appropriately marked plants were removed briefly for treatment. Canola oil (10 g per 0.990 L of RO water) was mechanically emulsified, and dinocap (0.091 g/L) was suspended and applied as above. The terminal three marked leaves were evaluated for the severity of powdery mildew 13 days after each of the therapeutic treatments.

Apple scab growth room experiment. Apple plants of the cultivar Summerland McIntosh on MM.106 rootstock were grown in potting mix in clay pots, 19 cm diameter, in a growth room at 20 C and 60% RH, with a 16-hr photoperiod. The prophylactic activities of three low-linoleic acid oils (sunflower, olive, and canola) and three high-linoleic acid oils (soybean, corn, and grapeseed) against *V. inaequalis* were compared against a water check. Half of the plants were treated with emulsions of homogenized oil in water; for the remaining half, Agral 90 (0.25 g) was mixed separately with 9.75 g of each oil, and the resulting solution was added with moderate agitation to 0.990 L of RO water, forming an emulsion. A check solution

Table 1. Principal fatty acid components of eight refined plant oils evaluated for their activity against fungal diseases

Category / Plant oil	Fatty acid composition (%)[x]		Ratio[y] (L:O)
	Oleic acid	Linoleic acid	
Low linoleic acid			
Sunflower[z]	80	10	0.13
Olive	70	16	0.23
Canola	58	26	0.45
Peanut	48	34	0.71
High linoleic acid			
Soybean	24	54	2.25
Corn	25	61	2.44
Grapeseed	16	73	4.56
Safflower	13	78	6.00

[x] Data provided by Daminco Inc., Mississauga, Ontario, Canada.
[y] The ratio of linoleic (L) to oleic (O) acid composition.
[z] Trisun 80 oil, from selected sunflower lines yielding oil especially high in oleic acid and correspondingly low in linoleic acid.

of Agral 90 contained 0.25 g of Agral 90 per 0.99975 L of RO water. The treatments were applied with a paint sprayer. The terminal four leaves on each of five replicate plants were treated, and 1 day later they were inoculated with a suspension of 5×10^4 conidia per milliliter prepared from heavily sporulating, dried, and frozen apple leaves. The inoculated plants remained wet in a mist room at 20 C for 22 hr before being returned to a 20 C growth room with 60% RH and a 16-hr photoperiod from fluorescent lights (300 $\mu E \cdot s^{-1} \cdot m^{-2}$). The area of each treated leaf occupied by apple scab lesions was assessed after 14 days of incubation.

Disease assessment. The severity of powdery mildew and scab on apple leaves was assessed with diagrams illustrating a gradation of percentage of area diseased, on a scale modified from Horsfall and Barratt (7). The categories 0–11 corresponded to ranges of percent area diseased: 0, 0.1–0.4, 0.4–0.8, 0.8–1.6, 1.6–3.1, 3.1–6.2, 6.2–12.5, 12.5–25, 25–50, 50–75, 75–87.5, and 87.5–93.8. The limits of each category were transformed by arcsine $\sqrt{\%}$ and averaged to give an angular mean for each category as described by Northover (16). The categories of disease for each of the four leaves evaluated on each plant were expressed as angular means and averaged to give an angular mean per replicate plant.

Apple scab field experiment. In 1990, a field trial was conducted to determine the efficacy of multiple applications of surfactant-emulsified canola and soybean oils, representative of low- and high-linoleic acid oils, respectively. The 16-yr-old apple orchard consisted of three rows, each with 20 trees spaced 2.4 × 4.8 m, divided into four equal blocks of 15 trees of the varieties McIntosh, Empire, Red Delicious, and Golden Delicious, on M.26 rootstock. The design was a randomized complete block, with a plot consisting of three trees of the same cultivar; cultivar was confounded with block.

Five treatments were compared: canola oil + Agral 90 (975 g + 25 g/100 L), soybean oil + Agral 90 (975 + 25 g/100 L), Agral 90 (25 g/100 L), captan (100 g a.i./100 L), and a water check. Treatments were applied hydraulically to initial runoff, using a solid cone nozzle at a pressure of 1,400 kPa. Plots consisted of three adjacent trees, and interplot drift was minimized with a large plastic sheet. A total of 10 applications were made, on the following dates in 1990: 2 (pink stage), 8, 15 (35% petal fall), 22, and 28 May; 5, 11, and 21 June; and 3 and 13 July. Infection was initiated by a low dose of ascospores supplemented on 4 May by an application of 4 L of conidial suspension (1×10^6 conidia per milliliter) misted lightly throughout the whole orchard during a wetting period. The incidence of apple scab infection was evaluated on 150 clusters per replicate plot (13 June), on 150 apples per plot (19 July), and on 15 leaves on each of 20 terminal shoots per plot (23 July). The harvested apples were also examined for the incidence of insect injury. Russetting of Golden Delicious apples and leaf spotting of Red Delicious leaves were evaluated with three lots of 50 apples per treatment (30 July) and three lots of 140 leaves per treatment (24 July), respectively.

Spinach white rust. Six to eight seeds of spinach, *Spinacia oleracea* L. 'Longstanding Bloomsdale,' were sown 1 cm deep in greenhouse potting mix in clay pots, 13.6 cm in diameter, and raised in a heated greenhouse at 20 C during November and December. Supplemental halogen lighting was used to extend the daily photoperiod to 16 hr. At the second true leaf stage, the seedlings were thinned to four per pot, and at the fifth true leaf stage (41 days after seeding) the cotyledons were removed, and a small notch cut into the second true leaf. A total of 50 pots with plants at the fifth leaf stage were randomly assigned to 10 treatments, each with five replicates. The 10 treatments consisted of four low-linoleic oils (sunflower, olive, canola, and peanut), four high-linoleic oils (soybean, corn, grapeseed, and safflower), a water check, and chlorothalonil as a reference fungicide treatment (6). The oils were prepared as mechanical emulsions (10 g of oil per 0.990 L of RO water), and chlorothalonil (1.0 g a.i./L) as a suspension.

The oil and fungicide treatments were applied thoroughly to both leaf surfaces, and the plants were held overnight at 20 C. The following day, abaxial leaf surfaces were inoculated with a freshly prepared, cooled suspension of 4×10^5 sporangia per milliliter of *A. occidentalis*, using a glass compressed-air chromatographic atomizer, and the plants remained wet in a dark mist room (20 C) for 22 hr. The inoculum originated in a local spinach planting and had been maintained in the greenhouse by the serial inoculation of young plants.

Symptom development was optimal 12 days after inoculation. The abaxial surface area of second to fifth individual true leaves, outlined by sori, was estimated to the nearest 5 or 10%. For each replicate (pot), the percentage of diseased area values for the four leaves on each of the four plants were transformed by arcsine $\sqrt{\%}$ and averaged.

Statistical analysis. All statistical analyses were performed on arcsine $\sqrt{\%}$ transformed data by the general linear models procedure of SAS (19). Treatment differences were determined by either Fisher's protected LSD at the 5% level of probability for paired treatment comparisons or single degree of freedom contrasts for specific grouped-treatment comparisons. For experiment 1, an analysis of covariance was used to adjust for the initial severity of powdery mildew infection. Treatment differences were examined by least squares means.

RESULTS

Apple powdery mildew. The naturally inoculated seedlings used in experiment 1 had a mean of 7% adaxial foliar surface infection 1 day before treatment. At 7 days after treatment, mildew severity had increased to 30% in the water check. Agral 90 was the only surfactant that was therapeutic relative to the water check (Table 2). Mechanically emulsified canola oil reduced powdery mildew to 3.4%, and each of the four surfactant–canola oil treatments was significantly ($P = 0.0001$) more effective than the corresponding surfactant-only treatment. Canola oil emulsified with Agral 90 and with Triton XR were the most effective combination treatments, reducing powdery mildew infection to 0.1%.

In experiment 2, groups of low- and high-linoleic acid oils showed similarly high prophylactic and therapeutic activity comparable to that of dinocap, when used 1 day before or 1 day after inoculation of apple leaves with powdery

Table 2. Efficacy of a therapeutic application of surfactants alone and combined with canola oil against apple powdery mildew (caused by *Podosphaera leucotricha*)

	Leaf area infected (%)[y]	
Surfactant[x]	Surfactant alone	Surfactant or water and canola oil
Agral 90	16 a[z]	0.1 a[z]
Tween 20	22 ab	2.0 ab
Triton XR	27 b	0.1 a
Triton B 1956	32 b	2.0 ab
Water check	30 b	3.4 b

[x] Concentrations of surfactants and oil were 0.25 g/0.99975 L and 9.75 g/0.990 L, respectively.
[y] At 7 days after treatment.
[z] Means were transformed by arcsine $\sqrt{\%}$ and subjected to covariance analysis to allow for nonuniform initial infection. Means were obtained by averaging over 25 leaves for each of five plants per treatment and were detransformed to the tabulated percentage values. Means in the same column followed by different letters are significantly different ($P = 0.05$) in comparisons of least squares means. All canola oil combination treatments were significantly different ($P = 0.0001$) from the corresponding treatment of surfactant or water alone.

mildew (Table 3). The experiment was repeated, with very similar results.

In experiment 3, significant effects were shown for chemicals, postinoculation treatment intervals, and the chemicals × intervals interaction; therefore, the individual intervals were separately analyzed. Mechanically emulsified canola oil and dinocap gave comparably high levels of control when applied 1, 2, or 4 days after inoculation and evaluated 13 days after treatment (Table 4). When these treatments were applied to young sporulating lesions occupying 3.5% of the leaf surface, 7 days after inoculation, canola oil and dinocap gave excellent deactivation for at least 13 days after treatment.

Apple scab growth room experiment. In preliminary experiments, plant oils emulsified with surfactants showed moderate prophylactic activity but no therapeutic activity (17). In this experiment, we examined only the prophylactic action of low- and high-linoleic acid oils emulsified either mechanically or with Agral 90. There was no significant ($P = 0.07$) paired treatment effect. The group of six mechanically emulsified oils significantly reduced the severity of apple scab relative to that of the water check (4.9 versus 11.6%, respectively), but there was no group difference between the low- and high-linoleic acid oils (Table 5). Agral 90 did not reduce scab infection relative to the water check, nor was there a difference between the Agral check and the oil + Agral treatments as a group. The use of Agral 90 had no effect on oil activity, and there was no difference between the two groups of oils when emulsified with Agral 90.

Apple scab field experiment. Despite 10 applications at 6- to 10-day intervals between 2 May and 13 July, the Agral 90–emulsified oils provided only moderate control of scab infection (Table 6). The Agral 90–emulsified canola and soybean oils were not better than Agral 90, which alone significantly reduced terminal leaf infection from 50 to 13% and fruit infection from 64 to 16%. Captan used at the recommended commercial rate gave significantly ($P = 0.05$) better control than the oils and Agral 90 alone, reducing terminal leaf and fruit infection to 1 and 2%, respectively.

The emulsified-oil treatments were appreciably phytotoxic, causing more than 5% of surface russeting on 70–73% of Golden Delicious apples and nondefoliating leaf spotting on 50–75% of terminal shoot leaves of Red Delicious (Table 6). Severe black scaling of apples on the occasional outer branches of the varieties McIntosh and Empire was attributed to incompatibility between captan and both canola and soybean oils, caused by slight and infrequent marginal spray drift between adjacent plots.

The experiment was conducted in an ecological orchard that had been maintained insecticide-free for several years. The principal pests were codling moth (*Cydia pomonella* L.), plum curculio (*Conotrachelus nenuphar* Herbst), and various spring-feeding caterpillars, which seriously affected 28, 39, and 12% of the apples, respectively. Relative to the water check, the oils, Agral 90, and captan did not alter the incidence of apple infestation and injury by these pests. Populations of the European red mite (*Panonychus ulmi* Koch) were generally low, and treatment effects were not examined.

Spinach white rust. In the water check treatment, 50% of the abaxial leaf surface was covered by sori of *A. occidentalis*. Leaves treated with eight plant oils prior to inoculation showed 30–52% surface infection. None of the oils, either individually or as groups of oils, either low or high in linoleic acid, significantly reduced disease severity. This confirmed the results of a preliminary experiment. In contrast, chlorothalonil reduced leaf surface infection to less than 0.5% and exhibited significant ($P = 0.0001$) prophylactic activity.

DISCUSSION

In the present study, six plant oils were very efficacious against apple powdery

Table 3. Effect of pre- or postinoculation treatment of apple seedlings with plant oils low (LLA) and high (HLA) in linoleic acid upon percentage of leaf area infected by *Podosphaera leucotricha*

	Leaf area infected (%)	
	Time of treatment	
Chemical treatment	One day preinoculation	One day postinoculation
LLA oils		
Sunflower	0.02[z]	0.16
Olive	0.01	0.03
Canola	0.02	0.04
HLA oils		
Corn	0.01	0.01
Soybean	0.00	0.10
Grapeseed	0.02	0.11
Dinocap	0.00	0.01
Water check	7.89	12.45
	Probability	
Contrasts	Preinoculation	Postinoculation
LLA oil vs. water check	0.0001	0.0001
HLA oils vs. water check	0.0001	0.0001
LLA oils vs. HLA oils	0.9351	0.9754
LLA oils vs. dinocap	0.6114	0.3204
HLA oils vs. dinocap	0.6522	0.3309

[z] Data were transformed by arcsine $\sqrt{\%}$; means were obtained by averaging over three leaves for each of the five plants per treatment and detransformed to the tabulated percentage values.

Table 4. Effect of postinoculation treatments with canola oil and dinocap on the percentage of leaf area bearing *Podosphaera leucotricha* lesions

	Leaf area with lesions (%)[y]		
	Treatment		
Postinoculation treatment interval (days)	Canola oil	Dinocap	Water check
1	0.04 a[z]	0.12 a	13.89 b
2	0.08 a	0.00 a	20.01 b
4	0.04 a	0.02 a	43.16 b
7	0.61 a	0.67 a	52.18 b

[y] Data were transformed by arsine $\sqrt{\%}$; means were obtained by averaging over three leaves for each of the five plants per treatment and detransformed to the tabulated percentage values.

[z] Means in the same row followed by the same letter are not different ($P = 0.05$), using transformed values.

Table 5. Effect of the prophylactic application of low- (LLA) and high-linoleic acid (HLA) plant oils, emulsified either mechanically or with the surfactant Agral 90, on the percentage of area of McIntosh apple leaves infected by *Venturia inaequalis*

	Leaf area infected (%)	
	Oil emulsification	
Treatment	Mechanical	Agral 90
LLA oils		
Sunflower	4.9[z]	4.3
Olive	5.5	4.8
Canola	5.4	2.0
HLA oils		
Soybean	5.3	6.9
Corn	4.5	4.7
Grapeseed	4.0	6.0
Check (water/Agral solution)	11.6	8.0

Table of contrasts, probability (*P*)
Water check vs. oils alone, $P = 0.0019$
HLA oils vs. LLA oils, $P = 0.5970$
Agral check vs. oils + Agral, $P = 0.0746$
Oils alone vs. oils + Agral, $P = 0.7522$
HLA oils + Agral vs. LLA oils + Agral, $P = 0.0692$

[z] Data were transformed by arsine $\sqrt{\%}$; means were obtained by averaging over four leaves from each of the five plants per treatment, then detransformed to the tabulated percentage values.

mildew when used either prophylactically or therapeutically. Similarly, Martin and Salmon described the therapeutic (postlesion) activity of 12 plant oils, including corn, olive, and soybean oils, against hop powdery mildew (12,13). Previously, we showed that canola oil emulsified with Agral 90 surfactant was better than Agral 90 alone in the control of powdery mildew of greenhouse cucumbers (20). However, plant oils were only slightly effective against apple scab infection under growth room conditions and were ineffective against spinach white rust, peach brown rot (18), and plum black knot (caused by *Apiosporina morbosa* (Schwein.:Fr.) Arx) (J. Northover, *unpublished*).

There was no difference in fungicidal activity between the two groups of oils with compositions either high or low in linoleic acid toward the three foliar pathogens we examined. Our results therefore contrast with those of Clayton et al, (4) who showed that oils from cottonseed, corn, linseed, peanut, soybean, and tung were fungicidal to *P. tabacina*, and that oils from castor bean, coconut, olive and palm were nonfungicidal. They concluded that linoleic acid "occurs in large amounts in most of the fungicidal oils, but not to any extent in the nonfungicidal oils." They further concluded that there were "strong indications that linolenic acid (in linseed oil) and eleostearic acid (in tung oil) are associated with positive fungicidal activity." Corroborating evidence was recently obtained by Cohen et al, (5) using water sonicates of free unsaturated fatty acids instead of oils. Against *Phytophthora infestans* (Mont.) de Bary they found that linoleic and linolenic acids were fungicidal, whereas oleic acid was nonfungicidal. Martin and Salmon (13) concluded that the fungitoxicity of oils was associated with the glyceridic structure and was not affected by impurities such as free acid.

From a taxonomic perspective, the fungitoxicity of unsaturated acids toward *P. infestans* is consistent with the activity of linoleic acid oils to *P. tabacina*, since both pathogens are phycomycetes. *A. occidentalis* was used in our work because it is also in the Peronosporaceae, but it was controlled by neither the high- nor the low-linoleic acid oils. Against ascomycetes, glyceridic oils were effective against several powdery mildews of different genera (10,12,13,20), but they were only slightly effective against *V. inaequalis* and were ineffective against *M. fructicola* (18) and *A. morbosa* (Northover, *unpublished*). Surfactant-emulsified neem seed oil was shown by Locke (10) to be very effective against *U. appendiculatus* (cause of bean rust), a basidiomycete. However, Skellon et al (21) showed that neem oil was high in saturated acids (34%) and low in linoleic acid (10%). Therefore, there is no clear relationship between the composition of glyceridic oils and their fungicidal activity.

Paraffinic oils were fungicidal to *M. musicola* (1,3) and *Sphaerotheca pannosa* (Wallr.:Fr.) Lév. var. *rosae* Woronichin) (cause of rose powdery mildew) (8,15), both of which are ascomycetes, but paraffinic oils were ineffective against *P. tabacina* (4). They reduced photosynthesis in banana leaves, and Calpouzos (2) suggested that this might have suppressed the pathogenesis of *M. musicola*. Paraffinic oils were more effective than soybean oil against *Septoria apiicola* Speg. on celery by reducing sporulation and the severity of secondary infections (22). The efficacy of certain oils against particular pathogenic fungi may be related more to induced physiological changes in the host–pathogen interaction than to differences in the chemical composition of the oils.

In this study, the surfactant Agral 90 was fungicidal to apple powdery mildew. Additionally, Agral 90 gave appreciable control of apple scab under field conditions without causing as much phytotoxicity as the oil–Agral 90 emulsions. Surfactants used alone increased the susceptibility of grape berries to infection by *Botrytis cinerea* Pers.:Fr. (11). These divergent actions of surfactants illustrate the importance of defining the fungicidal activity of the surfactants used as emulsifiers of oils, so that the individual activities of oils and surfactants are not confounded any more than necessary.

Our findings contribute to a relatively small body of data on the fungicidal activity of plant oils. Plant oils are effective against powdery mildew diseases, without much specificity attributable to chemical structure. Paraffinic oil is effective against superficial powdery mildew lesions. However, the activity toward the deep-seated fungal infections is much more variable, and oils differ in their activity against even closely related genera. It appears probable that glyceridic and paraffinic oils, though chemically distinct, could act similarly by altering the physiology of the pathogen–host relationship. However, no guiding principle can be offered as to which diseases might be amenable to control with plant oils. In view of the intense interest in novel means of disease control, further study of the efficacy of both glyceridic and paraffinic oils appears warranted.

Table 6. Effect of multispray programs of canola oil and soybean oil emulsified with Agral 90 on the incidence of *Venturia inaequalis* lesions on fruit clusters, terminal leaves, and apples and on the incidence of fruit russeting on Golden Delicious fruits and leaf spotting on Red Delicious terminal leaves

Treatment	Infected by *V. inaequalis* (%)			Golden Delicious apples russeted (%)	Red Delicious leaves spotted (%)
	Clusters	Leaves	Apples		
Canola oil + Agral 90	40 b[y]	14 b	9 b	73 (64–78)[z]	75 (36–100)
Soybean oil + Agral 90	54 b	20 b	15 b	70 (52–82)	50 (29–64)
Agral 90	36 b	13 b	16 b	25 (24–26)	7 (0–36)
Captan	2 a	1 a	2 a	1 (0–4)	19 (0–36)
Water check	93 c	50 c	64 c	13 (0–38)	4 (0–14)

[y] Percentage data were transformed by arcsine $\sqrt{\%}$ prior to analysis. The means were averaged over three replicates each of 50 clusters, 300 leaves and 50 apples, respectively, and were detransformed to the tabulated value. Means in the same column followed by a different letter differ significantly ($P = 0.05$) using Fisher's protected LSD.

[z] Tabulated values are the arithmetic means, with the ranges given in parentheses, of three subsamples of 50 Golden Delicious apples and a total of 10 shoots, each with 14 leaves, collected from three Red Delicious trees.

ACKNOWLEDGMENTS

We take pleasure in thanking Celia Smeenk and Margaret McKay for their technical assistance, Gordon Franklin (Daminco Inc.) for samples of refined oils, and the Ontario Pesticides Advisory Committee of the Ontario Ministry of the Environment for partial funding of this project.

LITERATURE CITED

1. Calpouzos, L. 1966. Action of oil in the control of plant disease. Annu. Rev. Phytopathol. 4:369-390.
2. Calpouzos, L. 1969. Oils. Pages 367-393 in: Fungicides: An Advanced Treatise. Vol. 2, Chemistry and Physiology. D. C. Torgeson, ed. Academic Press, New York. 742 pp.
3. Calpouzos, L., Theis, T., Rivera, C. M., and Colberg, C. 1959. Studies on the action of oil in the control of *Mycosphaerella musicola* on banana leaves. Phytopathology 49:119-122.
4. Clayton, E. E., Smith, T. E., Shaw, K. J., Gaines, J. G., Graham, T. W., and Yeager, C. C., Jr. 1943. Fungicidal tests on blue mold (*Peronospora tabacina*) of tobacco. J. Agric. Res. 66:261-276.
5. Cohen, Y., Gisi, U., and Mosinger, E. 1990. Germination and infectivity of *Phytophthora infestans* in the presence of fatty acids. (Abstr.) Phytopathology 80:1067.
6. Dainello, F. J., and Jones, R. K. 1984. Continuous hours of leaf wetness as a parameter for scheduling fungicide applications to control white rust in spinach. Plant Dis. 68:1069-1072.
7. Horsfall, J. G., and Barratt, R. W. 1945. An improved grading system for measuring plant diseases. (Abstr.) Phytopathology 35:655.
8. Horst, R. K., Kawamoto, S. O., and Porter, L. L. 1992. Effect of sodium bicarbonate and oils of the control of powdery mildew and black spot of roses. Plant Dis. 76:247-251.
9. Lawson, D. S., and Weires, R. W. 1991. Management of the European red mite (Acari: Tetranychidae) and several aphid species on apple with petroleum oils and an insecticidal soap. J. Econ. Entomol. 84:1550-1557.
10. Locke, J. C. 1990. Activity of extracted neem seed oil against fungal plant pathogens. Pages 132-136 in: Neem's Potential in Pest Management Programs. J. C. Locke and R. H. Lawson, eds. U.S. Dep. Agric. Agric. Res. Serv. (Ser.)

ARS-86.
11. Marois, J. J., Bledsoe, A. M., Bostock, R. M., and Gubler, W. D. 1987. Effects of spray adjuvants on development of *Botrytis cinerea* on *Vitis vinifera* berries. Phytopathology 77:1148-1152.
12. Martin, H., and Salmon, E. S. 1931. The fungicidal properties of certain spray-fluids. VIII. The fungicidal properties of mineral, tar and vegetable oils. J. Agric. Sci. 21:638-658.
13. Martin, H., and Salmon, E. S. 1933. The fungicidal properties of certain spray-fluids. X. Glyceride oils. J. Agric. Sci. 23:228-251.
14. Maruzzella, J. C. 1963. The effect of perfume oils on the growth of phytopathogenic fungi. Plant Dis. Rep. 47:756-761.
15. McWhorter, F. P. 1927. Fungicidal value of oil sprays. Phytopathology 17:201-202.
16. Northover, J. 1986. Characterization and detection of benomyl-resistant *Venturia inaequalis* in Ontario apple orchards. Can. J. Plant Pathol. 8:117-122.
17. Northover, J. 1991. Control of apple scab and powdery mildew with plant oils. (Abstr.) Phytopathology 81:1137.
18. Northover, J., and Schneider, K. E. 1991. Efficacy of canola and soybean oils against peach brown rot, 1990. Fungic. Nematicide Tests 46:68.
19. SAS Institute. 1989. SAS/STAT User's Guide. Version 6. 4th ed. Vol. 2. SAS Institute, Cary, NC. 846 pp.
20. Schneider, K. E., and Northover, J. 1991. Efficacy of canola oil and Agral 90 against cucumber powdery mildew, 1990. Fungic. Nematicide Tests 46:129.
21. Skellon, J. H., Thorburn, S., Spence, J., and Chatterjee, S. N. 1962. The fatty acids of neem oil and their reduction products. J. Sci. Food Agric. 13:639-643.
22. Wilson, J. D. 1961. Oils reduce sporulation of *Septoria* on celery. Plant Dis. Rep. 45:282-285.