Effects of Canola Oil or White Mineral Oil at Dust Suppressant Levels on the Storage Characteristics of Wheat

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ABSTRACT

The storability of wheat, treated with canola oil or white mineral oil at levels used for dust suppression, was studied in the laboratory. Oils were applied at 100, 200, 400, 600, and 1,000 ppm, and treated and untreated wheat samples were stored for up to one year at 2.5, 10, 20, 30, and 40°C. Moisture content of wheat was unaffected by all oil concentrations but was lower at the higher temperatures. Dry grain did not produce moldy or rancid odors after one year, but wheat at 15–18.6% moisture content and 2.5°C produced odor regardless of oil treatment. Fat acidity values (FAV) for the wheat were unaffected by mineral oil after one year, but canola oil initially caused an increase of 6–7% in FAV, from values of 14.5 mg of KOH per 100 g of dry seed, for every 100 ppm of oil. Although germination tended to be lower at higher oil treatment levels, the differences generally were not significant. Microfloral associations with seeds were not clearly affected by any oil treatment. The reproduction of five female and five male *Tribolium castaneum* or *Cryptolestes ferrugineus* was unaffected by canola oil at 100–1,000 ppm in eight weeks. Mineral oil had no effect on *T. castaneum,* but it decreased *C. ferrugineus* offspring by 50% at 1,000 ppm. Degradation of the insecticides malathion or chlorpyrifos-methyl on wheat with 200 or 600 ppm of mineral oil, stored at varying ambient temperatures (30 to −20°C) or 20°C, was largely unaffected by the oils after one year.

Oil coatings can effectively reduce the production of dust that becomes suspended in air, whether the oil is applied on roads or on grain in grain elevators (Verkade and Chiotti 1976). In North America, oils rarely were used in the grain industry as an additive to bulk grain before 1982, when the U.S. Food and Drug Administration approved the use of food-grade white mineral oil at 0.02% (200 ppm), by weight, on grain for human consumption or 0.06% (600 ppm) on animal feed (FDA 1982). By 1988, white mineral oil was used on grain as a dust suppressant in 10% of U.S. grain elevators (Ennis 1988). A recent regulation by the Occupational Safety and Health Administration in the United States requires elevator operators to control grain dust on the premises (Ennis 1988). Aspiration systems generally have been used to collect dust in grain elevators, but this can be expensive and impractical in older elevators or on farms. Dust reduction in grain-handling facilities provides a safer and healthier environment for workers (Wrigley et al 1979) and reduces the risk of dust explosions (Verkade and Chiotti 1976).

Oil application to grain on the farm could reduce grain weight loss as well as the farmers' dust exposure. The average weight loss from dust dispersion in each movement of grain can be reduced from 0.14% for untreated grain to 0.03% for oil-treated grain (Lai et al 1984). However, oil application reduces grain test weight by affecting the packing characteristics of kernels in a given volume (Anonymous 1988).

The application of various vegetable oils and mineral oils at 200–1,000 ppm was effective in reducing airborne dust in handled corn, wheat, and soybeans by up to 92% (Cocke et al 1978, Lai et al 1981, 1984). The effects of rapeseed oil for dust suppression on the functional qualities of processed wheat were negligible (Hsieh et al 1982). Soybean oil, soybean oil and lecithin, and white mineral oil had negligible effect on grade, odors, or milling and baking qualities of wheat and corn during one year of storage at 200–800 ppm (Mounts et al 1988). Higher levels occasionally have significant effects.

Insects, such as weevils (*Sitophilus* spp.), are not affected by oil at levels below 3,500 ppm (Don-Pedro 1989). Limited research has been done studying vegetable or white mineral oils as insecticide carriers and their effects on the quality of grain during long-term storage. Some countries, such as Australia, treat most of their wheat with contact insecticides; application of insecticides in an oil that acted as a dust suppressant would be beneficial.

This study aimed to measure the effect of canola oil (canola is defined as rapeseed with low glucosinolates in the meal and low erucic acid in the oil) and white mineral oil applied to wheat at 100–1,000 ppm on seed moisture, germination, seedborne microflora, free fatty acids, odor, and milling and baking qualities of wheat stored for up to one year at various temperatures. The effects of the oils on reproduction by the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), and the red flour beetle, *Tribolium castaneum* (Herbst), and the degradation of the insecticides malathion and chlorpyrifos-methyl on mineral oil-treated wheat during one year of storage also were studied.

MATERIALS AND METHODS

Grain

Two hundred kilograms of hard Canada western red spring wheat (cv. Katepwa), harvested at Glenlea, Manitoba, in 1987 and stored at 12.2% moisture content (MC) in bags in an unheated shed until June 1989, were used in this study.

Oil Type and Storage Conditions

Pure canola oil (Canbra Foods, Lethbridge, Alberta) was purchased from a local food retailer and food-grade Amoco 5-NF white mineral oil was obtained from Amoco Corp. (Chicago, IL).

Wheat was treated with either canola oil or mineral oil by adding the required amount of oil, by weight, at 0, 100, 200, 400, 600, and 1,000 ppm to 2-kg lots of wheat in 4-L glass jars. The oil was added by pipette (Qi and Burkholder 1981), followed by three acetone washes of the pipette totaling 8 ml. The wheat was continuously rotated in the jar for 2 min, then emptied into cotton bags that were left unsealed for 24 hr to allow acetone evaporation. The oils were assumed to have been evenly distributed over all of the kernels as demonstrated with insects, which rapidly become coated with oil when only their legs touch a treated surface (Champ and Dyte 1976). The controls received 8 ml of acetone only. The cotton bags were 38 cm wide and 61 cm long. Before use, they were sterilized in an autoclave at 120°C for 20 min and then dried in the autoclave for another 45 min.

There were 55 bags each containing 2 kg of wheat that was untreated (0 ppm of oil) or treated with canola oil or mineral oil at 100, 200, 400, 600, and 1,000 ppm. Each of the 10 treatments and a control were stored in cabinets at five temperatures, 2.5 ± 1, 10 ± 1, 20 ± 1, 30 ± 1, and 40 ± 1°C, and ambient relative humidity. The bags within a cabinet were separated by sheets of 300-μm-thick plastic to prevent any migration of oil between bags if they should contact one another.

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Sample Analysis

About 200 g of wheat was sampled from each of the 55 bags at zero, three, six, nine, and 12 months of storage. Variables monitored from these samples included free fatty acid values (FAV), grain moisture content, seed germination, seedborne microflora, and subjectively determined odors.

Free fatty acid levels in wheat samples were determined by a modification of the AACC (1983) method 02-01, incorporating Soxhlet extraction of oil from 5 g of wheat with petroleum ether for 16 hr. After evaporation of the solvent, 50 ml of 0.02% phenolphthalein in propanol-toluene (1:1, w/w) was added and titrated with 0.02167*N* ethanolic KOH. FAV were determined as milligrams of KOH needed to neutralize acids in 100 g of dry wheat.

Grain moisture content was determined on a wet-mass basis by drying whole seeds at 130°C for 19 hr (ASAE 1987).

Seed germination and microfloral presence were determined by placing 25 seeds around the perimeter of sterile plastic petri dishes, 90 mm in diameter, containing filter paper saturated with sterile distilled water (Wallace and Sinha 1962). Other petri dishes containing filter papers saturated with 7.5% aqueous NaCl solution were used to facilitate the growth of storage fungi (Mills et al 1978). Duplicate petri dishes for both water and NaCl solutions were used for each sample from each sampling date. All dishes were covered, sealed in plastic bags, and incubated at 22 ± 1°C for seven days, when germination or fungi and bacteria associated with the seeds were identified using a stereo microscope.

Moldy or rancid odors were subjectively noted during sampling and classed as absent or present.

Standard milling and baking tests were done on wheat, untreated or treated with 1,000 ppm of canola or mineral oil and stored at 2.5, 20, or 40°C, after zero and 12 months of storage. Grain protein content (percentage) was determined using AACC method 46-12, Hagberg falling number (sec) by AACC method 56-81B, and flour yield by AACC method 26-20 (AACC 1983). Particle size index (percentage) of the grain was determined with the method of Williams and Sobering (1986). Flour protein content (percentage), ash content (percentage), and amylograph peak viscosity (BU) were determined by AACC methods 46-12, 08-01, and 22-10, respectively (AACC 1983). Flour wet gluten content (percentage) was determined by ICC method 137 (ICC 1980).

Dough development time (min), mixing tolerance index (BU), and farinograph absorption (percentage) (AACC method 54-21) were measured. Baking absorption (percentage), remix loaf volume (cm^3) (Kilborn and Tipples 1981), and blend baking strength index (percentage) also were measured.

Insect Multiplication in the Presence of Oil

Adults of *C. ferrugineus* and *T. castaneum* were exposed to wheat treated by pipette with 0, 100, 200, 400, 600, or 1,000 ppm of canola oil or mineral oil. About 200 g of whole wheat was added to each of 96 glass bottles (397 ml capacity). The set of 48 bottles in the canola oil test contained four replicates of wheat without oil and four replicates of each of the five oil concentrations for each insect species. A similar set of treatments was used in the mineral oil test (two oil types × six treatments, including controls, × two insect species × four replicates = 96 bottles). Five adult males and five adult females of *C. ferrugineus* or *T. castaneum* were added to each bottle. The adults were one to four days old and were from cultures maintained on whole wheat and wheat germ (95:5) for *C. ferrugineus,* or wheat flour and brewer's yeast (95:5) for *T. castaneum,* at 30 ± 1°C and 65 ± 5% rh.

The tops of the bottles were covered with filter papers and sealed at the periphery with paraffin wax. All bottles were stored in an environmental chamber at 30 ± 1°C and 70 ± 5% rh for eight weeks. After incubation, the numbers of adult *C. ferrugineus* or larval, pupal, or adult *T. castaneum* were determined by sifting the wheat. Because immature *C. ferrugineus* developed in the germ of kernels and could not be consistently removed, they were not included in the assessment. The mean developmental time for both species at the conditions used is about one month (Howe 1965).

Effects of Oil on Insecticide Degradation

The organophosphorus insecticides malathion (85% emulsifiable concentrate, determined by gas chromatography in our laboratory) and chlorpyrifos-methyl (Reldan, 43.2% emulsifiable concentrate, also determined in our laboratory) were mixed with white mineral oil and applied to wheat using a pipette, acetone rinses, and grain mixing. The application rate of malathion was 8 ppm and that of chlorpyrifos-methyl was 6 ppm. Oil concentrations were 200 and 600 ppm. Each insecticide, with 0, 200, or 600 ppm of oil, was applied to 6 kg of wheat. The acetone was allowed to evaporate and 1.5 kg of wheat was added to each of four sterilized cotton bags. Two bags from each treatment were stored for 12 months at 20 ± 2°C, and the other two bags from each treatment were stored at varying ambient temperature (30 to −20°C) and relative humidity in an unheated barn (two insecticides × three treatments [0, 200, and 600 ppm of oil] × two storage environments × two replicate bags = 24 bags). Grain samples of 200 g were taken from each bag at zero, six, and 12 months of storage. All bags were separated from one another with a polyethylene divider.

Moisture content of each sample was determined in duplicate as previously outlined. Insecticide residues were determined from 10-g samples per bag by extracting the lipids and insecticides using gel-permeation chromatography with either Sephadex LH-20 (for malathion) or Biobeads (for chlorpyrifos-methyl) and gas chromatography (White 1985). The gas chromatograph was a Perkin-Elmer Sigma 3B (Norwalk, CT) with a nitrogen-phosphorus detector and a column packed with 3% OV-17 on Chromosorb W-HP 100/120, and data were summarized with a Sigma 15 data integrator (White 1988). There were three analyses for each grain sample.

Grain from each bag and each sampling date also was bioassayed with adult *C. ferrugineus.* Three replicates of 25 insects were added to 8 g of wheat from each bag in vials 5 cm high × 2.5 cm diameter, with ventilated snap-on lids (two insecticides × three treatments [0, 200, and 600 ppm of oil] × three replicates × two bags × two storage environments × three sampling dates = 216 vials). The bioassay was done at 30 ± 10°C and 70 ± 5% rh. After 24 hr, the numbers of walking or incapacitated ("knocked down") insects were determined. All insects then were removed from the treated grain and placed in corresponding vials containing 8 g of untreated (no oil and no insecticide) ground wheat for seven days at 30 ± 1°C and 70 ± 5% rh, when all insects were classified as alive or dead.

Statistical Analyses

Multiple linear regressions were calculated for FAV using the predictor variables oil concentration, seed moisture content, and temperature for data pooled from six and 12 months of storage for each oil.

Moisture content of the wheat for each sampling date and particular oil at all five concentrations was compared with that of untreated wheat using one-way ANOVA (Snedecor and Cochran 1971).

Seed germination percentages and percentage of seeds with various microflora were transformed using arcsin $\sqrt{x}$. *Alternaria alternata* (Fr.:Fr.) Keissl., *Rhizopus* sp., bacteria, and germination data were from incubation on water; *Aspergillus glaucus* (Link:Fr.) group data were from incubation on NaCl solution. A one-way ANOVA was used to determine the effect of oil concentration by comparing 0 ppm of oil and all canola oil concentrations, or 0 ppm of oil and all mineral oil concentrations, for each temperature using data from all sampling dates (three, six, nine, and 12 months; n = eight plates). The effect of temperature was determined using one-way ANOVA to compare wheat treated with canola oil or mineral oil at all concentrations with the same oil (all concentrations) at different temperatures for data collected at 12 months.

The effects of the oils on insect multiplication were determined

TABLE I
Fat Acidity Values[a] of Wheat Treated with Canola Oil or White Mineral Oil

Storage[b] Time (months)	Storage[b] Temperature (°C)	No Oil	Canola Oil (ppm) 100	200	400	600	1,000	Mineral Oil (ppm) 100	200	400	600	1,000
0	...	15	15	17	21	21	24	17	15	15	17	17
6	2.5	13	17	21	23	25	33	15	15	15	15	15
	10	14	18	19	25	28	34	13	16	16	15	16
	20	12	18	21	25	28	31	12	13	13	13	13
	30	13	19	20	21	20	27	13	13	14	15	14
	40	13	20	19	23	24	27	13	14	14	12	14
12	2.5	19	17	21	24	29	36	18	17	18	18	19
	10	22	20	23	26	31	33	19	19	20	20	20
	20	17	17	20	22	23	31	19	17	15	16	16
	30	17	17	19	19	25	28	18	18	16	18	17
	40	16	17	20	21	21	25	16	17	17	16	17

[a] Milligrams of KOH per 100 g of dry seed.
[b] Wheat stored at 2.5 to 40°C for zero to 12 months.

TABLE II
Percent Seed Germination of Wheat Treated with Canola or Mineral Oil[a]

Storage Conditions Temperature (°C)	Oil Type[b]	Oil Amount (ppm)	Time (months)[c] 6	12
2.5	...	0	82	88
	C	100	76	80
	C	1,000	66	70
	M	100	88	84
	M	1,000	54	80
10	...	0	74	86
	C	100	92	86
	C	1,000	72	76
	M	100	78	82
	M	1,000	70	72
20	...	0	72	86
	C	100	86	92
	C	1,000	74	80
	M	100	78	70
	M	1,000	72	80
30	...	0	86	86
	C	100	86	92
	C	1,000	60	64
	M	100	94	84
	M	1,000	78	68
40	...	0	76	60
	C	100	92	70
	C	1,000	76	44
	M	100	92	82
	M	1,000	50	82

[a] Seeds were incubated at 22°C for one week on water-saturated filter paper. Initial germination was 79%; n = two plates of 25 seeds.
[b] C = Canola oil; M = mineral oil.
[c] Seeds were stored at 2.5 to 40°C.

using one-way ANOVA and Duncan's new multiple range test (Duncan 1955).

RESULTS AND DISCUSSION

Grain Storage

The application of canola oil or mineral oil to wheat at concentrations as high as 1,000 ppm could not be detected visibly.

Moisture content of the wheat was unaffected ($P > 0.05$) by either canola oil or mineral oil at 100–1,000 ppm. Qi and Burkholder (1981) also found no effect of four vegetable oils at 5,000 and 10,000 ppm on moisture absorption of wheat. The grain equilibrated with the uncontrolled relative humidity in the various storage chambers. The initial grain moisture content was 12.2%. From three to 12 months of storage at 2.5°C, MC varied from 15 to 18.6%, reflecting 75–85% rh (Brooker et al 1974) (15.0–16.9% MC at three months, 15.7–16.6% MC at 12 months for canola oil; 15.8–17.6% MC at three months, 16.7–17.4% MC at 12 months for mineral oil). At 10, 20, 30, and 40°C, the moisture contents of wheat samples and corresponding relative humidities were 13–14% MC (65–70% rh), 8–9% MC (30–40% rh), 7–8% MC (20–30% rh), and 4–6% MC (10–20% rh), respectively.

FAV were significantly ($P < 0.01$) affected by canola oil, with higher oil levels producing higher FAV, even immediately after application (Table I). An addition of 100 ppm of oil linearly increased FAV by 6–7% from initial values of 14.5, indicating that the free fatty acids were from the oil. Mineral oil had no significant effect ($P > 0.05$) on FAV (Table I).

FAV did not change dramatically during 12 months of storage, because the grain at 20–40°C was dry. The wheat at 2.5 and 10°C was relatively moist, and the largest changes in FAV over 12 months were evident at those temperatures. Free fatty acid levels in seeds increase primarily because of the lipolytic activity of fungal enzymes (Zeleny 1954) when fungi are able to grow in the seeds. Fungi do not develop at relative humidities below 70% (Wallace 1973).

Odors were not detected in any samples until 12 months, when a slightly moldy, rancid smell was evident on all samples treated with canola oil held at 2.5°C; a weaker but similar odor was detected on untreated wheat or wheat treated with mineral oil at 2.5°C. The odor was mainly related to storage at higher moisture levels. Mounts et al (1988) reported objectionable odors from wheat treated with 800 ppm of mineral oil and stored for six months at ambient conditions but not from wheat treated with soybean oil and lecithin at 800 ppm.

Seed Germination and Microflora

Based on data from four sampling times, canola oil at 100–1,000 ppm had no effect on germination ($P > 0.05$) at 2.5, 10, 20, and 40°C (Table II; data for 200, 400, and 600 ppm of oil are not shown). At 30°C, germination was significantly ($P < 0.05$) lower at 1,000 ppm, although this was probably an anomaly related to a small sample size. Mineral oil at 100 to 1,000 ppm had no effect ($P > 0.05$) on germination at any temperature (Table II). A previous study using four vegetable oils noted some germination loss in two months at 1,000 ppm with a 50–70% loss at 5,000 or 10,000 ppm of oil (Qi and Burkholder 1981). Mineral oil or soybean oil at 200–800 ppm on wheat reportedly has little effect on wheat germination (Mounts et al 1988).

The fungi *A. alternata* and *A. glaucus* group species and bacteria were present on the wheat at time 0 at levels of 39, 22, and 19%, respectively. During one year of storage no changes in microflora could be clearly attributed to oil treatment. Fungi grew slightly in the wheat stored at 2.5°C and high humidity but not in the wheat stored at higher temperatures and low humidities.

Milling and Baking Tests

Standard milling and baking tests indicated minimal effects

of both canola and mineral oil on wheat quality test parameters (Table III). Any changes that occurred in wheat utilization quality were due to storage temperature. At 2.5°C, the grain accumulated moisture, causing a substantial decrease in test weight. There was also a small decrease in wet gluten content and a slight strengthening in farinograph MTI. At 40°C, the grain was desiccated and suffered typical detrimental effects caused by prolonged storage at high temperature. Generally, the effects of the amount or type of oil, or both, were slight at all three storage temperatures. However, at 1,000 ppm of oil and 40°C, wheat with mineral oil did have a lower falling number, lower amylograph peak viscosity, and longer dough development time than wheat treated with canola oil. Mounts et al (1988) observed that 200 ppm of mineral oil, soybean oil or soybean oil/lecithin, or 400 ppm of soybean oil had no consistent adverse effects on dry and wet milling parameters of corn.

Insect Reproduction

Exposure of five male and five female *C. ferrugineus* or *T. castaneum* adults to wheat treated with canola oil for eight weeks resulted in no significant effects ($P > 0.01$) on reproduction of either insect (Table IV). Mineral oil had no effect on *T. castaneum* reproduction, but 1,000 ppm of oil resulted in significantly fewer ($P < 0.01$) offspring of *C. ferrugineus* than in controls.

The larvae of *C. ferrugineus* develop inside the germ of wheat kernels (White and Bell 1990), and mineral oil at 1,000 ppm may have interfered with the respiration of the young developmental stages. Don-Pedro (1989) reported that relatively high levels of various vegetable oils (3,500–14,000 ppm) applied to wheat were necessary to affect *Sitophilus zeamais* Mots. reproduction, and the main toxic action was probably by interference of respiration in the egg. Qi and Burkholder (1981) observed that 5,000 ppm of cottonseed, soybean, maize, or peanut oil reduced offspring

TABLE III
Wheat Quality Test Parameters for Grain Stored for 0 and 12 Months at 2.5, 20, or 40°C and Treated with No Oil or 1,000 ppm of Canola Oil (C) or White Mineral Oil (M)

	Storage Conditions									
		12 months								
		2.5°C			20°C			40°C		
	0 months		1,000 ppm			1,000 ppm			1,000 rpm	
Tests[a]	0 ppm	0 ppm[b]	C	M	0 ppm	C	M	0 ppm	C	M
Initial grain moisture, %	12.6	16.7	16.7	16.8	7.6	7.7	7.7	3.5	3.9	4.2
Grain										
Hwt, Kg	75.7	70.0	69.3	69.4	76.1	76.6	76.2	75.7	75.6	75.7
PSI, %	52	51	53	53	54	56	55	56	57	56
WPro, %	14.3	14.3	14.3	14.4	14.2	14.2	14.3	14.2	14.3	14.3
FN, sec	495	525	515	475	560	570	520	1,060	930	845
Yield, %	73.7	73.2	74.0	73.7	74.1	73.8	73.7	73.6	73.5	73.8
Flour										
FPro, %	13.3	13.5	13.3	13.4	13.3	13.2	13.2	13.3	13.3	13.2
Ash, %	0.52	0.57	0.56	0.58	0.48	0.49	0.48	0.48	0.49	0.47
WG, %	38.7	35.3	36.1	34.2	38.0	37.9	38.1	38.3	38.2	38.5
V_p, BU	820	780	790	800	840	890	840	1,650	1,600	1,530
Farinograph										
Abs_f, %	63.2	62.8	62.7	62.6	62.8	63.0	63.1	63.6	63.3	63.4
DDT, min	5.5	6.5	6.0	6.5	5.5	5.5	5.5	2.5	3.5	4.0
MTI, BU	30	20	20	15	30	25	30	25	20	20
Baking										
Abs_r, %	63	63	63	63	63	63	63	63	63	63
LV_r, cc	845	840	840	830	850	860	860	770	780	795
BSI, %	97	95	96	94	97	99	99	88	89	91

[a]Hwt = hectoliter weight, PSI = particle size index, WPro = wheat protein content (14% mb), FN = Hagberg falling number, FPro = flour protein content, WG = flour wet gluten content, V_p = Amylograph peak viscosity, Abs_f = Farinograph absorption, DDT = dough development time, MTI = mixing tolerance index, Abs_r = remix baking absorption, LV_r = remix loaf volume, BSI = blend baking strength index.
[b]Amount of oil. Control = 0 ppm.

TABLE IV
Effect of Canola Oil or White Mineral Oil Applied to Whole Wheat on Reproduction of the Rusty Grain Beetle, *Cryptolestes ferrugineus*, and the Red Flour Beetle, *Tribolium castaneum*[a]

			T. castaneum		
Oil Type	Oil Concentration (ppm)	*C. ferrugineus* Adults	Adults	Larvae	Pupae
Canola oil	0	86 ± 10 a[b]	45 ± 4 a	57 ± 2 a	7 ± 2 a
	100	86 ± 10 a	53 ± 5 a	50 ± 7 a	6 ± 1 a
	200	81 ± 8 a	40 ± 5 a	54 ± 7 a	5 ± 2 a
	400	114 ± 5 a	39 ± 4 a	49 ± 7 a	6 ± 1 a
	600	94 ± 18 a	40 ± 3 a	55 ± 8 a	7 ± 1 a
	1,000	82 ± 8 a	47 ± 7 a	48 ± 7 a	9 ± 1 a
Mineral oil	0	102 ± 20 a	46 ± 10 a	52 ± 13 a	6 ± 2 a
	100	77 ± 4 ab	43 ± 6 a	49 ± 1 a	7 ± 2 a
	200	69 ± 3 ab	42 ± 7 a	36 ± 6 a	4 ± 1 a
	400	68 ± 9 ab	47 ± 3 a	35 ± 3 a	3 ± 2 a
	600	75 ± 3 ab	51 ± 2 a	41 ± 5 a	5 ± 1 a
	1,000	51 ± 8 b	50 ± 6 a	47 ± 13 a	7 ± 1 a

[a]Five male adults and five female adults of each species were exposed to the treated wheat for eight weeks at 30°C and 70% rh. n = four replicates.
[b]Means followed by the same letter within a column for a particular oil type are not significantly different ($P > 0.05$).

TABLE V
Insecticide Concentration and Moisture Content of Wheat Treated with Malathion or Chlorpyrifos-Methyl in White Mineral Oil[a]

Treatment		Storage time (months)[b]					
		0		6		12	
Insecticide	Oil (ppm)	20°C	Amb	20°C	Amb	20°C	Amb
Insecticide concentration (ppm)							
Malathion	0	7.36 ± 0.56	7.69 ± 0.02	3.38 ± 0.01	7.68 ± 0.01	2.32 ± 0.21	3.09 ± 0.01
	200	6.61 ± 0.35	5.71 ± 0.20	2.49 ± 0.10	4.55 ± 0.09	1.88 ± 0.09	2.40 ± 0.13
	600	8.54 ± 0.11	9.36 ± 1.36	3.32 ± 0.16	5.02 ± 0.60	5.92 ± 0.41	4.70 ± 1.32
Chlorpyrifos-methyl	0	5.99 ± 0.26	6.39 ± 0.22	2.92 ± 0.10	2.88 ± 0.03	2.08 ± 0.10	2.68 ± 0.19
	200	3.41 ± 0.13	4.06 ± 0.16	1.45 ± 0.13	1.61 ± 0.06	1.07 ± 0.10	1.52 ± 0.11
	600	6.45 ± 0.26	7.33 ± 0.52	3.65 ± 0.28	4.06 ± 0.08	2.71 ± 0.04	3.51 ± 0.03
Moisture content (%)							
Untreated	0	14.0 ± 0	13.8 ± 0.1	9.9 ± 0.1	11.5 ± 0.1	8.1 ± 0.1	12.2 ± 0.1
Malathion	0	13.8 ± 0.1	13.7 ± 0.1	9.3 ± 0.3	11.6 ± 0.1	7.8 ± 0.1	12.0 ± 0.1
	200	14.1 ± 0	14.0 ± 0.2	9.2 ± 0.1	11.6 ± 0	7.9 ± 0.1	12.3 ± 0.1
	600	14.0 ± 0	13.9 ± 0.1	9.4 ± 0.2	11.8 ± 0	8.1 ± 0.2	11.9 ± 0
Chlorpyrifos-methyl	0	14.3 ± 0.1	14.2 ± 0	9.8 ± 0.1	11.6 ± 0	8.1 ± 0.1	12.0 ± 0
	200	14.1 ± 0	13.9 ± 0.1	9.6 ± 0.2	11.8 ± 0.1	8.1 ± 0.2	12.1 ± 0
	600	14.2 ± 0.1	14.1 ± 0.1	9.8 ± 0.1	11.6 ± 0	8.2 ± 0.1	12.5 ± 0.3

[a] n = six (triplicate analysis of two bags of wheat); when oil = 0 ppm, insecticide was applied as an emulsion in water.
[b] Wheat was stored at 20 ± 5°C or ambient (Amb) outdoor conditions of 30 to −20°C.

TABLE VI
Bioassay (Mean Percentage of Knockdown or Mortality) of Wheat Treated with Insecticides and White Mineral Oil Using *Cryptolestes ferrugineus* Adults[a]

Temperature (°C)	Insecticide[b]	Oil (ppm)	Storage time (months)					
			0		6		12	
			Kd[c]	M[c]	Kd	M	Kd	M
20	None	0	1 ± 1	4 ± 2	0	0	0	0
	Malathion	0	100	100	0	8 ± 1	5 ± 2	11 ± 4
		200	100	100	0	3 ± 2	6 ± 3	11 ± 2
		600	100	100	2 ± 1	7 ± 2	5 ± 1	14 ± 3
	Chlorpyrifos-methyl	0	100	100	87 ± 5	84 ± 3	17 ± 2	43 ± 4
		200	100	100	5 ± 3	27 ± 7	5 ± 2	16 ± 4
		600	100	100	96 ± 1	88 ± 3	16 ± 5	43 ± 11
Ambient[d]	None	0	0	0	0	0	0	9 ± 1
	Malathion	0	100	100	35 ± 6	32 ± 7	43 ± 3	15 ± 8
		200	100	100	11 ± 3	12 ± 2	18 ± 4	33 ± 4
		600	100	100	49 ± 8	51 ± 10	33 ± 5	50 ± 8
	Chlorpyrifos-methyl	0	100	100	100	96 ± 2	95 ± 4	95 ± 2
		200	100	100	42 ± 5	56 ± 6	78 ± 7	61 ± 3
		600	100	100	100	100	100	97 ± 1

[a] Insects were exposed for 24 hr at 30°C and 70% rh and then allowed a seven-day recovery period on untreated ground wheat. n = six replicates of 25 insects (three samples from two bags each). Storage period was April 1989 to April 1990.
[b] Malathion = 8 ppm, chlorpyrifos-methyl = 6 ppm.
[c] Kd = knockdown; M = mortality.
[d] 30 to −20°C.

production in the granary weevil, *Sitophilus granarius* (L.), and controlled this insect at 10,000 ppm.

Insecticide Degradation

The insecticides degraded appreciably during 12 months, often slightly more rapidly at 20°C, although grain under ambient conditions was more moist (Table V). After 12 months, malathion residues decreased by about 69% in controls, 72% with 200 ppm of oil, and 31% with 600 ppm of oil at 20°C; and by 60% in controls, 58% with 200 ppm of oil, and 50% with 600 ppm of oil at ambient storage conditions. Chlorpyrifos-methyl residues decreased by about 65% in controls, 69% with 200 ppm of oil, and 58% with 600 ppm of oil at 20°C; and by 58% in controls, 63% with 200 ppm, and 52% with 600 ppm of oil at ambient conditions. Levels of 600 ppm of oil resulted in slightly slower rates of insecticide degradation.

Insect mortality (Table VI) was directly related to the decreasing insecticide levels (Table V). Malathion often breaks down on wheat more rapidly than does chlorpyrifos-methyl (White 1988); however, all of the grain in the current study was dry after one month, slowing insecticide hydrolysis. Occasional apparent increases in insecticide levels during storage resulted from variation within samples. There was no clear-cut effect of 200 or 600 ppm of mineral oil on insecticide degradation. Relatively high insecticide levels (>3 ppm) often resulted in little insect mortality, possibly indicating that these lipophilic insecticides were being bound inside the seed rather than at the surface. However, this also was observed in seeds without added oil.

Effects of Oils on Wheat Quality During Storage

Neither canola oil nor white mineral oil had appreciably negative effects on a wide range of parameters that reflect wheat quality if the grain was stored in a dry condition. Canola oil contains free fatty acids and oxidizes more readily than mineral oil, potentially leading to high FAV in wheat oil that could be interpreted as a sign of grain deterioration. The oils used are reported to be effective in controlling dust; benefits of their use could outweigh added cost and the inconvenience of applying the oil.

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