Applied Science Labs

P O Box 2416
McKinney, Texas
USA 75070

appliedsciencelabs@att.net
619 825 2121

BULLETIN (01.14.25)

89.6% IS THE AMOUNT OF PESTICIDE REMAINING 122 DAYS AFTER APPLICATION

89.6% of initial concentration, that's the level of pesticide, found remaining after **122** days from treatment. *Journal of Exposure Science & Environmental Epidemiology*. 29 March 2019

Can this be fixed? Yes, decontamination and detoxification is actually easy and inexpensive using ACD, *1st Place Science's* aqueous chlorine dioxide. Mist spray and leave to dry. You're done.

Is residue dangerous? What do you think? What will government policy makers think?

Will toxic pesticide use be outlawed?

Will toxic pesticide be permitted for agriculture but not residential or commercial use?

Will special taxes be assessed for those that use toxic chemicals to defray the health and environmental costs?

All or any combination of the above could be on the horizon.

But no one will consider **limiting or banning non-toxic** pest control products especially when they've been proven to work.

And those that decontaminate and detoxify and then use Toxic Free formulas as part of their professional protocols will be the **heroes that everyone wants to hire!**

In the meantime, here's what manufacturer's say about their own toxic products. (source: SDS forms)

- Considered hazardous
- Acute toxicity
- Do Not breathe
- Use only outdoors.... (*but plenty used inside*)
- Very toxic to aquatic life
- Keep people and animals away....(*but this isn't done either*)
- Danger, Poison, Corrosive
- Fatal if swallowed
- Can cause headache, nausea, vomiting, diarrhea, abdominal cramps, excessive sweating, salivation and tearing,
- constricted pupils, blurred vision, tightness in chest, weakness, muscle twitching and confusion
- Unconsciousness, convulsions, severe respiratory depression and death

Journal of Exposure Science & Environmental Epidemiology

Article | Published: 29 March 2019

Persistence of indoor permethrin and estimation of dermal and non-dietary exposure

Lia Emi Nakagawa ✉, Cristiane Mazarin do Nascimento, Alan Roberto Costa, Ricardo Polatto & Solange Papini

Journal of Exposure Science & Environmental Epidemiology **30**, 547–553 (2020)

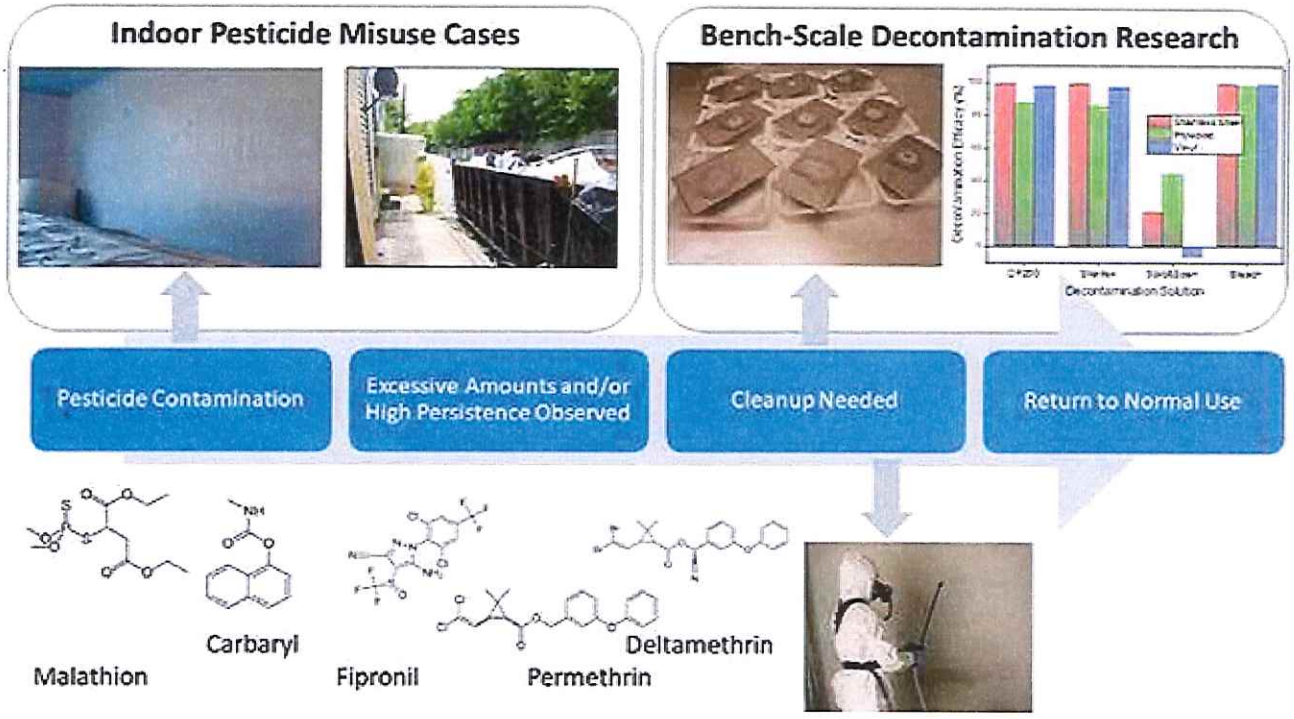
Abstract

Pesticides applied indoors may persist longer than they would in outdoor environments, making people more vulnerable to the risk of exposure. Permethrin is a pyrethroid insecticide used in agricultural, residential, and public health sites, and is commonly detected in indoor environments. The objectives of this study were to evaluate the persistence of permethrin indoors and to estimate the levels of possible dermal and non-dietary exposure to this insecticide. Permethrin was applied on aluminum foil and kept in a glass chamber and a test house for 112 days; its concentration was measured at application and after 28, 56, and 112 days. Permethrin persisted for the entire 112 days in concentrations equal to a maximum of 89.6% of the initial concentration. We observed low levels of human dermal and non-dietary exposure to permethrin.

virtually unchanged after 140 days. Indoor light conditions degraded some of the pesticides, but estimated half-lives exceeded the study period. Decontamination efficacy results indicated that the application of household bleach or a hydrogen peroxide-based decontaminant offered the highest efficacy, reducing malathion, fipronil, and deltamethrin by >94–99% on some surfaces. Bleach effectively degraded permethrin (>94%), but not carbaryl (<70%) while the hydrogen peroxide containing products degraded carbaryl (>71–99%) but not permethrin (<54%). These results will inform responders, the general public and public health officials on potential decontamination solutions to remediate indoor surfaces.

Keywords: pesticide, misuse, decontamination, cleanup, persistence

Graphical Abstract



1. Introduction

Under the U.S. Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), it is a violation to use a pesticide in a manner inconsistent with the product's labeling. Applying pesticides in ways that deviate from the label directions is illegal and considered a misuse or a misapplication. Misusing pesticides can include the application of products not registered by the U.S Environmental Protection Agency (EPA) (Pesticide Registration Manual, 2020), off-label application in areas where the product is not intended, or at higher rates or concentrations (mass per unit area) than

specified on the product label. Misapplications also include disregarding safety instructions and applying restricted-use pesticides without proper applicator certification.

Misapplying pesticides in homes, schools, businesses or other indoor environments can lead to adverse health effects and contamination (Rubin and Esteban, 2002; Markowitz, 1992; Centers for Disease Control and Prevention, 2011; Liu et al., 2018; Buhl et al., 2010; Health Consultation, 2010; Clark et al., 2002), often impacting vulnerable populations. Building occupants and federal, state and local agencies responding to pesticide misuse incidents seek information about whether pesticide residues present exposure risk and how to clean treated surfaces to reduce pesticide levels, if necessary (Health Consultation, 2010; Clark et al., 2002; McCaule et al., 2006; National Pesticide Information Center Annual Reports, 2019). This study does not attempt to evaluate whether pesticide levels are unsafe but provides decontamination information should remediation be desired or deemed appropriate.

Tools to determine the potential risk to occupants from misused pesticides are limited, and there are few known effective cleaning procedures to reduce pesticide levels in affected structures. Proper cleanup can also be very costly, presenting significant challenges for individuals with limited economic resources. As a result, occupants could continue to inhabit contaminated buildings, could be forced to vacate contaminated properties, or could attempt to remediate on their own, possibly creating toxic byproducts or further spreading pesticides residues. Science based remediation methods are needed to safely reduce occupant exposure following pesticide misapplication incidents.

Although the fate and transport of pesticides in the environment has been studied extensively including those completed for pesticide registration (Test Guidelines for Pesticides and Toxic Substances, 2019), there is very limited information on the persistence of pesticides in indoor environments (Class and Kintrup, 1991; Lu and Fenske, 1998; Wright and Jackson, 1976; Starr et al., 2014) where degradation mechanisms, such as direct sunlight, water, and soil microbes, do not exist. Numerous studies have documented the presence of many different pesticides inside homes and day care centers in indoor air, in dust and on surfaces (Stout and Bradham, 2009; Tulve and Jones, 2006; Julien and Levi, 2008; Quandt and Arcury, 2004; Julien and Adamkiewicz, 2008; Bradman and Whitaker, 2007) indicating long-term persistence. Few studies evaluate indoor pesticide fate for extended periods but results from previous pesticide misuse cases (reference 8 and personal communication) suggest that pesticide residues persist indoors due to the absence of the primary degradation factors found outdoors. To confirm that pesticides of interest (malathion, carbaryl, deltamethrin, fipronil, and permethrin) do persist in the indoor environments, the present study included persistence tests conducted in a controlled environment under dark and

indoor light conditions, to assess the rate of dissipation of the pesticides from the surface via volatilization and/or degradation.

Managing outdoor pesticide spills (Pesticide spill management, 2020) and remediating pesticide contaminated soil or water traditionally focus on control, containment and various cleanup technologies. The cleanup procedures following an outdoor release tend to focus on the physical removal of the contamination and, if applicable, leaving pesticide residues associated with normal application conditions in place to breakdown naturally. Leaving residues to degrade naturally indoors may not be a suitable approach due to extended indoor persistence (reference 8 and verbal communication). Additionally, when pesticide misuse results in an unsafe environment or occupant evacuation, more immediate and proactive residue removal or reduction is required.

Information about decontamination approaches for pesticides on indoor surfaces is almost nonexistent and knowledge on complete chemical degradation pathways is limited to general concepts derived from processes observed in water or soils. Initial attempts to remediate pesticide contaminated surfaces through general washing and physical removal are rarely successful (Health Consultation, 2010; Clark et al., 2002; McCaule et al., 2006) and physical removal may not be possible for all surfaces. Pesticide manufacturer labels or safety data sheets (SDS) identify decontaminants such as chlorine bleach, caustic soda, or lime without evidence or reference to degradation rates. Use of these products by building occupants may pose health risks and may not be practical for use on common household items or for extensive use throughout grossly contaminated residential or business settings. Further, potentially toxic byproducts may be formed during decontamination, which would require additional chemical analysis and costs in order to verify a successful cleanup.

To inform safer and effective application of decontaminants, we conducted a series of decontamination experiments on malathion, carbaryl, deltamethrin, fipronil, and permethrin contaminated materials. Because these studies were the first of their kind, they focused strictly on chemical interactions to degrade pesticides on indoor surfaces to better understand efficacy independent of various scrubbing, rinsing and other physical removal procedures. In addition, physical removal processes introduce numerous variables beyond the scope of this investigation.

The efficacies of selected commercially available decontamination solutions (Spic and Span® cleaner, Clorox® Bleach, EasyDECON DF200®, and Sterilex® Ultra-Kleen) were examined for their ability to degrade the pesticides under operationally realistic conditions such as application of a representative decontaminant volume per surface area and contact time. These solutions were selected based on their observed effectiveness (Sterilex® Ultra-Kleen) for remediating

organophosphate pesticide (methyl parathion) contaminated homes (Clark et al., 2002), and on the chlorine-based oxidation chemistry (Clorox® Bleach) (U.S. Environmental Protection Agency, 2011), because they were designed to degrade organophosphate chemical warfare agents (EasyDECON DF200®) (Love et al., 2011), or because they are a conventional, commercially available detergent solution (Spic and Span® cleaner). This included a measurement of the efficacy of decontamination solutions on three building materials (stainless-steel, plywood, and vinyl flooring) using representative decontamination solution dwell times on the pesticide contaminated surfaces and contamination levels measured in pesticide misuse incidents (25–2,400 $\mu g/100cm^2$). The measured contamination levels vary due to (1) the amount and concentration of the product applied at the site; (2) the surface types sampled and sampling methods used; (3) the time that passed between the application and the sampling; or (4) previous applications and residues from other sources, such as being tracked-in from outdoors or from use of pet products containing the same pesticides. SDS and other health and safety information on any decontamination solution should be reviewed as the decontamination solution itself may introduce an additional exposure risk to personnel. This study included a semi-quantitative analysis for known byproducts of noticeable toxicity following the decontamination process which were identified for two pesticides, malathion and fipronil.

2. Materials and Methods

2.1. Pesticides

Targeted pesticides were technical grade malathion (CAS Number 121–75-5), carbaryl (CAS Number 63–25-2), fipronil (CAS Number 120068–37-3), deltamethrin (CAS Number 52918–63-5), and permethrin (CAS Number 52645–53-1) as well as two commercial pesticide formulations, Ortho® MAX® Malathion Inspect Spray Concentrate [Ortho MAX] (The Scotts Company LLC, Huntsville, TX) and Sevin® Carbaryl Insecticide [Sevin] (TechPac, LLC, Atlanta, GA). All pesticides and pesticide containing formulations that were part of this study are tabulated in Table 1 and were procured from either a commercial source (Sigma Aldrich, St. Louis, MO) at 97% or higher purity or as commercial formulations from local vendors. Labeled internal standards of pesticides were purchased from Cambridge Isotope Laboratories (Tewksbury, MA, USA), CDN Isotopes (Pointe-Claire, Quebec, Canada) and Dr. Ehrenstorfer® GmbH (Augsburg, Germany).

Table 1.

Targeted Pesticides

Pesticide	CAS #	Pesticide Family	Purpose	Target Surface Concentration (µg/100 cm^2)[a]
Malathion	121-75-5	Organophosphate	Insecticide	400
Carbaryl	63-25-2	Carbamate	Insecticide	2400
Fipronil	120068-37-3	Phenylpyrazole	Insecticide	150
Deltamethrin	2918-63-5	Pyrethroid	Insecticide	25
Permethrin	52341-32-9	Pyrethroid	Insecticide	500
Ortho® MAX® Malathion Inspect Spray Concentrate	N/A	Organophosphate	Commercial insecticide product (50% malathion)	400
Sevin® Carbaryl Insecticide	N/A	Carbamate	Commercial insecticide product (43% carbaryl)	2400

N/A: Not Applicable.

[a]Based on highest observed surface concentration from specific pesticide misuse cases.

The pesticides selected are common use, registered insecticides that have been misused indoors (Rubin and Esteban, 2002; Markowitz, 1992; Centers for Disease Control and Prevention, 2011; Liu

et al., 2018; Buhl et al., 2010; Health Consultation, 2010; Clark et al., 2002). They also represent a range of pesticide classes and physiochemical properties as to evaluate their behaviors on surfaces and chemical interactions with decontamination solutions. Surface contamination levels, as tabulated in Table 1, were different for each pesticide based on the highest observed surface concentrations reported in several pesticide misuse investigations conducted by state pesticide regulatory agencies and shared with US EPA. This study utilized these pesticide surface concentrations because a high level of surface contamination is likely more difficult to cleanup than a lower level of surface contamination.

Technical grade pesticides were dissolved in n-hexane (>98.5%, mixture of hexane isomers, HPLC, GC, pesticide residue analysis grade) or dichloromethane (>99.9% HPLC, GC, pesticide residue analysis grade) at stock concentration values that allowed for the application of a single 10 μL droplet of the dissolved pesticide on the targeted surfaces to reach the intended surface concentration. After chemical analysis of the concentration of target chemicals in commercial pesticide formulations, the Ortho MAX malathion-containing product was mixed with deionized water (1:125 ratio) to create the same malathion concentration on the surface as tested using the technical grade. Similarly, the Sevin carbaryl containing product was diluted 8.3-fold with deionized water to create the same carbaryl surface concentration for a direct comparison with the technical grade decontamination tests.

2.2. Test surface materials

Test materials were selected to represent a variety of commonly encountered indoor surfaces with potential different degrees of permeability to pesticides. The materials selection was based on its likely use as a subflooring material (plywood) under carpet or hardwood flooring, or actual flooring material (vinyl) in a residence. Stainless-steel was representative of a nonporous surface and served as a reference material since treatment and removal methods are expected to perform more efficiently on this material. Materials were also selected for relative simplicity to minimize potential interactions due to surface material interferences. For example, painted or stained surfaces commonly found in homes may interact with the pesticides and decontamination solutions and complicate interpretation of results. Further fate and transport research are needed on more complex surfaces before decontamination approaches can be developed. All test substrates were spiked with a pesticide and underwent decontamination treatments. Large sections or panels of each material were obtained from suppliers (stainless-steel, 304 Grade; McMaster-Carr; plywood, untreated pine plywood, Lowe's Home Improvement; and vinyl, TrafficMaster Allure, Lowe's Home Improvement). Small rectangular coupons (2.5 × 4.0 cm dimensions) were cut from the larger materials and were used as substrates for the application of

the pesticides and subsequent decontamination steps. All materials were cleaned prior to use by removal of any dust followed by a surface cleaning with methanol. Material coupons were spiked with a single 10 μL droplet, using a gas tight micro-syringe (SGE Analytical Science, Melbourne, Australia), of the targeted pesticide at pesticide specific stock concentrations in hexane or dichloromethane.

2.3. Decontamination solutions

Four decontamination products were initially chosen for testing. EasyDECON® DF200 (hereafter, DF200) solution was prepared by proportional mixing of DF200 Parts 1–3 (hydrogen peroxide solution as the active ingredient with surfactants; pH = 9.8). DF200 Part 1 is composed of cationic detergents and fatty alcohols; DF200 Part 2 is an 8% hydrogen peroxide stabilized solution; and DF200 Part 3 contains diacetin. Sterilex Ultra Kleen Solution 1&2 (hereafter, Sterilex) was prepared by proportional mixing of Solution 1 and 2 (peroxide solution, pH = 11). Sterilex Solution 1 contains hydrogen peroxide (6–6.6% by weight) as the active ingredient, quaternary ammonium compounds and ammonium salts while Solution 2 contains sodium- and potassium carbonates (approximately 6% by weight). Clorox® Concentrated Germicidal Bleach (8% sodium hypochlorite as the active ingredient, pH = 11.4) (hereafter, bleach) was applied as received without dilution. Spic and Span® Liquid Multi-Surface and Floor Cleaner (hereafter, Spic&Span) solution was prepared per manufacturer instructions (sodium carbonate as the active ingredient and surfactant, pH = 9.4–9.7). All decontamination solutions were prepared immediately prior to use. The use of full-strength bleach without dilution to clean surfaces is not recommended as per the manufacturer's label. Previous decontamination testing using ten-fold diluted bleach on materials contaminated with organophosphate nerve agents suggested low efficacy (U.S. Environmental Protection Agency, 2011). Therefore, this bench-scale study used full strength bleach to evaluate whether a concentrated solution would degrade the pesticides more completely without leaving toxic byproducts.

After a 5-min contact time of the pesticide solution with the flooring or nonporous reference material (to allow the solvent to evaporate), 75 μL of the decontamination solution was applied as a single droplet over the contaminant using a gas tight micro-syringe (SGE Analytical Science, Melbourne, Australia). Considering the small coupon sizes, the decontamination solution was applied as a single droplet that was large enough to cover the pesticide contaminated area on a coupon. This volume is representative of the volume of decontaminant solution applied to a surface from a back-pack type sprayer U.S. Environmental Protection Agency (2011). The decontamination solution was allowed to interact with the pesticide on the surface for 18 hours (representing an overnight drying of the decontamination solution). For a second set of test

coupons, the same decontaminant with the same volume was reapplied after 90 minutes followed by 16.5 hours contact time. Both sets of test coupons, as well as the positive controls (see below), were extracted at the same time (18 hr after contamination). Each test point consisted of two sets of three replicate test coupons (contaminated and decontaminated material). Each test point also included two positive controls that were contaminated with a pesticide but not decontaminated; one procedural blank that was not contaminated with a pesticide, but the decontamination solution was applied; and one laboratory blank that was not treated with either pesticides or decontamination solutions.

The decontamination testing started with all the decontaminants (DF200, Sterilex, bleach, Spic&Span) applied against the malathion contaminated materials (stainless-steel, plywood, and vinyl). Subsequent decontamination testing for other pesticide contaminated materials was limited to the better performing decontaminants and to a lower number of materials (see Table 2).

Table 2.

Test Matrix

Pesticide	Spic&Span	Bleach	DF200	Sterilex
Malathion	X	X	X	X
Carbaryl		X	X	X
Fipronil		X	X	
Deltamethrin		X	X	
Permethrin		X	X	

Open in a new tab

2.4. Pesticide persistence tests

Persistence tests were conducted for the targeted pesticides as applied to stainless-steel coupons (10 cm^2 surface area). Fourteen sets of triplicate stainless-steel coupons plus one triplicate Day 0 set were contaminated with a pesticide mixture containing malathion, carbaryl, fipronil,

deltamethrin, and permethrin at concentrations to reach the surface concentration in Table 1. All contaminated coupons, as well as single procedural blank coupons (no pesticide applied), were placed in two chambers with controlled temperature (24 ± 3 °C) and 50 ± 3% relative humidity (RH). Seven sets of contaminated coupons were placed in a dark chamber. The other seven sets were placed in the second chamber that simulated an indoor light environment. The indoor lighting was simulated using seven 4 Watt fluorescent warm white light fixtures (color temperature 3000 K). Light fixtures were present in close distance to the coupons (2–5 inch range). The air exchange rate for both chambers was controlled at one air exchange per hour representing a common air change rate for standard residences (Engineering ToolBox, 2005). At seven intermediate time points up to 140 days post pesticide application, coupon sets including the procedural blank coupon were removed from both chambers and extracted to quantify residual pesticide mass. One set of triplicate coupons was extracted immediately after spiking with the pesticide and functioned as the Day 0 starting pesticide mass.

2.5. Extraction of pesticides from materials and neutralization of residual decontaminant

After a 30-min contact time between the pesticide and surface, residual pesticide amounts were recovered by transfer of the coupon into an extraction vial containing 50 mL of n-hexane as the extraction solvent. Vials were then sonicated for 10 min. Following sonication, a 10 mL aliquot of the extract was solvent exchanged with a 10 mL 3:7 water: methanol ratio (v/v) solvent mixture for LC-MS/MS analysis. Extracts that were to be analyzed by GC-MS remained in the hexane solvent. Extracts were diluted as needed, spiked with internal standard (See Table A, Supporting Materials) and stored in a refrigerator (4 °C) or freezer (−20 °C) for interim storage until chemical analysis. Extraction efficiencies, defined as the percent ratio between recovered pesticide mass from a coupon material and that from a spike control into the same extraction solvent, were determined for all material / pesticide combinations prior to the decontamination study. Almost all recoveries (see Table A, Supplemental Materials) using this method exceeded the initial targeted recovery value (better than 70%, but not higher than 120%, recovered mass) with a low coefficient of variance among test coupons (less than 30%). In general, extraction efficiency increased for the extraction of pesticides from plywood to vinyl to stainless-steel. This can be attributed to the more porous nature of plywood and vinyl versus stainless-steel. Extraction of both permethrin and deltamethrin from vinyl and plywood did not reach the 70% target extraction efficiency but were in the 47–57% range, which were still deemed acceptable as lower recoveries would be associated with both positive controls and test coupons leading to a limited impact in calculated decontamination efficacy.

It is critical that the extract is neutralized as residual decontaminant that is part of the extract may continue to degrade the pesticide during the extraction and handling of the extract prior to the analysis. This would bias the recovered pesticide amount leading to artificially higher decontamination efficacy values than those associated with just the degradation of the pesticide on the surface with the decontaminant. The selection of hexane as a nonpolar solvent simplified the needed quenching of the decontamination reaction in the extract as the pesticides partitioned into this solvent layer while the residual decontaminant formed a separate aqueous layer. By taking an aliquot from the solvent phase rather than the reactive ingredient-containing aqueous phase, a further separation of reactant (the residual decontaminant) and pesticide is guaranteed. This was verified prior to the actual decontamination testing through spiking of a pesticide into a simulated extract.

2.6. Analytical methods

Chemical analysis of the coupon extracts occurred using two analytical methods, gas chromatography/mass spectrometry (GC/MS) for malathion (decontamination tests only) and liquid chromatography/tandem mass spectrometry (LC-MS/MS) for malathion (persistence tests only), carbaryl, fipronil, deltamethrin, and permethrin. Details on the analytical methods are provided in the Supplemental Materials. The lowest recovered pesticide mass is reported at the method quantification level (MQL), which was defined in this study as the lowest calibration curve standard for each pesticide in the study. All malathion extracts were screened for the presence of malaoxon, a toxic oxidation byproduct of malathion (Bavcon Kralj et al., 2007; Shelat and Piper, 2016). For the fipronil decontamination tests, extracts were screened for the presence of fipronil sulfone, fipronil amide, and fipronil desulfinyl as fipronil byproducts of noticeable toxicity (Tingle et al., 2003; Odenkirchen and Wente, 2011).

2.7. Decontamination test matrix, calculations, and statistical analysis

Table 2 summarizes the overall decontamination test matrix. Not all decontaminant-pesticide combinations were evaluated. Results from the first pesticide (malathion) decontamination tests were considered in the selection of decontamination solutions for the second pesticide (carbaryl) with two decontaminants being selected for the other three pesticides. Decontaminants that were excluded from the test matrix in this study should not *a priori* be considered ineffective unless explicitly noted. This decontamination study focused on the identification and efficacy measurement of decontamination solutions that were expected to be efficacious based on the limited literature on surface decontamination via chemical degradation of similar pollutants (Rubin and Esteban, 2002; Love et al., 2011). Decontamination efficacy tests were also executed for

two commercial pesticide products applied (at the same pesticide surface concentration) to address impacts of product formulation on the observed efficacy.

The decontamination efficacy was defined as the percentage decrease in the mean pesticide mass recovered from the decontaminated (test) coupons ($\overline{M}_{TC}$) compared to the mean pesticide mass applied to the test coupons (positive controls, ($\overline{M}_{PC}$). To account for possible losses, e.g., due to volatilization or natural degradation, the positive control coupons (contaminated but not decontaminated) were extracted at the same time as the test coupons (i.e., after 18 hr) and were used to account for such a decrease. For a given test coupon (*TC*), the response variable calculated for this analysis was:

$$Decontamination\ Efficacy = 100 \times \frac{\overline{M}_{PC} - \overline{M}_{TC}}{\overline{M}_{PC}}$$

The standard deviation in the mean mass recovered from test and positive control coupons was used to derive the standard deviation in decontamination efficacy through propagation of error.

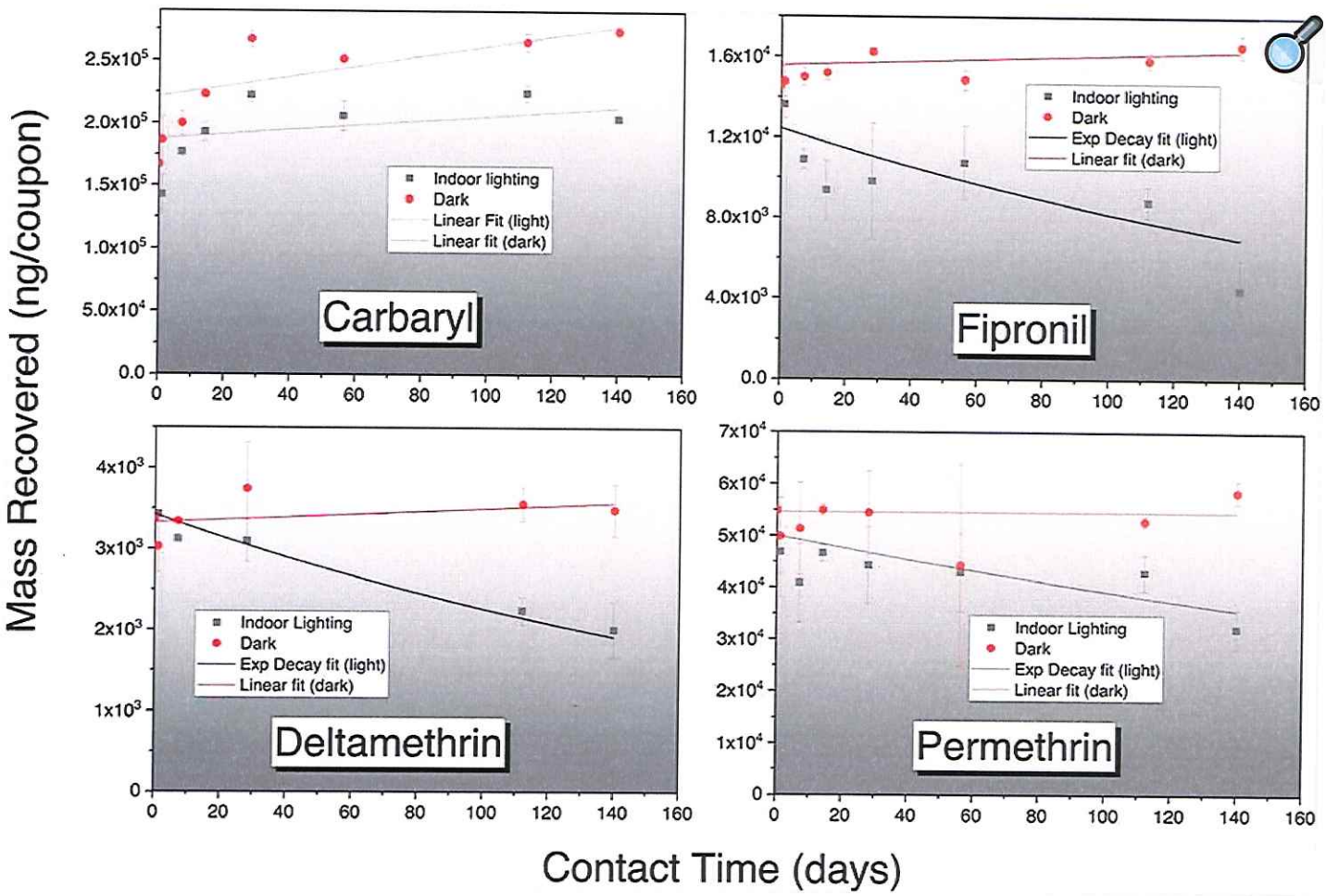
Two-tailed Student's t-tests were used to compare the means of the residual pesticide mass following the application of the decontamination solution. Unequal variance between the populations was assumed. A p-value is the result of such comparison and results are considered significantly different if $p < 0.05$. The statistical analysis included comparisons between pesticide residuals following different decontamination solution applications per pesticide; comparisons in pesticide residuals between single and double decontamination solution applications; and comparisons in residuals among the three materials per decontamination solution.

3. Results

3.1. Persistence of pesticides in simulated indoor environment

The mean recovered mass for carbaryl, fipronil, deltamethrin, and permethrin from a stainless-steel material surface as function of time (up to 140 days) is shown in Fig. 1. Persistence test results for malathion are not reported due to high inconsistencies in the extracted malathion within the first two weeks of the experiment. This was attributed to the high dilution ratio of the extract prior to analysis leading to concentrations close to the MQL. The malathion persistence test was not repeated. Analysis of the deltamethrin samples was limited to five time points as extracts were lost due to a solvent extraction step error for two time points.

Fig. 1.



Open in a new tab

Recovered pesticide mass as function of time in dark and indoor light conditions on stainless-steel. Error bars are one standard deviation from the mean (n = 3). Panel A: Carbaryl data. Panel B: Fipronil data. Panel C: Deltamethrin data. Panel D: Permethrin data.

None of the pesticides were detected on any of the procedural and laboratory blanks. In a dark environment, all pesticides were found to be highly persistent with near equal amounts of pesticide recovered after 140 days compared to the contamination level at the start. Initial contamination levels were based on observed surface concentrations from various pesticide misuse investigations. In the presence of simulated indoor light conditions, some degradation of most of the pesticides was observed. Estimated half-life values on a nonporous stainless-steel surface in an indoor light environment were derived from a single first-order kinetics model which

specifies that the rate of concentration decline is proportional to the concentration in the system. Fitted half-life values are tabulated in Table 3. Half-life values range from 166 days for fipronil and deltamethrin to 286 days for permethrin. A linear fit to the dark indoor condition persistence data for carbaryl, fipronil and deltamethrin resulted in slope values that were not statistically significantly different from zero ($p < 0.05$). Hence, half-life values in dark environments could not be calculated based on these data but are expected to exceed 500 days. No appreciable degradation was observed for carbaryl on stainless-steel over the 140-day period in both dark and indoor light environments. The initial increase (Day 1 to Day 21) in recovered amounts of carbaryl from the stainless-steel coupons in both the dark and indoor light environment is probably due to an analytical bias in the highly diluted carbaryl samples. For comparison, Table 3 includes reported half-life values for water and soil. Reported ranges in water and soil half-life values are mainly due to their dependence on pH in water or the soil type and depth (Gervais et al., 2009; Mastrota and Wente, 2009; Bond et al., 2016; Jackson et al., 2009; Fipronil, 2011; Johnson et al., 2010; Toynton et al., 2009). The analysis of the extracts by LC-MS/MS did not include identification of possible degradation products except for the fipronil persistence test where fipronil sulfone was included in the analysis. Fipronil sulfone (data provided in Supplemental Materials) was present in each sample (approximately 200 ng/coupon or less than 2% of applied fipronil mass) from Day 0 to Day 140 with no noticeable change in mass recovered as function of time and independent on dark/indoor light conditions.

Table 3.

Persistence Half-Life values of Selected Pesticides on Stainless-Steel

Pesticide	Half-Life on SS with Light ± SD (days)	Half-Life on SS in Dark (days)	Half-Life in Water (days)	Half-Life in Soil (days)	Soil/Water Reference
Malathion	Not measured	Not measured	1.7–17[1]	1–17	27,30,31
Carbaryl	ND; >500	ND; >500	4[2]	16 (at surface) –72 (in soil)	32
Fipronil	166 ± 62	ND; > 500	0.25–0.5[3]	125	33,34
Deltamethrin	166 ± 42	ND; > 500		5.7– 209	35
Permethrin	286 ± 91	ND; > 500	0.8–1.1[5]	40	36

Open in a new tab

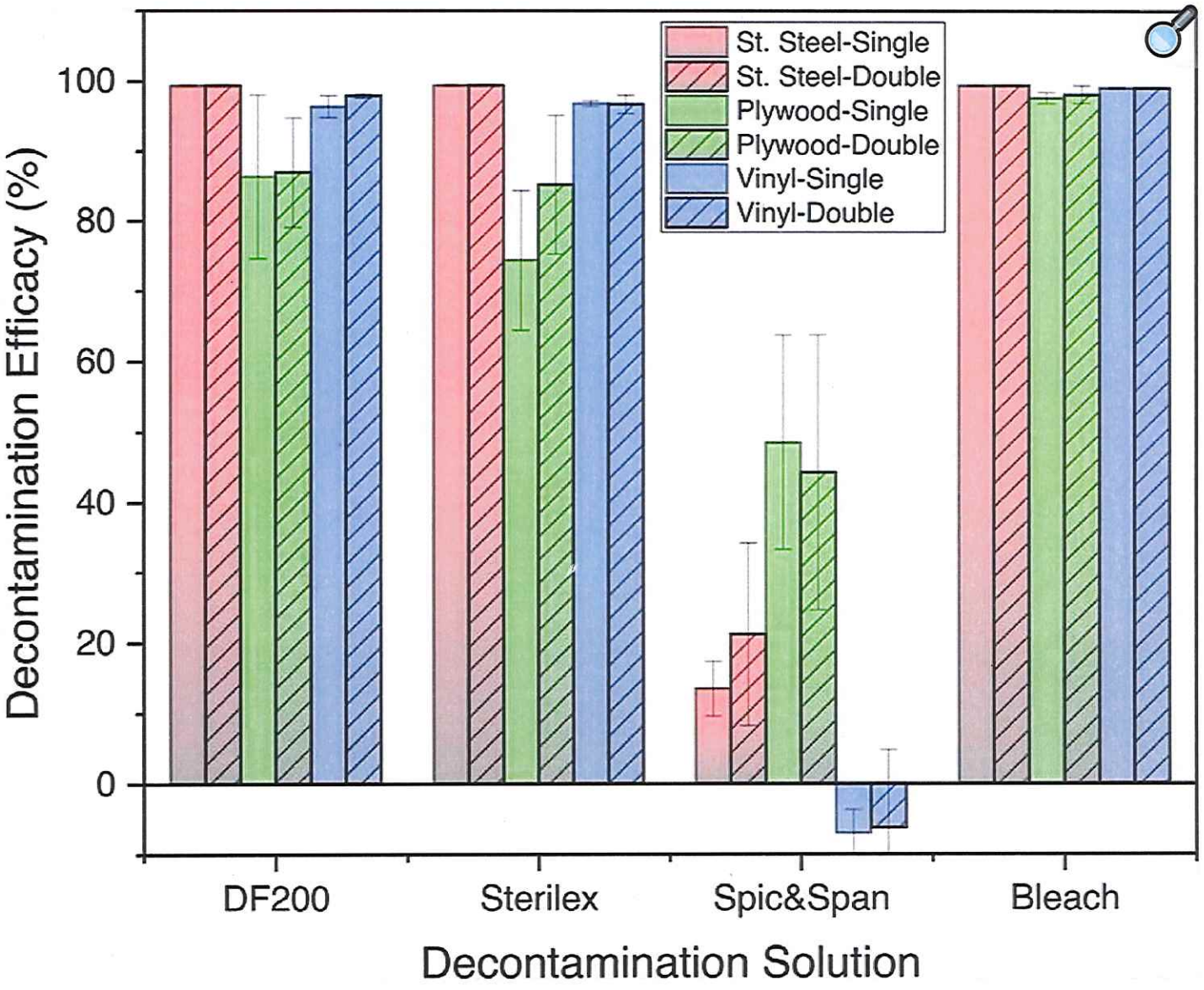
SS: Stainless-Steel.
ND: Not determined due to lack of decay.
SD: Standard deviation in fitted half-life value.

3.2. Decontamination results for indoor building materials contaminated with malathion

Decontamination efficacy values for a single or double application of the decontamination solution followed by an 18 hr contact time (simulating an overnight drying) are shown in Fig. 2 for indoor materials contaminated with 400 μg/100cm^2 malathion. For malathion, decontamination using Spic&Span left more than 50% of the initial malathion applied on the surface after an 18 hr contact time. All other tested decontaminants (DF200, Sterilex, and bleach) yielded greater than 96% reduction in malathion on stainless-steel and vinyl. Decontamination of plywood was noticeably less efficacious than that of stainless-steel or vinyl except when bleach was used. A second application of the same decontamination solution 90 min after the first application improved the

efficacy for plywood. For the other two materials, residual malathion levels were already at or just above the MQL (equivalent to 2.5 μg/100cm^2 malathion) after one application of DF200, Sterilex, and bleach. Hence, the impact of a second application for these two materials could not be established. Residual malathion levels after a single or double application are tabulated in Table 4. Malathion was not detected on any of the procedural and laboratory blanks.

Fig. 2.



Open in a new tab

Decontamination efficacies for tested decontaminants against malathion. Error bars in efficacy are one standard deviation from the mean (n = 3).

Table 4.

Pesticides Residuals after Decontamination of 10 cm^2 Surfaces

Pesticide	Decontaminant	Recovered mass from SS (Mean ± SD, µg)		Recovered mass from plywood (Mean ± SD, µg)		Recovered mass from vinyl (Mean ± SD, µg)	
		Number of Applications		Number of Applications		Number of Applications	
		1	2	1	2	1	2
Malathion	**DF200**	0.25*	0.25*	3.8 ± 3.2	3.6 ± 2.2	1.1 ± 0.5	0.6 ± 0.1
	Sterilex	0.25*	0.25*	8.1 ± 3.0	4.7 ± 3.1	1.2 ± 0.1	1.2 ± 0.5
	Spic&Span	37 ± 1.6	34 ± 5.5	18 ± 5.2	19 ± 6.6	30 ± 0.2	30 ± 3.0
	Bleach	0.25*	0.25*	0.91 ± 0.27	0.63 ± 0.41	0.25*	0.25*
Carbaryl	**DF200**	5.0 ± 0.0	0.08 ± 0.02	37 ± 20	31 ± 22	0.05 ± 0.02	0.04*
	Sterilex	49 ± 10	25 ± 12	129 ± 38	83 ± 32	36 ± 19	3.3 ± 1.9
	Bleach	158 ± 20	97 ± 21	141 ± 41	103 ± 23	122 ± 25	107 ± 28
Fipronil	**DF200**	0.05*	0.05*	0.97 ± 0.47	1.5 ± 0.95	0.07 ± 0.02	0.056 ± 0.001
	Bleach	0.05*	0.05*	3.9 ± 1.5	3.2 ± 2.5	0.05*	0.05*
Deltamethrin	**DF200**	0.05*	0.05*	0.24 ± 0.12	0.14 ± 0.09	0.15 ± 0.17	0.17 ± 0.18
	Bleach	0.05*	0.05*				
Permethrin	**DF200**	48	49	16 ± 2.0	14 ± 2.8	20 ± 7.1	15 ± 1.2
	Bleach	4.3 ± 3.4	3.1 ± 1.8				

SD: Standard deviation to the Mean.
*Method quantification level (MQL) with no standard deviation; residuals were at or below this value and not quantified.

Residual malathion amounts were highest when using Spic&Span followed by Sterilex, DF200 and bleach for the stainless-steel plywood, and vinyl materials. A statistical comparison of residual malathion amounts following decontamination showed that residue levels were only significantly different ($p < 0.05$) between those following the Spic&Span application and any of the other three decontaminants, while residuals among the three decontaminants were not significantly different statistically ($p > 0.05$). The observed reduction in residual malathion associated with two applications of decontamination solution were not significantly different from the results following a single application of decontamination solution ($p > 0.05$). When comparing malathion residuals after a double decontamination application, plywood generally had the highest amount of malathion remaining followed by vinyl and stainless-steel. However, the residual malathion on plywood was not significantly different statistically ($p > 0.05$) from that on stainless-steel or vinyl. The only exception was for the Spic&Span product where the residual amount of malathion on plywood was significantly different from that on vinyl or stainless-steel.

All malathion extracts were screened for the presence of malaoxon, a toxic oxidation byproduct of malathion. One extract out of three replicates associated with the bleach decontamination of the plywood contained malaoxon. The recovered malaoxon mass from this single coupon was not quantified. No malaoxon was observed in extracts following decontamination with the other decontaminants DF200, Sterilex, and Spic&Span.

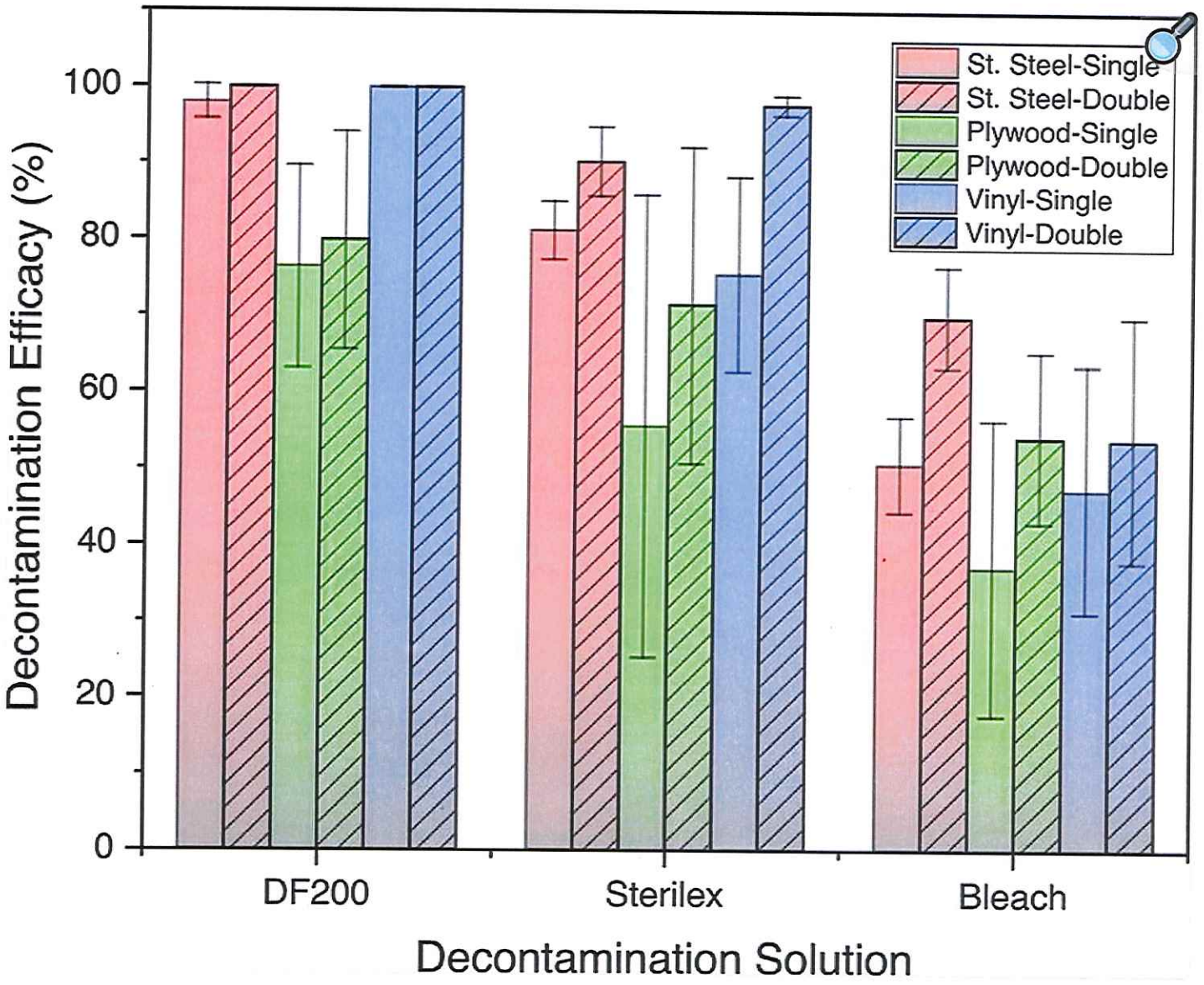
The Spic&Span product was not evaluated further against the other pesticides based on its poor decontamination performance against malathion and the lack of an active oxidative ingredient.

3.3. Decontamination results for indoor building materials contaminated with carbaryl

Fig. 3 summarizes the decontamination efficacies as observed when applying DF200, Sterilex, and bleach for single and double applications onto the three materials contaminated with carbaryl (at a 2400 $\mu g/100cm^2$ surface concentration). Efficacies were highest when using the DF200 product followed by Sterilex and bleach. For carbaryl, efficacies exceeding 99% were only observed for the DF200 solution when applied to stainless-steel and vinyl. This material dependence was not

observed with bleach although bleach efficacies never exceeded 70% across all materials. Residual carbaryl levels after one or two decontaminant applications are tabulated in Table 4. Carbaryl was not detected on any of the procedural and laboratory blanks. As was the case for malathion contaminated materials, a double application of decontamination solution did not yield significantly different ($p > 0.05$) residual carbaryl levels except for bleach on stainless-steel. Here, a significant reduction ($p = 0.02$) in residual carbaryl was observed when bleach was applied twice. Although residuals on plywood after any of the decontamination tests were higher than those on other materials, these differences were not significantly different statistically ($p > 0.05$) except when comparing carbaryl residuals on plywood against those on vinyl after decontamination with Sterilex.

Fig. 3.



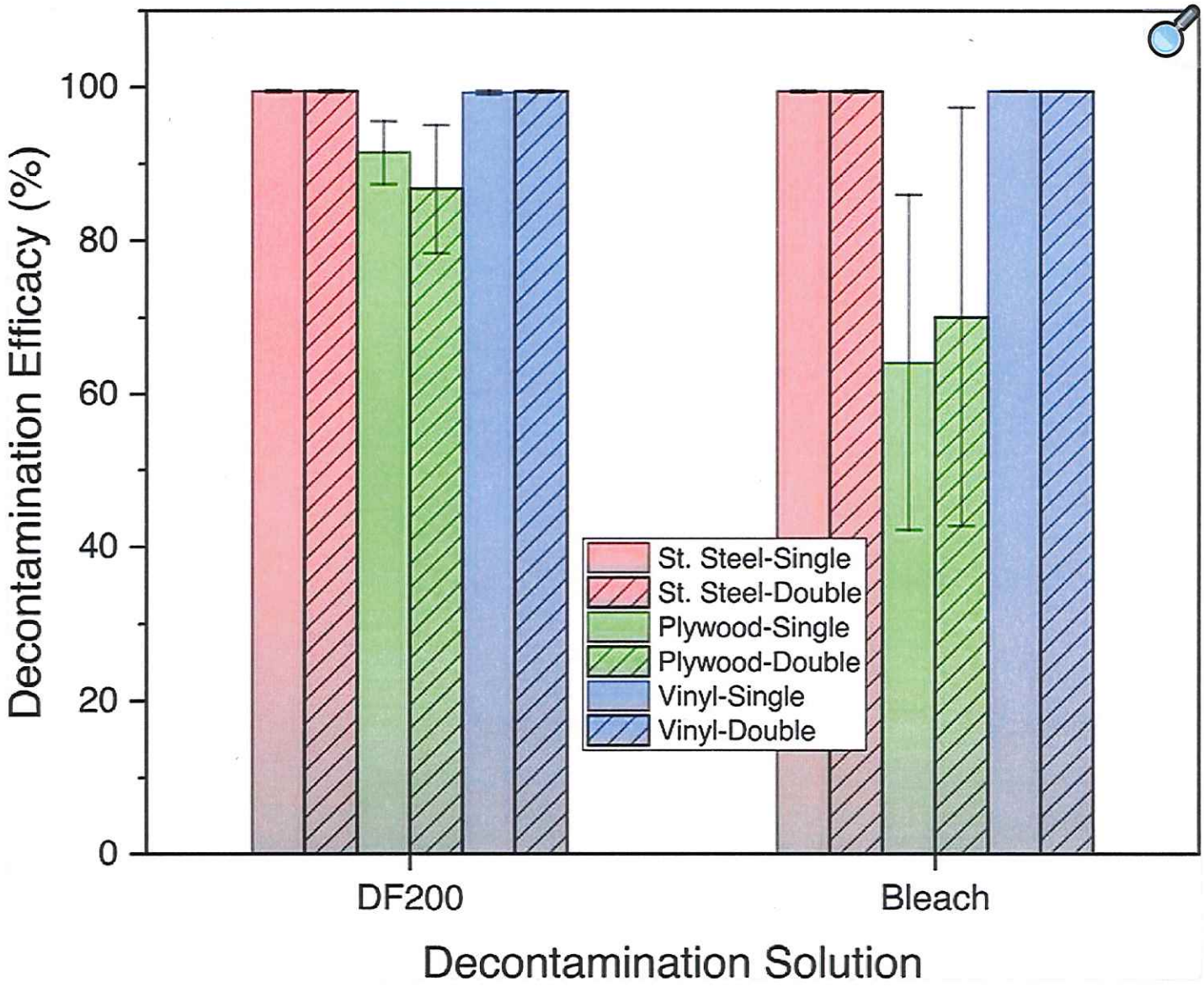
Open in a new tab

Decontamination efficacies for tested decontaminants against carbaryl. Error bars in efficacy are one standard deviation from the mean (n = 3).

3.4. Decontamination results for indoor building materials contaminated with fipronil

The decontamination efficacy results for fipronil contaminated materials are shown in Fig. 4. These decontamination tests were limited to the DF200 and bleach solutions. Both solutions accomplished a better than 99% reduction in fipronil mass (applied at 150 μg/100cm^2), even after a single application except when applied to plywood. The repeated application did not improve decontamination efficacy appreciably for both decontamination solutions. Residual fipronil amounts after decontamination are tabulated in Table 4. Fipronil was not detected on any of the procedural and laboratory blanks. Residual amounts of fipronil after one application were at or just above the MQL (equivalent to 0.5 μg/100cm^2 for fipronil) for both decontaminants on stainless-steel and vinyl. In decontamination tests in which residual fipronil was above the MQL, none of the residuals were found to be significantly different ($p > 0.05$) in a direct comparison between the two decontaminants. The changes in residual amount of fipronil after a repeated application of DF200 and bleach were not statistically significant ($p > 0.05$). Plywood was more difficult to decontaminate with bleach with statistically significant higher amounts of fipronil recovered after a single application. Residuals on plywood after a second application of bleach were not significantly different compared to the residuals on the other two materials.

Fig. 4.



Open in a new tab

Decontamination efficacies for tested decontaminants against fipronil. Error bars in efficacy are one standard deviation from the mean (n = 3).

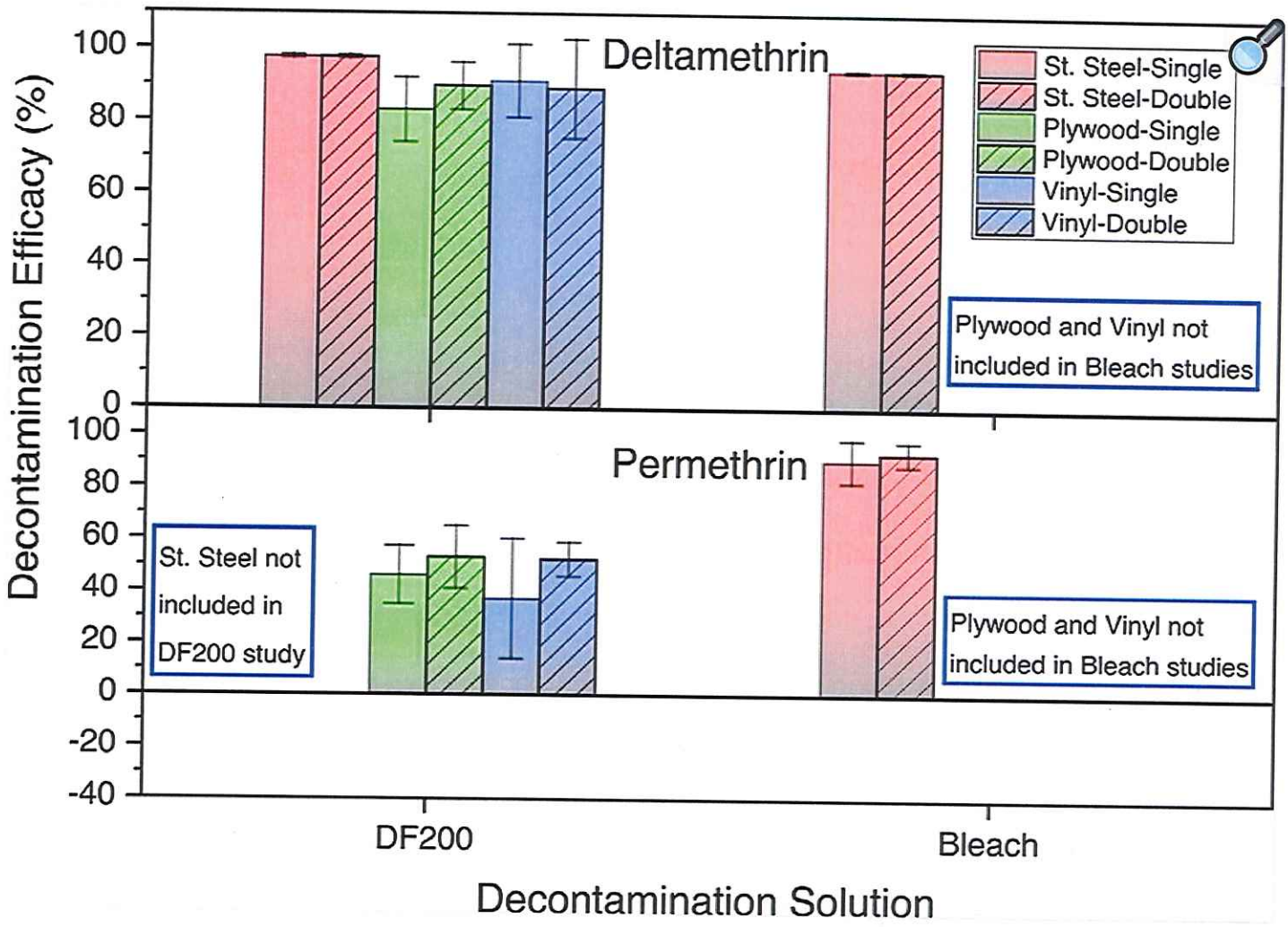
All extracts were screened for the presence of fipronil amide, fipronil desulfinyl, fipronil sulfone as three possible fipronil degradation byproducts (Tingle et al., 2003; Odenkirchen and Wente, 2011). All three byproducts were detected in small quantities (up to 0.015 µg fipronil amide; up to 0.05 µg for fipronil desulfinyl and up to 0.25 µg fipronil sulfone per extract / 10 cm^2 size coupon) in the

test coupon extracts of all materials and across both decontaminants. They were also detected in the positive control extracts at the same levels/concentrations. Hence, it was impossible to attribute the detection of these three byproducts to their formation during the decontamination process with either decontaminant. Further, these byproduct concentrations were in the same order of magnitude to a factor 10 lower than residual fipronil following decontamination of the materials.

3.5. Decontamination results for indoor building materials contaminated with pyrethroids

The efficacy testing for materials contaminated with the pyrethroids deltamethrin and permethrin (at 25 and 500 μg/100cm^2, respectively) are summarized in Fig. 5. Decontamination testing for bleach was limited to stainless-steel material only. For deltamethrin, stainless-steel was the easiest material to decontaminate (better than 94% efficacy) with both DF200 and bleach leading to residuals near or below the MQL of 0.5 μg/100cm^2. Where low efficacies were observed, a second application of the same decontaminant resulted in a slightly improved efficacy. The results for permethrin are different from deltamethrin as efficacy values with the DF200 product never reached 55%. Residual contamination levels for these two pyrethroid pesticides after decontamination with DF200 and bleach are summarized in Table 4. Both pyrethroids were not detected on any of the procedural and laboratory blanks. Deltamethrin residuals following decontamination with DF200 were below the MQL (0.05 μg/coupon) for stainless-steel while higher residuals were detected on vinyl and plywood. These higher residuals were not significantly different ($p > 0.05$) than those for stainless-steel. Deltamethrin residuals following decontamination with bleach were limited to the stainless-steel material. The repeated application of DF200 or bleach did not result in statistically significantly lower residuals of deltamethrin. This statement is biased since the MQL for residual deltamethrin was already reached for stainless-steel after a single application of both DF200 and bleach. The differences in residual deltamethrin levels across the three materials were not significantly different statistically ($p > 0.05$). Permethrin residuals following decontamination with DF200 were noticeably higher than those following bleach decontamination although there is no direct overlap in the tested materials. The repeated application did not significantly reduce residuals ($p > 0.05$) for either decontaminant on tested materials. Residuals pyrethroids on the plywood and vinyl surfaces following DF200 decontamination were not significantly different statistically ($p > 0.05$).

Fig. 5.



Open in a new tab

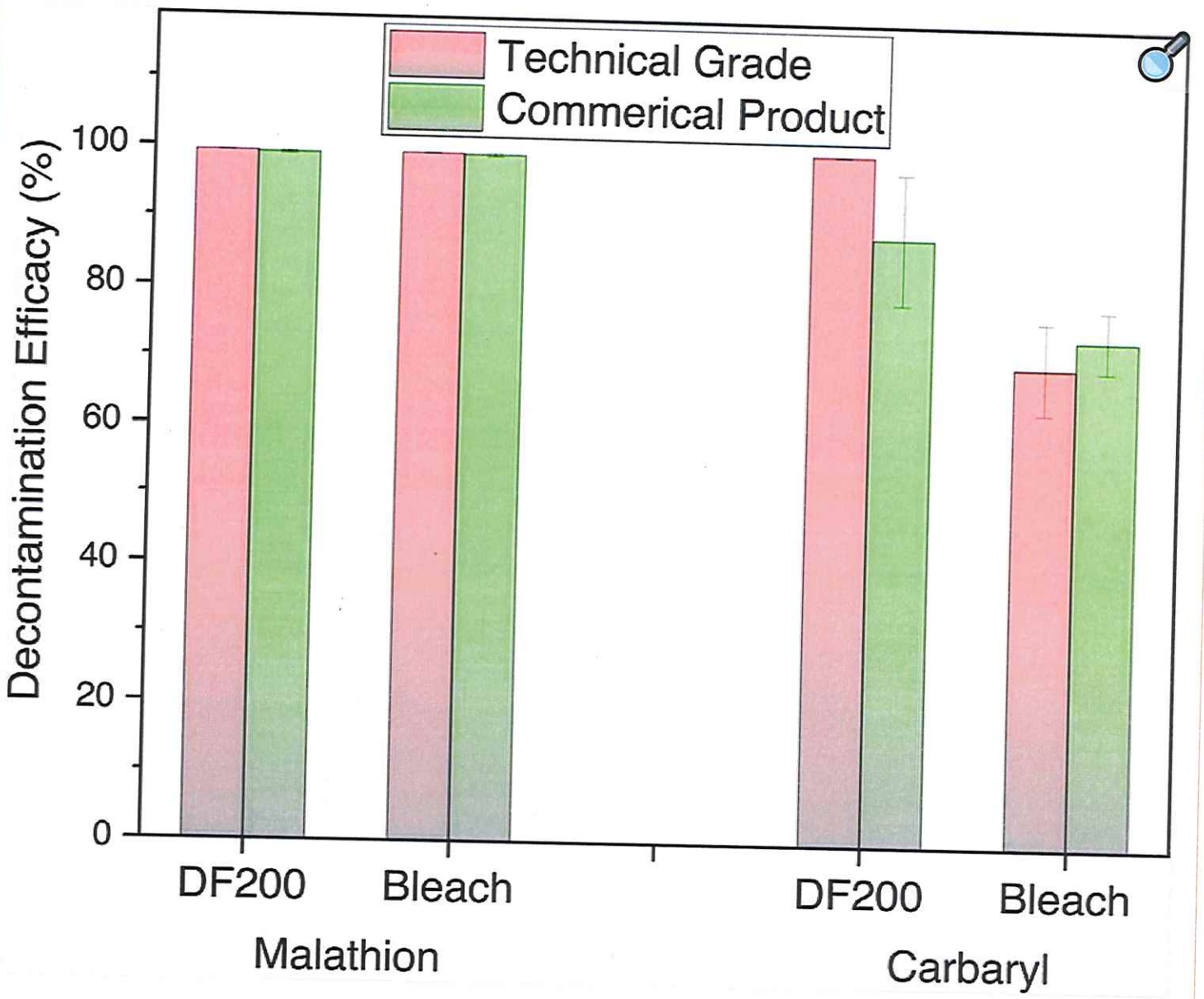
Decontamination efficacies for tested decontaminants against deltamethrin (upper panel) and permethrin (lower panel). Error bars in efficacy are one standard deviation from the mean (n = 3).

3.6. Decontamination results for indoor building materials contaminated with commercial pesticide formulations

Decontamination efficacy results shown so far were based on the use of a technical grade pesticide product. In most pesticide misuse cases, a commercial formulation would have been applied. Fig. 6

shows the observed efficacies for the DF200 and bleach products when decontaminating a stainless-steel surface contaminated with the formulated pesticide products Ortho MAX (containing 25–50% malathion) and Sevin (containing 43% carbaryl by weight) at the same pesticide loading used for the other decontamination studies. Decontamination efficacies were better than 99.2% with no detectable residual malathion after DF200 or bleach applications on stainless steel surfaces that were contaminated with either technical grade malathion or Ortho Max. Efficacies using the DF200 product were somewhat lower when decontaminating stainless steel contaminated with Sevin (88%) than with technical grade carbaryl (>99.9%). Efficacies when using bleach to decontaminate stainless steel contaminated with Sevin was 74% which is slightly higher than when contaminated with technical grade carbaryl (70%).

Fig. 6.



Open in a new tab

Decontamination efficacies for DF200 and bleach for decontamination of stainless-steel contaminated with malathion and carbaryl using a technical grade standard and commercial products Ortho MAX and Sevin, diluted to equal concentration of the technical grade standard.

4. Discussion

The persistence test results show that pesticide mass on the tested surfaces does not readily dissipate in indoor environments. Calculated half-life values from a first order exponential decay of the recovered mass data are noticeably longer than half-life in water and comparable to those in soil. The lack of liquid water, sunlight, or only low levels of (different) microbes in an indoor environment will limit the natural degradation of these pesticides. This is consistent with field observation of pesticide residues from applications that were made several years earlier (Starr et al., 2014). Further research should consider whether any toxic byproducts are formed during the prolonged presence of these pesticides on these indoor materials.

The decontamination efficacy tests show that effective decontamination approaches exist that can reduce the initial pesticide mass by more than 95%. The hydrogen peroxide chemistry existing in DF200 and Sterilex products was found to be highly effective for degrading malathion, carbaryl, fipronil, deltamethrin, and permethrin on stainless-steel, plywood, and vinyl. Hydrogen peroxide is a strong oxidant with a pH dependent electrochemical oxidation potential ranging between 0.87 and 1.80 V (Neyens and Baeyens, 2003). Similarly, the hypochlorite oxidation (oxidation potential 0.95 V at pH 9.5 Lavkulich and Wiens, 1970) in bleach effectively reduced the mass of all tested pesticides except for permethrin. A comprehensive understanding of the decontamination mechanisms/reactions cannot be derived from this study alone. Such effort requires liquid reactor chemistry experiments that utilize a comprehensive suite of chemical analysis instrumentation that were beyond the scope of this study.

Based on the observed degradation of malathion in the environment, malathion is expected to have been initially oxidized at the P = S bond to its P = O oxon analog, malaoxon, which is more toxic than the parent compound but would have likely degraded further to O,S-Dimethyl phosphorothioate and diethyl succinate (Laveglia and Dahm, 1997). Malaoxon was detected as a malathion degradation product in one of the seventy-two decontamination test samples. The very limited detection of malaoxon as an oxidation byproduct can be attributed to the continued degradation of malaoxon by the same decontaminant, especially under higher pH conditions (Paschal and Neville, 1976). Similarly, malathion can also rapidly hydrolyze without malaoxon formation at more alkaline pH levels as present in bleach (pH > 11) (Brown et al., 1993).

Degradation of carbaryl is likely to have involved the hydrolysis to 1-naphthol and methylamine (Siampiringue et al., 2019) followed by further degradation into more benign byproducts. The current toxicological profile for carbaryl (Blacker et al., 2010; Jones and Steeger, 2010) does not identify degradation byproducts of significant toxicity that should be avoided or minimized in the carbaryl degradation process.

Degradation of fipronil in the presence of hydrogen peroxide or hypochlorite is expected to lead to the intermediate formation of fipronil sulfone and fipronil-desulfinyl (oxidation) and fipronil-amide (hydrolysis) (Tingle et al., 2003; Odenkirchen and Wente, 2011). These byproducts were detected in extracts following decontamination of a fipronil-contaminated surface but also in the not-decontaminated positive control extracts. There was no noticeable difference in byproduct concentration between test coupon and positive control coupon extracts which suggests that no additional byproducts were created during the degradation by bleach or DF200 of fipronil on these surfaces.

The degradation of the pyrethroids deltamethrin and permethrin is expected to follow a combined hydrolysis and/or oxidation process (Agency for Toxic Substances and Disease Registry (ATSDR), 2003). The hydrolysis is enhanced under alkaline conditions such as observed when using bleach. The current toxicological profile for these pyrethroids (Agency for Toxic Substances and Disease Registry (ATSDR), 2003) does not identify degradation byproducts of significant toxicity that should be avoided or minimized in the permethrin or deltamethrin degradation process.

The use of full-strength bleach without any dilution to clean surfaces is not recommended under normal conditions. Further research is needed to address whether a diluted bleach product can still be as efficacious as observed in this study. Such effort would also need to verify whether the degradation reaction may become incomplete leaving malaoxon as a persistent toxic degradation byproduct on the surface.

The limited improvement in efficacy and associated limited reduction in residual pesticides on these surfaces by including a second application suggests that the amount of decontaminant on a molar basis in a single application is enough to reach high efficacy. Efficacy for bleach was not significantly affected by the presence of other ingredients that are included in the tested commercial formulations Ortho Max and Sevin. When DF200 was used to decontaminate the Sevin product on stainless steel, more unreacted carbaryl remained on the surface in comparison to the decontamination of technical grade carbaryl on the same surface. This suggests that other ingredients in the Sevin product provide demand for the DF200 active ingredients which prevents a full degradation of carbaryl on the surface. Such loss may be overcome through reapplication of the decontamination product,

Investigations of the efficacy of surface decontaminants, against VX, a highly persistent OP compound, produced comparable results. Efficacy values for bleach against most of the tested pesticides were similar or higher than those obtained for VX (Love et al., 2011). In that study, the reported efficacies were 42–67% after a 24 hr contact time, depending on the material. A 10×

diluted bleach solution with an added surface wetting agent (trisodiumphosphate) was used and the starting concentration of VX was higher (10 mg/100cm^2 range) in comparison to the pesticide surface concentrations. This suggests that the use of diluted bleach in the presence of high levels of contamination may not be as efficacious, however, such decontamination efficacy is chemical specific and can be material dependent. The VX study also evaluated DF200 and the efficacy results are similar to those observed in this pesticide study. In the VX study, efficacies were 75–99% after a 24 -h contact time depending on the material, with one exception of noticeably lower efficacy for vinyl tile material (20%). Consistent high efficacy values on vinyl material were observed in the pesticide study.

In this study, initial pesticide surface concentrations were representative of the pesticide-specific levels measured during field investigations involving misapplications of pesticides in homes or businesses. These concentrations varied widely from 25 μg/100cm^2 (deltamethrin) to 2,400 μg/100cm^2 for carbaryl yielding molar ratios of active ingredient in the decontamination solution over the pesticide solution ranging from approximately 40 (Sterilex/carbaryl) to over 22,000 (DF200/deltamethrin). Although this study was limited to one surface concentration per pesticide, it is expected that surfaces contaminated with a lower pesticide surface concentration would be equal or easier to clean as this molar ratio would be larger. For higher pesticide surface concentrations, the molar ratio may become close to the stoichiometric ratio likely resulting in lower decontamination efficacy values.

The long contact time (18 hr), simulating an overnight drying of the decontamination solution, allows for degradation reactions to continue potentially longer than if the decontaminant was rinsed or neutralized shortly after application. However, it is expected that the eventual drying of the decontaminant through evaporation (occurring in time frame of several hours; no information collected) will limit further degradation beyond the time of decontamination solution evaporation. Among the materials tested, residual pesticide amounts on plywood were in most cases higher than those on stainless-steel and vinyl. In addition, the variability in recovered pesticide mass from plywood was noticeably higher than those from stainless-steel and vinyl. This may be due to the nonhomogeneous nature of plywood that can lead to variations in the degree of pesticide permeation. Water-based decontaminants applied to the surface would be unable to access pesticides that permeate into the plywood.

5. Conclusions

The bench scale decontamination efficacy test results reported here are a first step in identifying and developing decontamination strategies for indoor environments following pesticide misuse.

Further research is needed to evaluate the potential effects of decontamination methods used in the field, including material compatibility, safety concerns, how decontaminant solutions are applied, and the use of physical removal processes, such as scrubbing and/or rinsing of surfaces. * Also, the decontamination efficacy values are not connected to achieving a particular cleanup level or health-based criteria. As noticed when decontaminating plywood and as observed in other studies (Oudejans et al., 2018) for a painted drywall material, the transport of a pesticide into a permeable material or into paint/coating covering a material plays a significant role in whether these decontamination technologies are equally successful in cleaning surfaces that are abundant in an indoor environment. The presence of these permeable materials in an environment where pesticide misuse occurs may drive the decision to forego *in situ* cleaning and instead remove the material to meet the health-risk based cleanup standard. Such clearance goals are pesticide specific and may be depend on the extent of pesticide application and the potential exposure to the affected indoor surfaces.

This study was conducted to provide information to federal, state, tribal, and local agencies about decontamination approaches for residential or commercial buildings to reduce occupant exposure following pesticide misuse incidents. The mechanistic details of the degradation chemistries are pesticide specific, although the same degradation approach may be applicable by first approximation for the same class of pesticides such as pyrethroids, organophosphate or carbamates. Decontamination practices should be tailored to the specific pesticide(s) involved to maximize its efficacy and minimize the risk of transferring contamination within and from the site. Further, formation of toxic decontamination byproducts should be avoided. This may need to be evaluated on a case-by case basis.

* As opposed to molecular reconstruction using balanced and buffered ClO_2.

Supplementary Material

NOT AVAILABLE AT the time of This test.

* ClO_2 does NOT remove/EXTRACT, it decompoles AT molecular level. No worries AS to WHAT to do with highly toxic WASTE AS it is eliminated through molecular chemical reaction AND reduced to harmless by products

Sup1

NIHMS1602240-supplement-Sup1.docx (55.6KB, docx)

Highlights.

- Decontamination solutions were assessed on the ability to degrade misused pesticides.
- The persistence of selected pesticides on a building material was measured.
- Initial pesticide contamination levels were based on pesticide misuse cases.
- High efficacies were measured leading to significant degradation of the pesticides.
- More research is needed to evaluate effects of decontamination methods in the field.

Acknowledgments and Disclaimer

The authors thank Eric Morris for his contributions to the development of procedures for preparation of spiking solutions of commercial formulations as part of the decontamination tests. The "Pesticide Contamination" image in the graphical abstract was provided courtesy of Lyn Garling, Penn State University (retired). The U.S. EPA Region 5 Office funded the research through the Regional Applied Research Effort (RARE) program administered by the Office of Science Policy (OSP). The EPA Office of Research and Development managed the research described herein under contracts EP-C-09–027 with ARCADIS U.S., Inc. and EP-C-15–008 with Jacobs Technologies, Inc. It has been reviewed by the Agency but does not necessarily reflect the Agency's views. No official endorsement should be inferred. EPA does not endorse the purchase or sale of any commercial products or services.

Footnotes

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Appendix A. Supplementary data

The following are Supplementary data to this article:

https://ars.els-cdn.com/content/image/1-s2.0-S0304389420307329-mmc1.docx

References

1. Pesticide Registration Manual 2020, U.S. Environmental Protection Agency, Last accessed August 14, 2019, https://www.epa.gov/pesticide-registration/pesticide-registration-manual

2. Rubin C, Esteban E, Assessment of human exposure and human health effects after indoor application of methyl parathion in Lorain County, Ohio, 1995–1996, Environmental Health Perspectives, 110 (2002), pp. 1047–1051 [DOI] [PMC free article] [PubMed] [Google Scholar]

3. Markowitz SB, Poisoning of an urban family due to misapplication of household organophosphate and carbamate pesticides, Clinical Toxicology., 30 (1992), pp. 295–303 [DOI] [PubMed] [Google Scholar]

4. Centers for Disease Control and Prevention, Acute Illnesses Associated with Insecticides Used to Control Bed Bugs – Seven States, 2003–2010, Morbidity and Mortality Weekly Report (MMWR), 60 (37) (2011), pp. 1269–1274, Last accessed September 1, 2019, https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6037a1.htm [PubMed] [Google Scholar]

5. Liu R, Alarcon WA, Calvert GM, et al. , Acute Illnesses and Injuries Related to Total Release Foggers — 10 States, 2007–2015.Centers for Disease Control and Prevention, Morbidity and Mortality Weekly Report (MMWR), 67 (4) (2018), pp. 125–130, 10.15585/mmwr.mm6704a4, Last accessed September 16, 2019 [DOI] [PMC free article] [PubMed] [Google Scholar]

6. Buhl K, Stone D, Powers L, Bedbug-related pesticide incidents reported to the National Pesticide Information Center (poster), Oregon State University, Department of Environmental and Molecular Toxicology; National Pesticide Information Center (NPIC) (2010), Last accessed September 1, 2019, http://npic.orst.edu/NPICbedbugposter101510 [Google Scholar]

7. Health Consultation, Pesticide Misapplication in a Private Residence, Parsons, Labette County, KS, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry; (2010),

https://www.atsdr.cdc.gov/HAC/pha/ParsonsMalathionStrikeTeam/ParsonsMalathionStrikeTeamHC1117.pdf., Last accessed September 1, 2019. [Google Scholar]

8. Clark JM, Bing-Canar J, Renninger S, et al. , Methyl Parathion in Residential Properties: Relocation and Decontamination Methodology, Environmental Health Perspectives, 110 (2002), pp. 1061–1070 [DOI] [PMC free article] [PubMed] [Google Scholar]

9. McCaule LA, Travers R, Lasarev M, Muniz J, Nailon R, Effectiveness of Cleaning Practices in Removing Pesticides from Home Environments, Journal of Agromedicine., 11 (2006), pp. 81–88 [DOI] [PubMed] [Google Scholar]

10. National Pesticide Information Center Annual Reports, National Pesticide Information Center Annual Reports, Oregon State University, Department of Environmental and Molecular Toxicology; NPIC (2019), pp. 1995–2018, Last accessed September 1, http://npic.orst.edu/reports.htm [Google Scholar]

11. Test Guidelines for Pesticides and Toxic Substances, Series 835 Fate, Transport and Transformation Test Guidelines, U.S. Environmental Protection Agency; (2019), https://www.epa.gov/test-guidelines-pesticides-and-toxic-substances/series-835-fate-transport-and-transformation-test . Last accessed September 16 [Google Scholar]

12. Class TJ, Kintrup J, Pyrethroids as household insecticides: analysis, indoor exposure and persistence, Fresenius J of Analytical Chemistry, 340 (1991), pp. 446–453 [Google Scholar]

13. Lu C, Fenske RA, Air and Surface Chlorpyrifos Residues following Residential Broadcast and Aerosol Pesticide Applications, Environ Sci Technol, 32 (1998), pp. 1386–1390 [Google Scholar]

14. Wright CG, Jackson MD, Insecticide movement following application to crevices in rooms, Archiv Environ Contam Toxicol, 4 (1976), pp. 492–500 [DOI] [PubMed] [Google Scholar]

15. Starr JM, Gemma AA, Graham SE, Stout II DM, A test house study of pesticides and pesticide degradation products following an indoor application, Indoor Air, 24 (2014), pp. 390–402 [DOI] [PubMed] [Google Scholar]

16. Stout II DM, Bradham KD, et al. , American Healthy Homes Survey: A National Study of Residential Pesticides Measured from Floor Wipes, Environ Sci Technol, 43 (2009), pp. 4294–4300 [DOI] [PubMed] [Google Scholar]

17. Tulve NS, Jones PA, et al. , Pesticide measurements from the first national environmental health survey of child care centers using a multi-residue GC/MS analysis method, Environ Sci Technol, 40 (2006), pp. 6269–6274 [DOI] [PubMed] [Google Scholar]

18. Julien R, Levi JI, et al. , Pesticides in urban multiunit dwellings: Hazard identification using classification and regression tree (CART) analysis, J Air Waste Manag. Assoc, 58 (2008), pp. 1297–1302 [PubMed] [Google Scholar]

19. Quandt SA, Arcury TA, et al. , Agricultural and Residential Pesticides in Wipe Samples from Farmworker Family Residences in North Carolina and Virginia, Environmental Health Perspectives, 112 (2004), pp. 382–387 [DOI] [PMC free article] [PubMed] [Google Scholar]

20. Julien R, Adamkiewicz G, et al. , Pesticide loadings of select organophosphate and pyrethroid pesticides in urban public housing, J Exposure Science and Environmental Epidemiology, 18 (2008), pp. 167–174 [DOI] [PubMed] [Google Scholar]

21. Bradman CAA, Whitaker D, et al. , Pesticides and their Metabolites in the Homes and Urine of Farmworker Children Living in the Salinas Valley, J Exposure Science and Environmental Epidemiology, 17 (2007), pp. 331–349, 10.1038/sj.jes.7500507, Last accessed September 16, 2019 [DOI] [PubMed] [Google Scholar]

22. Pesticide spill management, 2020. Pesticide spill management, Last accessed September 1, 2019, http://npic.orst.edu/incidents.html

23. U.S. Environmental Protection Agency, Evaluation of Household or Industrial Cleaning Products for Remediation of Chemical Agents, U.S. Environmental Protection Agency, Washington DC: (2011), EPA report 600-R-11–055. [Google Scholar]

24. Love AH, Bailey CG, Hanna ML, et al. , Efficacy of liquid and foam decontamination technologies for chemical warfare agents on indoor surfaces, Journal of Hazardous Materials, 196 (2011), pp. 115–122 [DOI] [PubMed] [Google Scholar]

25. Engineering ToolBox, Air Change Rate, [online] Available at: https://www.engineeringtoolbox.com/air-change-rate-d_882.html . Last accessed September 1, 2019, (2005)

26. Bavcon Kralj M, Černigo U, Franko M, Trebše P, Comparison of photocatalysis and photolysis of malathion, isomalathion, malaoxon, and commercial malathion—Products

and toxicity studies, Water Research, 41 (2007), pp. 4504–4514 [DOI] [PubMed] [Google Scholar]

27. Shelat S, Piper S, et al. , Malathion: Human Health Draft Risk Assessment for Registration Review, U.S. Environmental Protection Agency, Office of Chemical Safety and Pollution Prevention, Washington, DC: (2016), p. D414107, Last accessed September 12, 2019, https://www.regulations.gov/document?D=EPA-HQ-OPP-2009-0317-0080 [Google Scholar]

28. Tingle CC, Rother JA, Dewhurst CF, Lauer S, King WJ, Fipronil: Environmental fate, ecotoxicology, and human health concerns, Rev Environ Contam Toxicol, 176 (2003), pp. 1–66 [DOI] [PubMed] [Google Scholar]

29. Odenkirchen E, Wente S, et al. , Registration Review - Preliminary Problem Formulation for Ecological Risk and Environmental Fate, Endangered Species, and Drinking Water Assessments for Fipronil, U.S. Environmental Protection Agency (2011), p. DP387319, Last accessed September 12, 2019, https://www.regulations.gov/document?D=EPA-HQ-OPP-2011-0448-0006

30. Gervais JA, Luukinen B, Buhl K, Stone D, Malathion Technical Fact Sheet, National Pesticide Information Center, Oregon State University Extension Services (2009), Last accessed September 16, 2019, http://npic.orst.edu/factsheets/archive/malatech.html

31. Mastrota N, Wente S, et al. , Registration Review – Preliminary Problem Formulation for Ecological Risk, Environmental Fate, and Endangered species Assessments for Malathion, U.S. Environmental Protection Agency (2009), p. D359863, Last accessed September 12, 2019, https://www.regulations.gov/document?D=EPA-HQ-OPP-2009-0317-0002 [Google Scholar]

32. Bond C, Hallman A, Buhl K, Stone D, Carbaryl General Fact Sheet, National Pesticide Information Center, Oregon State University Extension Services (2016), Last accessed September 16, 2019, http://npic.orst.edu/factsheets/carbarylgen.html

33. Jackson D, Cornell CB, Luukinen B, Buhl K, Stone D, Fipronil General Fact Sheet, National Pesticide Information Center, Oregon State University Extension Services (2009), Last accessed September 16, 2019, http://npic.orst.edu/factsheets/fipronil.html

34. Fipronil, Human-Health Assessment Scoping Document in Support of Registration Review, U.S. Environmental Protection Agency (2011), p. D387318, Last accessed

September 12, 2019, https://www.regulations.gov/document?D=EPA-HQ-OPP-2011-0448-0004 [Google Scholar]

35. Johnson M, Luukinen B, Buhl K, Stone D, Deltamethrin General Fact Sheet, National Pesticide Information Center, Oregon State University Extension Services (2010), Last accessed September 16, 2019, http://npic.orst.edu/factsheets/DeltaGen.html

36. Toynton K, Luukinen B, Buhl K, Stone D, Permethrin General Fact Sheet, National Pesticide Information Center, Oregon State University Extension Services (2009), Last accessed September 16, 2019, http://npic.orst.edu/factsheets/PermGen.html

37. Neyens E, Baeyens J, A review of classic Fenton's peroxidation as an advanced oxidation technique, J. Hazard. Mater, 98 (2003), pp. 33–50 [DOI] [PubMed] [Google Scholar]

38. Lavkulich LM, Wiens JH, Comparison of Organic Matter Destruction by Hydrogen Peroxide and Sodium Hypochlorite and Its Effects on Selected Mineral Constituents, Soil Science Soc. of America Journal, 34 (1970), pp. 755–758 [Google Scholar]

39. Laveglia J, Dahm PA, Degradation of organophosphorus and carbamate insecticides in the soil and by soilmicroorganisms, Annu Rev Entomol, 22 (1997), pp. 483–513 [DOI] [PubMed] [Google Scholar]

40. Paschal DC, Neville ME, Chemical and Microbial Degradation of Malaoxon in an Illinois Soil, Journal of Environmental Quality, 5 (1976), pp. 441–443 [Google Scholar]

41. Brown MA, Petreas MX, Okamoto HS, Mischke TM, Stephens RD, Monitoring of malathion and its impurities and environmental transformation products on surfaces and in air following an aerial application, Environ. Sci. Technol, 27 (1993), pp. 388–397 [Google Scholar]

42. Siampiringue M, Chahboune R, Wong-Wah-Chung P, Sarakha M, Carbaryl Photochemical Degradation on Soil Model Surfaces, Soil Syst, 3 (2019), p. 17 [Google Scholar]

43. Blacker AM, Lunchick C, Lasserre-Bigot D, Payraudeau V, Krolski ME, Toxicological Profile of Carbaryl. Chapter 64 in Hayes' Handbook of Pesticide Toxicology, (Third Edition), Academic Press; (2010), pp. 1607–1617 [Google Scholar]

44. Jones RD, Steeger T, et al. , Registration Review – Preliminary Problem Formulation for Ecological Risk and Environmental Fate, Endangered Species, and Drinking Water Assessments for Carbaryl, U.S. Environmental Protection Agency (2010), p. D374937, https://www.regulations.gov/document?D=EPA-HQ-OPP-2010-0230-0004

45. Agency for Toxic Substances and Disease Registry (ATSDR), Toxicological profile for Pyrethrins and Pyrethroids, U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA: (2003) [PubMed] [Google Scholar]

46. Oudejans L, Wyrzykowska-Ceradini B, Morris E, Korff A, Assessment of Decontamination Solution Application Methods for Decontamination of Surfaces Contaminated with Pesticides, U.S. Environmental Protection Agency, Washington, DC: (2018), EPA/600/R-17/394. [Google Scholar]

Associated Data

This section collects any data citations, data availability statements, or supplementary materials included in this article.

Supplementary Materials

Sup1

NIHMS1602240-supplement-Sup1.docx (55.6KB, docx)