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Résumé de l’article
Des applications de lindane et de chlorpyrifos ont été étudiées pour déterminer si l’encapsulation dans un polymère augmente la répression du dendroctone méridional du pin (Dendroctonus frontalis), diminue l’étendue des retombées, augmente la durée d’adhésion à l’écorce ou réduit les contacts humains, en comparaison avec des applications de concentrés émulsifiés. L’encapsulation n’augmente pas l’efficacité et ne réduit pas les retombées des insecticides par rapport aux applications émulsifiées normales. L’encapsulation du chlorpyrifos augmente la persistance résiduelle mais n’affecte pas la persistance du lindane. Le risque de contact humain avec l’écorce encore humidifiée par le chlorpyrifos encapsulé est 2,2 fois plus élevé tandis que le risque de contact du lindane n’est pas influencé par l’encapsulation. Cependant, une fois l’insecticide séché, les applications encapsulées réduisent le risque de contact humain de 90% pour le lindane et de 83% pour le chlorpyrifos.
Efficacy, persistence, ground deposition, and human exposure of polymer-encapsulated lindane and chlorpyrifos used for control of the southern pine beetle

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Formulations of lindane and chlorpyrifos were evaluated to determine if polymer encapsulation extended the duration of southern pine beetle (Dendroctonus frontalis) control, reduced ground deposition, increased persistence on bark or reduced potential human exposure relative to emulsifiable concentrate formulations. Encapsulation did not extend efficacy or reduce ground deposition of either insecticide when compared with the standard emulsifiable formulations. Encapsulation extended residue persistence of chlorpyrifos on bark, but not of lindane. The potential risk of human exposure to bark which was still wet with chlorpyrifos was increased 2.2 times by encapsulation, whereas, similar exposure to lindane was unaffected by encapsulation. After the insecticides had dried on the bark, the encapsulated formulations reduced risk to lindane by approximately 90% and by 83% for chlorpyrifos.


Des applications de lindane et de chlorpyrifos ont été étudiées pour déterminer si l’encapsulation dans un polymère augmente la répression du dendroctone méridional du pin (Dendroctonus frontalis), diminue l’étendue des retombées, augmente la durée d’adhésion à l’écorce ou réduit les contacts humains, en comparaison avec des applications de concentrés émulsifiés. L’encapsulation n’augmente pas l’efficacité et ne réduit pas les retombées des insecticides par rapport aux applications émulsifiées normales. L’encapsulation du chlorpyrifos augmente la persistance résiduelle mais n’affecte pas la persistance du lindane. Le risque de contact humain avec l’écorce encore humidifiée par le chlorpyrifos encapsulé est 2.2 fois plus élevé tandis que le risque de contact du lindane n’est pas influencé par l’encapsulation. Cependant, une fois l’insecticide séché, les applications encapsulées réduisent le risque de contact humain de 90% pour le lindane et de 83% pour le chlorpyrifos.

Introduction

Lindane and chlorpyrifos are used for remedial and preventive control of bark beetles (Dendroctonus spp.) in high value pines (Pinus spp.) (Berisford and Brady 1976; Berisford et al. 1981a, 1981b; Billings 1980; Brady et al. 1980; Smith 1967). These pines are an important asset in residential and private landscaping programs and in public recreational areas such as parks and campgrounds. One application of lindane can prevent successful attack by the southern pine beetle (Dendroctonus frontalis Zimmermann) for up to one year, but at least two annual applications of chlorpyrifos are needed for comparable protection (Berisford and Brady 1976; Berisford et al. 1981a, 1981c; Brady et al. 1980). Because humans may contact sprayed bark, there is a potential risk of dermal absorption of the insecticides. This risk could be reduced by using a formulation which strongly binds to the bark so that the insecticide cannot easily be rubbed off or by decreasing the number of insecticide applications by using a formula-
tion which extends the protection period of
the insecticide.

One approach to extending the effective
life of insecticides is to encase them in a
polymer. In a laboratory bioassay study, a
polymer-encapsulated formulation of chlorpy-
rifos extended its efficacy (against cock-
kroaches, *Blatella americana* L.) up to 12
times that of the unencapsulated formulation
(C. M. Himel, University of Georgia, unpub-
lished data). In the field, encapsulated formu-
lations may extend the effective life of insec-
ticides by protecting them from weathering
and wash-off. The encapsulated formulations
may also reduce nontarget exposure since the
toxic materials are encased in the polymer
and, therefore, are not directly exposed to
humans or other animals which may contact
sprayed surfaces.

The objective of this study was to compare
the encapsulated formulation (ENC) of lindane
and chlorpyrifos with the standard emulsifi-
able concentrate formulation (EC) to déter-
mine if encapsulation can: 1) prolong or
enhance the efficacy of lindane and chlorpy-
rifos against the southern pine beetle; 2) re-
duce the potential deposition of pesticide on
the ground during application; 3) increase
residue persistence on bark; and 4) reduce
human exposure from incidental contact with
insecticides on bark.

**Material and methods**

Insecticides used in this study included
lindane (1, 2, 3, 4, 5, 6-hexachlorocyclohex-
ane, at least 99% gamma isomer) and chlorpy-
rifos (0, 0-diethyl, 0-[3, 5, 6-trichloro-2-pyr-
idyl] phosphorothioate, Dursban® formul-
ation). Insecticides were applied either as an
emulsifiable concentrate formulation (EC) or
as a polymer-encapsulated formulation (ENC).
The polymer encapsulated formulations were
supplied by Spray Control Systems, Inc.,
Watkinsville, GA, USA. The EC spray solu-
tions were made from either Lindane 20 EC
(20% lindane) or Dursban 4E (42.8% chlorpy-
rifos). Lindane and chlorpyrifos were applied
at 0.5% active ingredient and 2.0% active
ingredient, respectively, regardless of the
formulation used. All applications were made
with a high pressure hydraulic sprayer (1373-
2746 kPa). Tree boles were sprayed about
half way into the live crown.

**Efficacy study.** Loblolly pines (*Pinus taeda*
L.) at the University of Georgia School of
Forest Resources Experimental Forest,
Whitehall, Georgia, were sprayed with the
ENC or EC formulations between November
1985 and April 1986. Thirty trees were treated
with each formulation to allow up to two
years for evaluation if necessary. After the
insecticides had dried on the bark and at three-
month intervals thereafter, three trees per treat-
ment were felled, and two 1.5-m long bolts
(sections) were removed from the central
portion of each tree trunk for a total of 6
replicates per treatment. These bolts were
then exposed to southern pine beetle attack
within nearby infestations for two weeks by a
“hanging bolt” assay (Berisford *et al.* 1980).
Each bolt was baited with the southern pine
beetle aggregation pheromone, frontalure, and
fitted with a Stickem Special®-coated métal
screen (50 cm X 20 cm) to monitor beetle vi-
sitations. After two weeks, the numbers of
southern pine beetles trapped were counted.
The numbers of attacks identified by boring
holes and the total length of egg galleries were
recorded in a 1000 cm² area on each bolt
opposite the Stickem screen trap. Treatment
efficacy was determined by comparing the
mean number of attacks and the mean egg
gallery length among treated and control bolts.

**Persistence and ground deposition stud-
ies.** These studies were conducted on short-
leaf pine (*Pinus echinata* Miller) in the U.S.
Forest Service Beech Creek Seed Orchard,
Murphy, North Carolina from July 1985
through January 1987. Bark samples were
taken at breast height from three différent
trees per treatment at 2-3 h after spraying and
thereafter at three-month intervals for 18
months. Samples of the outer 1.27 cm of bark
to 100 g) were collected and processed for
pesticide residue analysis as described in Bush

Insecticide deposition on the ground was
measured on 9-cm diameter filter discs placed
beneath each of 10 trees per treatment. The
area circumscribed by a 3.65-m radius be-
neath each tree was sectored into four quad-
rants and two filter discs were randomly placed
in each quadrant. Trees were 4.5 m apart in
rows which were 9.12 m apart. Samples were
processed as described above for residues on
bark.
Human exposure study. Potential human exposure by contact with sprayed trees was simulated by firmly rubbing the chest area of cotton T-shirts for 30 s over a 0.37 m² area of treated bark. For residue analysis, a 20 cm X 20 cm patch from each T-shirt was extracted in toluène (lindane) or ethyl acetate (chlorpyrifos) and analyzed by gas chromatography (Bush et al. 1987). The test was conducted while bark was still wet with the insecticides and then one day later after the insecticides had dried on the bark. Each test was replicated 10 times. This study was conducted on loblolly pines at the University of Georgia School of Forest Resources Experimental Forest, Whitehall, Georgia, in December 1989.

Data analysis. The effect of formulation on pesticide efficacy, persistence, deposition on the ground, and human exposure was assessed by subjecting the data to an analysis of variance for unbalanced data. When the treatment effect was significant ($P < 0.05$), means were compared and separated by Duncan’s multiple range test. Statistical analyses were performed using programs from the SAS Institute, Inc. (SAS 1988).

Results and discussion

Efficacy. Encapsulation did not increase or extend the efficacy of lindane or chlorpyrifos (Fig. 1), even though chlorpyrifos residues were higher (Fig. 2). Although lindane dissipated from bark more rapidly than chlorpyrifos, it was more effective than chlorpyrifos, protecting trees from successful southern pine beetle attack (i.e., gallery construction) for at least 12 months. On lindane-treated trees, successful beetle attack occurred between 12 and 21 months after application (Fig. 1C). During this interval, bark residues fell below 30 ppm (Fig. 2A). These results are similar to previous reports of successful pine beetle attacks when bark residues fell to 37 ppm (Brady et al. 1980) or attacks of *Ips* spp. bark beetles when residues fell below 30 ppm (Berisford and Brady 1976). However, even at 21 months, both formulations of lindane provided a substantial level of protection relative to control trees. Whether this represents a biologically significant level of efficacy is unknown, since beetles had established a few egg galleries at the time of evaluation. The exact number of southern pine beetles required to kill trees has not been established. An 18-month evaluation could not be made because beetle populations were unavailable. However, lindane formulations should have been effective in preventing attack based on the 21-month data (ENC - 78% reduction in attacks and 90% reduction in total egg gallery length; EC - 90% reduction in attacks and 97% reduction in total egg gallery length).

Encapsulated chlorpyrifos afforded some protection initially but three months after application, mean gallery length was not significantly different between control and treated trees.

Persistence on bark. Lindane residues on bark sprayed with either formulation were not significantly different (Fig. 2A). In contrast, chlorpyrifos residues from the encapsulated formulation were 2.5 to 4.5 times higher than residues from the EC formulation on each sampling date (3 to 18 months after application, Fig. 2B). At the end of the 18-month sampling period, 39.2% of the initial chlorpyrifos residues remained on the bark of ENC-sprayed trees whereas, only 12.9% remained on the bark treated with the EC formulation.

Encapsulation increased the chlorpyrifos residue level on bark and decreased the degradation rate. The residue level from treatments sampled 0 to 18 months after application was high enough to prevent southern pine beetle attack (Fig. 2B). However, the amount of active ingredient actually available to the beetles was apparently unaffected by formulation and may have been “tied up” by the polymer. The net result was higher and more persistent bark residues but no increase in bark beetle control. It may be possible to adjust the polymer or similar systems to maintain the higher residues and still release enough toxicant to increase efficacy.

Deposition of insecticides on the ground. Encapsulation did not significantly affect the deposition of chlorpyrifos or lindane on the ground. The mean deposition ($±$ S.D.) of each formulation was as follows: chlorpyrifos EC - 1.837 ± 2.506 kg/ha, ENC - 1.167 ± 1.350 kg/ha; lindane EC - 0.026 ± 0.031 kg/ha, ENC - 0.047 ± 0.034 kg/ha.

Human exposure. Chlorpyrifos residues on T-shirts rubbed on the bark that was still wet with the encapsulated formulation were...
2.2 times greater than that from the EC formulation, but there was no significant difference in lindane residues between the different formulations (Fig. 3A). The higher residue levels on the T-shirts rubbed on bark wet with encapsulated chlorpyrifos may be at least partly due to differential drying times between the ENC and EC formulations. The

Figure 1. Efficacy of lindane and chlorpyrifos formulations in controlling the southern pine beetle: (A) number of beetles on traps placed on treated tree bolts, (B) number of boring holes in bark, and (C) total length of southern pine beetle egg galleries. The same letters over graph bars indicate no significant difference ($P > 0.05$) between formulations at each month following application. EC: emulsifiable formulation; ENC: encapsulated formulation.
encapsulated formulation may have taken longer to soak into or to bind with the bark. Once the insecticides had dried, residues on the T-shirts from trees treated with the encapsulated formulations were approximately 10% and 17% of that from the EC formulations for lindane and chlorpyrifos, respectively (Fig. 3B). Therefore, once dried on the bark, the encapsulated formulations significantly reduced human exposure risk relative to the EC formulations.

**Conclusion**

The encapsulated insecticides greatly reduced human exposure to both lindane and chlorpyrifos. These formulations might therefore be desirable for protection of trees in high-use areas such as parks and campgrounds. Although residues of encapsulated chlorpyrifos persisted at levels which should have extended protection from bark beetle attack relative to the EC formulation, actual efficacy was not significantly different between formulations. The toxicant was apparently tied-up within the polymer and was not contacted by attacking beetles. Encapsulation was therefore advantageous in reducing human exposure, but did not improve bark beetle control, nor did it reduce the amount of insecticide deposited on the ground during application. Perhaps the encapsulated formulations could be refined to release more toxicant to the beetles without significantly decreasing bark residues.
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