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HAL Id: hal-02665001

<https://hal.inrae.fr/hal-02665001>

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Access details: Access Details: [subscription number 788018687]

Publisher Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK

International Journal of Pest Management

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title-content=t713797655>

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Online Publication Date: 01 January 2008

To cite this Article Dabel, F. Al, Mensah, R. K. and Frerot, B. (2008) 'Effects of nC24 and nC27 petroleum spray oils on oviposition and egg survival of *Ostrinia nubilalis* Hübner (Lepidoptera, Pyralidae) and *Trichogramma brassicae* Bezdenko (Hymenoptera, Trichogrammatidae) adults on maize plants', *International Journal of Pest Management*, 54:1, 5 — 11

To link to this Article: DOI: 10.1080/09670870701549632

URL: <http://dx.doi.org/10.1080/09670870701549632>

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Effects of *n*C24 and *n*C27 petroleum spray oils on oviposition and egg survival of *Ostrinia nubilalis* Hübner (Lepidoptera, Pyralidae) and *Trichogramma brassicae* Bezdenko (Hymenoptera, Trichogrammatidae) adults on maize plants

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Abstract

The study determined the effectiveness of *n*C24 and *n*C27 petroleum spray oils (PSOs) to reduce oviposition of *Ostrinia nubilalis* and survival of *O. nubilalis* eggs and *Trichogramma brassicae* adults. Under choice and no-choice tests, maize treated with 3, 5 and 10% (v/v) of both oils deter *O. nubilalis* oviposition on maize. The study also showed that treatment of 1–3-day-old *O. nubilalis* eggs with 1 and 2% (v/v) *n*C24 oil caused 6% mortality compared with 99.5% when treated with 3, 5 and 10% (v/v) oil. In contrast, treatment with 1–10% (v/v) *n*C27 oil caused 99% mortality. *Trichogramma brassicae* is a major parasitoid of *O. nubilalis*. The mortality of *T. brassicae* 24 h after exposure to maize sprayed with 2% (v/v) *n*C24 and *n*C27 oils was 8.3 and 12.7%, respectively. At 5% (v/v), the mortalities were 24.9 and 23.5%, respectively. Therefore, application of 3% (v/v) PSO may deter *O. nubilalis* egg lay, egg mortality and survival of *T. brassicae* on maize.

Keywords: Petroleum spray oils, *Ostrinia nubilalis*, *Trichogramma brassicae* oviposition, deterrence, parasitoid

1. Introduction

The European corn borer, *Ostrinia nubilalis* Hübner (Lepidoptera: Pyralidae), is regarded as one of the major pests on maize (*Zea mays* L.) in Europe, particularly France (Naibo 1980). The female moths *O. nubilalis* prefer to lay egg masses on the underside of maize leaves (Mensah et al. 2000). The newly hatched larvae feed on leaves in the whorl of the plant (Sayers et al. 1994). When larvae has developed to the third or fourth instar, they tunnel into the maize stalk or ear shank (Calvin et al. 1988; Jarvis 1988). This can reduce seed yield through physiological effects resulting in stalk breakage and ear dropping (Bode and Calvin 1990; Sayers et al. 1994). The larvae can also feed directly on the kernels, resulting in grain losses (Lynch et al. 1980).

Synthetic insecticides remain the most used control method for *O. nubilalis* on maize in most countries in Europe (S. Derridj, pers. comm.), but over-reliance on insecticides can result in the development of insecticide resistance, disruption of natural enemies and adverse environmental impacts. This has cast doubt on the long-term viability of the traditional insecticide control approach. As a result of the negative impacts of insecticide use within the communities where maize is grown, there has been a

strong push to move away from the dependence on synthetic insecticides and to adopt alternative methods of pest control which are environmentally benign.

Several studies have been conducted to find alternative methods of controlling *O. nubilalis* using biological control agents such as *Trichogramma brassicae* Bezdenko, an egg parasitoid. Other studies have also demonstrated that epiphytic micro-organisms and food sprays can deter oviposition of *O. nubilalis* on maize (Derridj et al. 1989; Martin et al. 1993; Mensah et al. 2000). Deterring oviposition of pests on plants in general will affect the insect population on the plant because it will reduce the number of eggs deposited by pests on the plant, leading to a reduced pest population (Hagen et al. 1971; Abivardi and Benz 1986; Mensah et al. 2000).

Petroleum spray oils (PSOs) have been used extensively on agricultural crops and are important components of integrated pest management (IPM) programmes worldwide for a range of pests such as scales, mites, aphids, *Helicoverpa* spp., etc. (Riehl 1969; Nasca et al. 1981; Credland 1992; Mensah et al. 1995; Beattie and Smith 1997). According to Davidson et al. (1991), the risk of phytotoxicity with PSOs is low on most plants, and the use of UV additives (e.g. sunscreens) to reduce the detrimental effect of the ultraviolet light on the breakdown of oil molecules has

reduced the potential of some PSOs to damage plants (Hodgkinson 1999; Hodgkinson et al. 2002).

Recent studies by Mensah et al. (2001, 2002) have also shown that application of 2% (v/v) rate of Canopy[®] oil (nC27 oil) to cotton and 4 and 5% (v/v) Texaco[®] oil (nC24 oil) to maize plants can reduce oviposition of *Helicoverpa* spp. and *O. nubilalis* on cotton and maize plants, respectively. However, PSOs have not been extensively evaluated on maize crops in France because there exists a perception that they may not be efficacious against maize pests. On another hand, it is thought that they may cause phytotoxicity or disrupt the activities of natural enemies, especially *T. brassicae*, a parasitoid species, successfully used in France to control *O. nubilalis* on maize crops. In 2002, this parasitoid was released on over 70 000 ha of maize plants in France (Frandon et al. 2002). As a result, the use of *T. brassicae* as a biological control agent has become widely accepted and its use is increasing. Subsequently, it is crucial that any pest control tool used against *O. nubilalis* have minimal impact on *T. brassicae*. However, no studies have been conducted on the effect of PSOs or any other spray oils on the deterrence of *O. nubilalis* oviposition, and on the survival of *T. brassicae* on maize plants.

The aims of this study were to: (1) determine the efficacy, if any, of the two nC24 and nC27 PSOs in deterring *O. nubilalis* oviposition on maize; (2) evaluate the effects of the two PSOs on development of *O. nubilalis* egg; and (3) assess the effect of the two PSOs on survival of *T. brassicae*.

2. Methodology

2.1. Plant and insect materials

2.1.1. Plant. Unless otherwise stated, all experiments were conducted in the Phytopharmacie laboratory at the Institut National Recherche Agronomique (INRA) in Versailles in France. The maize plants used for the studies were the 'Dea' variety widely grown in France and is susceptible to *O. nubilalis* (Derridj et al. 1989). Plants were grown from seeds in plastic pots (7.4 l) in a glasshouse until they were at the four-leaf (early whorl) stage where plants were suitable for *O. nubilalis* to commence infestation (Sayer et al. 1994). The conditions in the glasshouse were 25°C, 75% RH and a photoperiod of 16L:8D.

2.1.2. Insects. *Ostrinia nubilalis* adults used in the studies were obtained from the first generation colonies reared on artificial diet composed of maize flour (mil. Ostrinia, Pyrale, Korano 38390 Montalieu, France). All the stages were maintained in the laboratory on artificial diet under $25 \pm 1^\circ\text{C}$, $75 \pm 5\%$ RH and a photoperiod of 12L:2D. The adults from the laboratory culture were used to provide the egg masses used for all the laboratory studies.

Trichogrammatidae brassicae used for the study were supplied by the Biotop Company (Valbonne, France). The parasitoids were supplied in cardboard capsules containing parasitized *O. nubilalis* eggs. Each capsule contains about 1000 wasps.

2.2. Petroleum spray oil (PSO) products

Canopy[®] oil (developed by Caltex Australia) and Texaco[®] oil (Chevron Texaco, Belgium) were two PSO products used for the study. Canopy[®] is an nC27 base oil (median equivalent normal paraffin carbon number of 27) with a viscosity of about $28 \text{ mm}^2 \text{ s}^{-1}$ at 40°C (Hodgkinson et al. 2000). Texaco[®] spray oil is an nC24 base oil (median equivalent normal paraffin carbon number of 24) and has viscosities much lower than Canopy[®], of around $9 - 13 \text{ mm}^2 \text{ s}^{-1}$ at 40°C (Hodgkinson et al. 2002).

2.2.1. Oviposition preference of *O. nubilalis* on maize treated with nC24 oil (free choice tests). The experiment was conducted in a mesh cage ($170 \times 100 \times 70 \text{ cm}$). Six treatments representing nC24 PSO concentrations of 0 (control), 1, 2, 3, 5 and 10% (v/v) were evaluated. Six maize plants were randomly allocated to each treatment and each plant was labelled with a plastic card. Sprays were applied to maize until run-off using a hand held pressure sprayer (Home and Garden Trigger Sprayer, Canyon Corp. Ltd, Australia). The control plants were sprayed with water. All the treated plants were transferred into a mesh cage and placed in six rows using a completely randomised design. Plants were placed so that the foliage from adjacent plants did not touch. Twenty pairs of *O. nubilalis* adults were released in the dark into the cage to mate and oviposit on the plants. Each treatment was replicated five times.

The number of egg masses and eggs per plant were counted under a stereomicroscope 4 days after the release of the insects in the cage. The number of eggs per plant was computed to calculate an oviposition deterrence index (ODI) which determines oviposition preference of *O. nubilalis* to treated and untreated plants (Renwick et al. 1989; Mensah et al. 2000).

2.2.2. Oviposition preference of *O. nubilalis* on maize treated with nC24 oil (no-choice tests). Based on the results of the free choice test in experiment 2.2.1, no-choice experiment was conducted. In the experiment, nC24 PSO was applied at concentrations of 0 (control), 1, 2, 3, 5 and 10% (v/v). Each of the 'no-choice' tests was measured by counting the eggs laid by *O. nubilalis* females placed in cages with each treated plant.

In each of the experiments, five plants from each treatment were enclosed in separate mesh cage ($25 \times 35 \times 40 \text{ cm}$) and five pairs of *O. nubilalis* were released into each cage. Each treatment was

replicated five times. Number of egg masses per plant, and eggs per plant were recorded after 4 days. An ODI was calculated for each treatment.

2.2.3. Survival of *O. nubilalis* eggs to nC24 and nC27 PSOs. In this study, nC24 and nC27 oils were evaluated at concentrations of 0 (water), 1, 2, 3, 5 and 10% (v/v) on *O. nubilalis* egg survival. Separate trials were conducted using 1-day-old eggs (white eggs) and 3-day-old eggs (black eggs). Each PSO concentration was applied onto egg masses until run-off using a hand held pressure sprayer. After treatment applications, the egg masses were placed individually in a plastic Petri dish ($\varnothing = 5$ cm). Each treatment was replicated 20 times.

The number of white eggs that hatched was recorded 96 h after treatment, the time necessary for the viable white eggs and black eggs to hatch were recorded 24 h after treatment application. The number of eggs that did not hatch in each case was recorded and per cent mortality calculated for each treatment.

2.2.4. Survival of *T. brassicae* adults on maize treated with nC24 and nC27 PSOs. In this study, the residual effect of nC24 and nC27 oils on *T. brassicae* adult survival was studied on maize. Each oil was applied at 2 and 5% (v/v) concentration to maize plants using a hand-held pressure sprayer. Each concentration was applied to maize until run-off. After sprays on the leaves had dried, leaf disks ($\varnothing = 5$ cm) were taken for the first experiment 0 days after treatment (0 DAT) and for the second experiment 4 days after treatment (4 DAT). The treated plants were then placed individually into a glass Petri dish. A control treatment was set up with leaf disks taken from maize plants treated with water. In all, 15 leaf disks representing 15 replicates for each treatment and control were set up for each concentration and sampling date.

Ten *T. brassicae* adults without food were placed on each treated leaf disk and the number of dead and surviving adults was recorded at 1, 3, 5 and 24 h after treatment application. After, 24 h the natural mortality of unfed *T. brassicae* becomes very high and the mortality scored was mostly due to starvation.

3. Data analysis

All experimental data were analysed using repeated measures ANOVA (Instat 2.03 Graphpad Software Inc., San Diego, CA). Tukey–Kramer multiple comparisons test was used to separate the means. The ODI, computed using the number of eggs per treatment, was calculated as follows:

$$\text{ODI} = 100 \times (C - T)/(C + T)$$

where *C* represents the total number of eggs per control plant and *T* the total number of eggs on the

treated plants. An ODI significantly greater than zero (repeated measures ANOVA) indicates that *O. nubilalis* preferred to lay eggs on control plants; an ODI not significantly different from zero indicates no preference between control and treated plants and an ODI significantly smaller than zero indicates a preference for laying on treated plants relative to the control (Renwick and Radke 1985; Renwick et al. 1989; Mensah et al. 2000).

4. Results

4.1. Oviposition preference of *O. nubilalis* on maize treated with nC24 oil (free choice tests)

Significant difference ($P < 0.0001$) in oviposition-deterrent activity of nC24 oil against *O. nubilalis* was found among maize treated with both 5 and 10% (v/v) concentrations compared to other concentrations tested and the control (Table I). No significant difference in oviposition-deterrent activity of the PSO was found among the control plants and plants treated with 1, 2 and 3% (v/v) nC24 oil (Table I). The ODI was significantly higher ($P < 0.0001$) in maize plants treated with 5 and 10% (v/v) oil compared to the other concentrations and the control (Table I). However, moderate and severe phytotoxicity was observed on the leaves and stems of the plants treated with 5 and 10% (v/v) of nC24 oil, respectively. In contrast, no phytotoxicity was detected on plants treated with 1–3% (v/v) concentrations.

4.2. Oviposition preference of *O. nubilalis* on maize treated with nC24 oil (no-choice tests)

Under no-choice conditions, no significant difference ($P > 0.05$) was detected in the number of egg masses laid on plants treated with 1 and 2% (v/v) oil

Table I. Oviposition response of *O. nubilalis* adults to different concentrations of nC24 oil (PSO) sprayed on maize under free choice conditions in the laboratory at INRA, Versailles, France, 2003.

Treatment	Number of egg masses/plant Means $\pm$ SE	Number of eggs/plant Means $\pm$ SE	Mean oviposition deterrent index (ODI)
Control (water)	2.60 $\pm$ 0.25 a	73.80 $\pm$ 0.25 a	0.0 a
1% (v/v)	2.20 $\pm$ 0.37 a	59.40 $\pm$ 0.37 a	10.4 a
2% (v/v)	2.00 $\pm$ 0.55 a	46.00 $\pm$ 0.55 a	23.2 a
3% (v/v)	2.00 $\pm$ 0.32 a	37.80 $\pm$ 0.32 a	32.3 a
5% (v/v)	1.20 $\pm$ 0.58 a	21.20 $\pm$ 0.58 b	55.4 b
10% (v/v)	0.20 $\pm$ 0.20 b	0.20 $\pm$ 0.20 b	92.7 b

Means within columns followed by the same letter are not significantly different ($P > 0.05$) (Tukey–Kramer multiple comparison test).

and the control (Table II). The number of eggs recorded on 1 and 2% (v/v) treated plants were also not significantly different ($P > 0.05$) (Table II). Application of the *nC24* oil at 3% (v/v) deterred oviposition (ODI = 44.7) but when the rate was increased to 5 and 10% (v/v), respectively, oviposition deterrent activity increased to 75.9 and 96.2, respectively (Table II).

4.3. Survival of *O. nubilalis* eggs to *nC24* and *nC27* oils

4.3.1. Survival of *O. nubilalis* eggs after *nC24* oil spray. Survival of 1- and 3-day-old *O. nubilalis* egg masses was significantly different ($P < 0.0001$) between the *nC24* oil treatments and the control (water treated egg masses) (Tables III and IV). Over 94% of the 1- and 3-day-old eggs hatched in the water, 1 and 2% (v/v) oil treated eggs compared with 0.5% egg hatch in 3, 5 and 10% (v/v) oil treated eggs (Table III and IV).

4.3.2. *O. nubilalis* eggs survival and hatching after *nC27* oil spray. Survival of 1- and 3-day-old *O. nubilalis* egg masses was significantly different ($P < 0.0001$) between the *nC27* oil treatments and the control (Tables V and VI). Over 99% of

1- and 3-day-old *O. nubilalis* eggs did not hatch when treated with *nC27* oil concentrations compared with 4.1% in the control (water treated) (Tables V and VI).

4.4. Survival of *T. brassicae* adults on maize treated with *nC24* and *nC27* PSOs

Application of 2% (v/v) *nC24* and *nC27* oils to maize leaves killed 12.5 ± 0.9 and 19.0 ± 1.2 , respectively, of *T. brassicae* adults when the parasitoids were exposed to the leaves same day after

Table IV. Effect of *nC24* oil on *O. nubilalis* 3-day-old eggs in the laboratory at INRA, Versailles, France, 2003.

Treatments	Total number of treated eggs	Mean number of unhatched eggs $\pm$ SE
Control (water)	240	9.47 ± 1.92 a
1% (v/v)	240	0.22 ± 0.40 b
2% (v/v)	252	249.49 ± 0.09 b
3% (v/v)	235	232.65 ± 0.12 b
5% (v/v)	224	221.76 ± 0.07 b
10% (v/v)	223	222.90 ± 0.11 b

Means within columns followed by the same letter are not significantly different ($P > 0.05$) (Tukey–Kramer multiple comparison test).

Table V. Effect of *nC27* oil on *O. nubilalis* 1-day-old eggs in the laboratory at INRA, Versailles, France, 2003.

Treatments	Total number of treated eggs	Mean number of unhatched eggs $\pm$ SE
Control (water)	223	10.25 ± 1.35 a
1% (v/v)	201	200.92 ± 0.18 b
2% (v/v)	191	190.90 ± 0.01 b
3% (v/v)	207	206.90 ± 0.16 b
5% (v/v)	201	200.90 ± 0.19 b
10% (v/v)	184	183.90 ± 0.12 b

Means within columns followed by the same letter are not significantly different ($P > 0.05$) (Tukey–Kramer multiple comparison test).

Table II. Oviposition response of *O. nubilalis* adults to different concentrations of *nC24* oil (PSO) sprayed on maize under no-choice conditions in the laboratory at INRA, Versailles, France, 2003.

Treatments	Number of egg masses/plant Means $\pm$ SE	Number of eggs/plant Means $\pm$ SE	Mean oviposition deterrent index (ODI)
Control (water)	2.90 ± 0.43 a	86.80 ± 14.60 a	0.0 a
1% (v/v)	2.70 ± 0.34 ab	67.60 ± 11.76 ab	12.4 ab
2% (v/v)	1.90 ± 0.32 abc	44.70 ± 5.59 bc	32.0 bc
3% (v/v)	1.40 ± 0.34 bcd	33.20 ± 4.93 cd	44.7 cd
5% (v/v)	0.80 ± 0.25 cd	11.90 ± 3.77 cd	75.9 cd
10% (v/v)	0.50 ± 0.17 d	1.70 ± 0.80 d	96.2 d

Means within columns followed by the same letter are not significantly different ($P > 0.05$) (Tukey–Kramer multiple comparison test).

Table III. Effect of *nC24* oil on *O. nubilalis* 1-day-old eggs in the laboratory at INRA, Versailles, France, 2003.

Treatments	Total number of treated eggs	Mean number of unhatched eggs $\pm$ SE
Control (water)	219	13.06 ± 2.95 a
1% (v/v)	258	0.95 ± 1.62 a
2% (v/v)	299	0.70 ± 1.33 a
3% (v/v)	210	207.90 ± 0.09 b
5% (v/v)	248	245.52 ± 0.01 b
10% (v/v)	211	208.89 ± 0.07 b

Means within columns followed by the same letter are not significantly different ($P > 0.05$) (Tukey–Kramer multiple comparison test).

Table VI. Effect of *nC27* oil on *O. nubilalis* 3-day-old eggs in the laboratory at INRA, Versailles, France, 2003.

Treatments	Total number of treated eggs	Mean number of unhatched eggs $\pm$ SE
Control (water)	276	11.30 ± 1.59 a
1% (v/v)	226	225.15 ± 1.11 b
2% (v/v)	223	222.60 ± 0.64 b
3% (v/v)	223	222.80 ± 0.38 b
5% (v/v)	248	247.75 ± 0.82 b
10% (v/v)	266	265.85 ± 0.27 b

Means within columns followed by the same letter are not significantly different ($P > 0.05$) (Tukey–Kramer multiple comparison test).

treatment (day 0) (Table VII). Exposure of the parasitoids to leaves sprayed 4 days ago, the number of adults that died were 4.2 ± 0.8 and 11.3 ± 0.5 , respectively (Table VII). The number of parasitoids killed in the control (water treated) leaves was 5.33 ± 0.53 (Table VII).

When the PSOs were applied at 5% (v/v) concentration, exposure of *T. brassicae* adults to leaves treated on the same day were 37.3 ± 0.9 , 35.2 ± 1.2 , respectively (Table VIII). In contrast, when the parasitoids were exposed to leaves treated 4 days ago, mortalities were 11.1 ± 0.9 (nC24 oil) and 23.9 ± 0.9 (nC27 oil) (Table VIII). In this study, significantly higher ($P < 0.05$) *T. brassicae* mortalities occurred 1 h after exposure to both 0 (same day) and 4 DAT leaves (Tables VII and VIII). After 3 and 5 h of exposure, both the 0 and 4 days after treatment (DAT) leaves caused the same mortality to *T. brassicae* with the exception of 4 DAT nC24 oil which caused similar mortality as the water treated leaf at 5 h after *T. brassicae* exposure (Table VIII). No significant difference in mortality ($P < 0.05$) was detected among the treatments and control leaves 24 h after *T. brassicae* exposure (Table VIII).

5. Discussion

The study showed that application of petroleum spray oils (PSOs) to maize can deter oviposition of *O. nubilalis* on maize. Under free and no-choice tests,

significant differences in oviposition deterring activity of the nC24 oil against *O. nubilalis* was demonstrated among different concentrations of the oil tested. Similar effect was demonstrated for nC27 by Mensah et al. (2004). They reported that application of 3% (v/v) nC27 oil to maize plants significantly reduced *O. nubilalis* oviposition on maize in choice (ODI = 70.7) and no-choice (ODI = 32.4) tests. In this study, application of 3% (v/v) nC24 oil to maize reduced *O. nubilalis* egg lays (ODI = 32.3 and 44.7) for choice and no-choice tests, respectively. Increasing the nC24 oil rate to 5% (v/v), significantly increased the ODI to 55.4 for choice and 75.9 for no-choice tests. A further increase of the nC24 oil rate did not cause any significant difference in the ODI.

The study also showed that 5 and 10% (v/v) nC24 oil caused phytotoxicity to maize leaves and stems. This is in contrast to studies by Mensah et al. (2004) who reported that 5–10% (v/v) rates of nC27 oil, which is heavier than nC24 oil, did not cause any phytotoxicity to maize plants. The explanation to this may be due to the fact that the nC24 oil has no in-built UV light absorbers to prevent the breakdown of the oil molecules to cause phytotoxicity. In contrast the nC27 oil has in-built UV light absorbers in the formulation that can reduce the risk of PSO-induced phytotoxicity (Mensah et al. 2001, 2002). Subsequently, the risk of phytotoxicity of the nC24 oil at higher concentrations (5 and 10%) is very high. As a

Table VII. Cumulative mortalities of *T. brassicae* adults on leaves of maize plants treated with nC24 and nC27 oils at concentrations of 2% (v/v) ($n = 150$) in the laboratory at INRA, Versailles, France, 2003.

Treatments	Cumulative mortalities of <i>T. brassicae</i> adults after exposure to PSO sprays on maize leaves			
	1 h	3 h	5 h	24 h
Control (water)	0.00 a	1.33 ± 0.23 a	1.33 ± 0.00 a	5.33 ± 0.53 a
nC24 oil at 0 day	7.48 ± 0.62 b	8.33 ± 0.39 a	11.11 ± 0.48 a	12.50 ± 0.87 a
nC27 oil at 0 day	10 ± 0.93 b	11.49 ± 0.39 a	11.49 ± 0.00 a	19.01 ± 1.15 a
nC24 oil at 4 day	1.36 ± 0.53 a	2.08 ± 0.43 a	3.17 ± 0.32 a	4.17 ± 0.76 a
nC27 oil at 4 day	1.33 ± 0.23 a	5.41 ± 0.57 a	10.81 ± 0.71 a	11.27 ± 0.48 a

Means $\pm$ SE within columns followed by the same letter are not significantly different ($P > 0.05$) (Tukey–Kramer multiple comparison test).

Table VIII. Cumulative mortalities of *T. brassicae* adults on leaves of maize plants treated with nC24 and nC27 oils at concentrations of 5% (v/v) ($n = 150$) in the laboratory at INRA, Versailles, France, 2003.

Treatments	Cumulative mortalities of <i>T. brassicae</i> adults after exposure to PSO sprays on maize leaves			
	1 h	3 h	5 h	24 h
Control (water)	2.00 ± 0.32 a	4.00 ± 0.32 a	4.00 ± 0.00 a	16.00 ± 0.77 a
nC24 oil at 0 day	23.13 ± 1.31 b	29.86 ± 0.85 b	33.33 ± 0.53 b	37.30 ± 0.98 a
nC27 oil at 0 day	15.33 ± 1.38 b	19.59 ± 0.57 b	22.97 ± 0.53 b	35.21 ± 1.23 a
nC24 oil at 4 day	3.40 ± 0.64 a	5.56 ± 0.53 a	7.64 ± 0.32 ab	11.11 ± 0.89 a
nC27 oil at 4 day	7.33 ± 0.68 a	12.16 ± 0.56 b	19.59 ± 0.98 b	23.94 ± 0.88 a

Means $\pm$ SD within columns followed by the same letter are not significantly different ($P > 0.05$) (Tukey–Kramer multiple comparison test).

result, the optimum rate at which the *nC24* oil can be used to deter oviposition in *O. nubilalis* was determined at 3% (v/v) under laboratory conditions. This rate can deter oviposition and minimise the risk of phytotoxicity to maize plants.

The study also showed that the PSOs had a strong ovicidal effect on *O. nubilalis* eggs. Application of *nC24* caused over 99% mortality of *O. nubilalis* 1-day-old (white) eggs when applied at 3–10% (v/v) on egg masses. When applied to 3-day-old (black) *O. nubilalis* eggs, over 98% mortality was achieved with 3–10% (v/v) concentration. In contrast, *nC27* oil caused over 98% mortality at 1–10% (v/v) concentration. This indicates that irrespective of the oil type used, lower (1–3%, v/v) and higher (5 and 10%, v/v) concentrations can cause similar mortality to *O. nubilalis* egg masses. The PSO treatments seemed to stop the embryonic development and killed the embryo in the eggs but the mechanism involved in the ovicidal action remains to be studied.

The deterrence of *O. nubilalis* oviposition on maize and the direct mortality to eggs as a result of PSO spray indicate that the PSOs have effective oviposition deterrence activity as well as a strong ovicidal effect. This study supports the findings of Ochou (1985) and Hesler (1986) on *Heliothis virescens* F. and also Mensah and Singleton (2000), who reported that horticultural mineral oils in the *nC20*–*nC24* range produced significant mortality of *Helicoverpa armigera* Hubn. eggs when applied to egg batches. PSOs in general can directly kill adult insects by suffocation through the blocking of spiracles (Hodgkinson 1999). This insecticidal efficacy of PSOs is known to be directly proportional to their viscosity (D. Johnson, pers. comm.). High viscosity oils can more effectively smother eggs and larvae than low viscosity oils (Hodgkinson 1999). In this study we found that the difference in viscosity of both the *nC24* and *nC27* did not modify the oviposition deterrence and egg mortality of *O. nubilalis*. However, the *nC27* oil with an in-built UV light absorber minimised the risk of phytotoxicity to maize even at higher rates than *nC24* oils which have no UV light absorbers in their formulations. Thus, the use pattern for these oils should vary based on the oil type. Subsequently, growers targeting *O. nubilalis* egg pressure alone can use 1–2% (v/v) rate of the oils but for oviposition deterrence, as well as causing egg mortality, the 3% (v/v) rate will be more appropriate. In addition higher rates of *nC27* oils can be used without the risk of phytotoxicity.

In this study, the residual effect of 2 and 5% (v/v) PSO rates against *T. brassicae* adults was evaluated. The study also showed that the PSO residues were toxic to *T. brassicae* adults. The toxicity of the PSO appeared to be related with the dose of oil applied, duration after PSO treatment (i.e. days after treatment) and length of parasitoid exposure to the residues. Application of 2% (v/v) rate of both *nC24*

and *nC27* oils caused significant mortalities to *T. brassicae* adults when the parasitoids were exposed to plants sprayed the same day with oil (0 DAT). Mortality was highest after 1 h of exposure. Thereafter mortality was the same as in the control plants, indicating residual toxicity to the parasitoids will last for 1 h. When *T. brassicae* adults were exposed to leaves treated with 5% (v/v) oil, significant mortalities of the parasitoid was detected on both 0 and 4 DAT leaves 1 h after exposure and up to 5 h, indicating that the toxicity of the PSO residues increases with rate and persists longer. In general, similar mortality was achieved on both PSO treated and control plants 24 h after the parasitoids were exposed to the treated leaves. *Trichogrammatidae brassicae* is released in an inundative manner in maize fields to support IPM programmes in maize. This study has shown that *T. brassicae* adults are susceptible to oil residues 1–5 h after spray application. Subsequently, inundative releases of *T. brassicae* in maize crops treated with PSO should be undertaken at least 3–24 h after treatment application depending on the rate of oil used. This study has shown that PSO residues have minimal toxicity to *T. brassicae* adults especially at 2% (v/v) rate. This does not mean that direct application of the 2% (v/v) rate will have the same effect. The study did not determine the mortalities that may occur from direct oil application to the parasitoid. Under field situations, both direct and residual mortality may occur to cause significant mortalities to *T. brassicae*. Thus, the efficacy of the oil against the parasitoid through topical application should be examined. Additionally, the residual effect of the oil on the fecundity, searching behaviour and parasitism rates of *T. brassicae* should also be examined and addressed before PSOs are integrated with *T. brassicae* in IPM programmes in maize.

Nevertheless, this study has demonstrated that PSOs can be used to manage *O. nubilalis* in maize. This can be achieved by deterring adult oviposition and by direct egg mortality. In addition, our study has shown that the residual effect of the PSOs has low toxicity to *T. brassicae* adults on maize and that inundative releases of *T. brassicae* in conjunction with PSOs in maize crops can be undertaken successfully 5–24 h after PSO application. An optimum dose of 3% (v/v) is recommended in this study for use in maize crops against *O. nubilalis*. However, for *nC27* oils with in-built UV light absorbers a dose ranging from 2 to 5% (v/v) may be appropriate to deter *O. nubilalis* egg lay and mortality without any phytotoxicity to maize plants. Integration of PSOs into IPM programs in maize crops may not affect the survival and establishment of *T. brassicae* but rather complement the activities of the parasitoid and enhance the control of *O. nubilalis*. However, caution should be taken as to the type of oil to use and also the rate of application. We conclude that PSOs have the potential to complement IPM programmes in maize crops in France.

Acknowledgement

We thank Gilles Genestier, Herve Guenego, Gerard Vastra for their technical support and help. We also thank NSW Department of Primary Industries in Australia for giving permission for RKM to take up the Swire Group Churchill Fellowship offer to undertake the research, Institut National Recherche Agronomique (INRA) for hosting the visit, Caltex Australia Pty Ltd and Chevron Texaco for providing the Petroleum spray oil products. The project was funded by the Swire Group Churchill Fellowship under the Winston Churchill Memorial Trust in Australia. Chevron Texaco also provided financial assistance for the operating costs.

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