Chrysoeriol isolated from *Melientha suavis* Pierre with activity against the agricultural pest *Spodoptera litura*

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Abstract

**Background:** Flavonoids, a class of plant phenolic compounds, act as plant defense chemicals. Chrysoeriol is a naturally occurring flavonoid produced by *Melientha suavis* Pierre. The goal of this study was to investigate the insecticidal potential and mode of action of chrysoeriol isolated from *M. suavis* against *Spodoptera litura* (Fabricius).

**Results:** The effects of chrysoeriol on second-instar *S. litura* larvae were determined by topical application. Chrysoeriol was highly toxic to *S. litura* (24- and 48-h LD₅₀ values of ~ 6.99 and 6.51 µg/larva, respectively). Moreover, mode-of-action experiments demonstrated that this compound significantly decreased the activities of both detoxification-related enzymes [carboxylesterases (CarE) and glutathione S-transferase (GST)] and neurological enzymes (acetylcholinesterase).

**Conclusions:** These results indicate that chrysoeriol isolated from *M. suavis* could be used as a potential agent with activity against *S. litura*. However, it is necessary to determine the potential side effects on nontarget species for the further development of these novel insecticides.

**Keywords:** Chrysoeriol, *Melientha suavis* Pierre, *Spodoptera litura*, Insecticidal activity, Detoxification enzymes

Graphical Abstract

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tobacco [1]. Current control measures mostly rely on synthetic insecticides such as pyrethroids, carbamates, organochlorine, organophosphates, broflanilide, triflumizopyrim, and afidopyropen [2, 3]. However, intensive application of these compounds has negative impacts on nontarget organisms, contaminates the environment, and leads to insecticides resistance in pests [4, 5]. Such problems have led to a demand to identify new and safer active compounds of natural origin that are alternatives to existing synthetic insecticides [6].

Plant secondary metabolites are natural compounds originating from plants. They have long been used for various medical purposes and are recognized as safe and potent alternatives to synthetic insecticides in pest control [7, 8]. They are classified into three main groups according to their biosynthetic pathways (namely, alkaloids, terpenes, and phenolic compounds) and are known as chemical compounds of plant defence systems in response to environmental stresses, bacteria, fungi, viruses, and herbivores [9, 10]. Secondary metabolites can serve as insecticides and inhibitor agents for growth and oviposition of many pest species, especially *S. litura* [11, 12].

Pak Wanpa (*Melientha suavis* Pierre), an edible plant species belonging to the Opiliaceae family, can be found in South-East Asian countries, including Laos, Vietnam, Cambodia, Malaysia, the Philippines, and Thailand. Recently, *M. suavis* extracts have demonstrated the potential for use as ingredients for the development of cosmetics [13]. Their leaves and stems contain various types of compounds, such as alkaloids, coumarins, cinnamic acid, tannins, saponins, and flavonoids [13, 14]. Chrysoeriol, a flavonoid found in various herbs, is of great interest because of its medicinal properties, including its antioxidant, antimicrobial, anti-inflammatory, neuroprotective, cardioprotective, and cancer prevention activities [15–17].

The objective of the following research was to determine whether a compound isolated from *M. suavis*, chrysoeriol, could be used for the development of a novel insecticide to control *S. litura*. Moreover, our work aimed to examine the mode of action to explore the toxicity mechanisms of this compound.

**Materials and methods**

**Plant materials, extraction, and isolation**

Leaves and twigs of *M. suavis* (Fig. 1) were collected in December 2001 from Chanthaburi, Thailand. A voucher specimen (BKF No. 17967) of *M. suavis* was deposited at the Forest Herbarium, Royal Forest Department, Bangkok 10900, Thailand.

The sun-dried leaves and twigs of *M. suavis* were crushed into powder (1.7 kg) and extracted with dichloromethane (30 L × 5 days × 5 times) at room temperature to produce crude dichloromethane (47.3 g). The bioactive crude dichloromethane extract was isolated by silica gel No 7734 (1 kg), ethyl acetate–C$_6$H$_{14}$ and CH$_3$OH–ethyl acetate solvent gradient elution to yield fractions A$_1$–A$_8$. Fraction A$_6$ (3.17 g) yielded chrysoeriol (451.3 mg) after Si-gel CC (CH$_2$Cl$_2$–C$_6$H$_{14}$ solvent gradient elution), followed by recrystallization with EtOH–acetone.

**Insects and compound treatments**

An artificial diet was provided as food for larvae following Ruttanaphan et al. [18] and 20% honey solutions for adults of *S. litura*. The insects were maintained under controlled conditions [16:8 h (L:D) photoperiod, 25±1 °C and 65±5% RH] at the Laboratory of Department of Zoology, Faculty of Science, Kasetsart University.

The acute toxicity of chrysoeriol, *M. suavis* crude extract and cypermethrin (a commercial synthetic insecticide that is commonly used to control pest insects) to *S. litura* larvae was determined by topical application. Serial dilutions (0–40 μg/larva) of chrysoeriol were prepared with acetone (dilution factor = 0.5). Early second-instar larvae were treated with 1 μL of chrysoeriol and crude extract dilutions included in the treatment group, acetone alone (negative control group) and cypermethrin alone (positive control group), in the dorsal thoracic region using a microapplicator (Hamilton, Switzerland) (six replicates of 10 larvae per treatment; n = 60 per treatment) and subsequently fed artificial diets as described above. Mortality and characteristic behavioural changes were recorded at 24 and 48 h post-treatment.
Mode-of-action determination

After 24 and 48 h of treatment with chrysoeriol at LD₃₀, surviving S. litura were used for enzyme preparation. The homogenization of ten pooled second-instar larvae was conducted using pH 7.2 phosphate buffer [ethylenediaminetetraacetic acid (EDTA, 1 mM) and potassium phosphate buffer (PPB, 100 mM)]. The supernatant obtained by centrifugation (4 °C, 10,000 × g for 15 min) was used to measure detoxification-related and neurological enzyme activities and Bio-Rad protein assay kit was used to measure the protein content of each enzyme source [19].

The protocol of Ruttanaphan et al. [20] was used to determine the carboxylesterases (CarE) activity using p-nitrophenylacetate (pNPA) (Sigma-Aldrich, Germany) as a substrate. A microplate reader (Biotek PowerWave XS microplate spectrophotometer, US) was used to measure the crude enzymes in PPB (230 μL, pH of 7.4, 50 mM, and containing 10 mM pNPA in DMSO) at 410 nm for 90 s at 37 °C. 1-chloro-2,4-dinitrobenzene (Sigma-Aldrich, Germany) was used to determine glutathione S-transferase (GST) activities according to the method of Nobsathian et al. [21]. The mixture of PPB (110 μL, pH of 7.2, 50 mM, and containing the reduced form of 10 mM GSH in glutathione solution), 1-chloro-2,4-dinitrobenzene (100 μL, 150 mM), and supernatant (100 μL) was immediately measured at 340 nm for 3 min by a microplate reader. 5,5'-dithio-bis-(2-nitrobenzoic acid) was used to determine acetylcholinesterase (AChE) [22]. Crude enzymes were prepared from the supernatant (50 μL) and potassium phosphate buffer (pH 8.0, 100 mM). After incubation for 30 min, the mixture was added with phosphate buffer (pH of 7.2, 100 mM and containing 5,5'-dithio-bis-(2-nitrobenzoic acid) (10 mM), acetylthiocholine iodide (100 mM) and EDTA (0.1 mM). The AChE activities of the mixtures were measured by a microplate reader at 412 nm. Three biological replicates per treatment of enzyme activities were evaluated, with an extinction coefficient of 176.4705, 0.000137 and 1.36 × 10⁴/(M/cm) for CarE, GST and AChE, respectively.

Data analysis

The acute toxicity of chrysoeriol as determined by LD₅₀ values and confidence limits was determined by probit analysis, and statistical tests of enzyme activities were performed using one-way analysis of variance (ANOVA), and Tukey’s test was used for mean separation test by StatPlus Pro 7.3.0 (AnalystSoft, Inc., Canada).

Results

Isolated compounds

The chrysoeriol was isolated from leaves and twigs of M. suavis. The pure compound was verified by the comparison of their physical properties and spectroscopic data with those reported in the literature [23].

Chrysoeriol (Fig. 2): yellow powder from ethanol–acetone, m.p. 330–331.3 °C; UV (MeOH) λ max (log e): 269 (3.56), 340 (5.12) nm; FT-IR (KBr) ν max = 3350, 1655, 1607, 1561, 1507, 1164; 1H NMR 400 MHz (DMSO-d₆):12.97 (1H, s, OH-5) 6.87 (1H, s, H-3), 6.18 (1H, d, J=2.0 Hz, H-6), 6.49 (1H, d, J=2.0 Hz, H-8), 7.55 (1H, d, J=2 Hz-6), 6.91 (1H, d, J=8 Hz, H-5'), 7.55 (1H, d, J=2 Hz, H-2') and 3.87 (3H, s, 3'-OCH₃), 13C NMR (DMSO-d₆) 161.24 (C-2), 103.72 (C-3), 182.82 (C-4), 163.73 (C-5), 103.72 (C-5a), 98.89 (C-6), 164.24 (C-7), 94.12 (C-8), 157.39 (C-8a), 121.58 (C-1), 110.26 (C-2), 148.08 (C-3), 150.78 (C-4), 116.02 (C-5), 121.58 (C-6), 56.02 (3'-OCH₃); HR MS (ESI-TOF): m/z found 323.0521 [M + Na]⁺, (calcd. for C₁₆H₁₂O₆Na, 323.0532).

Acute toxicity and mode-of-action of chrysoeriol on S. litura larvae

A major constituent, chrysoeriol, was isolated from M. suavis, and its bioinsecticidal activity was demonstrated in an agricultural insect pest, S. litura. Our results showed that chrysoeriol was toxic to second-instar S. litura larvae, with LD₅₀ values of 6.99 and 6.51 μg/larva at 24 and 48 h post-treatment, respectively (Table 1). The mortality rates of larvae were 28.3% and 28.3%, 35.0% and 35.0%, 56.7% and 58.3%, 75.0% and 76.7%, and 81.7% and 81.7% after 24 and 48 h treated with 2.5, 5, 10, 20 and 40 μg/larva of chrysoeriol, respectively. Moreover, this compound induced larval agitation at all dilutions. However, no significant difference was observed between

Fig. 2 Chemical structure of chrysoeriol was verified by physical properties and spectroscopic data, as found in the literature [23].
chrysoeriol-treated group and crude extract-treated group ($P > 0.05$, Tukey’s test).

To further investigate the mode of action of chrysoeriol in *S. litura*, detoxification-related enzyme (CarE and GST) and neurological enzyme (AChE) activities were estimated and compared with those of a control group (an acetone-only treatment). All two enzymes showed significant inhibition at 24 and 48 h post-treatment with chrysoeriol (Table 2). The detoxification-related enzyme activities (CarE and GST) of *S. litura* were significantly inhibited by chrysoeriol ($P < 0.05$, Tukey’s test; Table 2). At 24 and 48 h post-treatment, the correlation factors of the CarE activity were 1.5 and 1.5, respectively. At the same time, the correlation factors of GST activity were 1.40 and 1.42 at 24 and 48 h post-treatment, respectively. Moreover, AChE activity was significantly inhibited at 24 and 48 h post-treatment, with correlation factors of 1.51 and 1.50, respectively ($P < 0.05$, Tukey’s test; Table 2).

### Discussion

Chrysoeriol, a 3’-methoxy derivative of luteolin, is present in many plant species; the present study is the first report of chrysoeriol isolated from *M. suavis*. Chrysoeriol is little known for its insecticidal potential compared with its medicinal properties [24]. The bioactivity of the crude extract does not significantly differ from that with the pure compound, indicating that it would be better to use a crude extract for controlling this insect than to make the effort to isolate the active principle, which is more convenient and economical for insecticide production. Our study provides essential information for the further development of novel compounds for use in agricultural production.

Detoxification mechanisms involve enzymes that catalyse reactions to make xenobiotics easier to excrete from an insect’s body. Phase I enzymes catalyse oxidation, hydrolysis or reduction reactions, and phase II enzymes catalyse conjugation reactions. Finally, xenobiotics are excreted via phase III excretion [5].

Insects resist insecticides by presenting increased activities of CarE (a phase I enzyme) and GST (a phase II enzyme) [25, 26]. Our results indicated that chrysoeriol decreased CarE and GST activities, which might associate with toxic activity the high insecticidal activity of this compound [21]. Acetylcholinesterase hydrolyses the neurotransmitter acetylcholine to terminate synaptic transmission in insects’ cholinergic nervous systems [27]. This enzyme has been exploited as a target of insecticides for insect pest control because the inhibition of AChE activity leads to increased insect mortality as a result of nervous system failure [28]. The present study demonstrated that *S. litura* larvae exposed to chrysoeriol exhibited decreased AChE activity and agitation, similar to the application of carbamate and organophosphate, indicating the occurrence of neurotoxic effects [28]. However, there are many enzymes associated with insect’s mortality such as cytochrome P450 monooxygenases, UDP-glycosyl transferases, antioxidant and peroxidation enzymes, further studies are needed to explain the insecticidal activity of this compound [29, 30].

### Conclusions

*Spodoptera litura* has developed resistance to many insecticides, so there is an urgent need to identify promising candidates for IPM to reduce the reliance on synthetic insecticides [31]. Chrysoeriol is highly toxic and inhibits the activity of enzymes critical to insect survival and has potential as a novel insecticidal agent against *S. litura*. Moreover, a keto group at C-4 of chrysoeriol exhibited strong antifeedant activity on *Mythimna unipuncta* [32]. However, further studies are needed to examine its potential in field trials and toxicity effects on nontarget organisms.
Table 2. Enzyme activities of *S. litura* after 24 and 48 h (h) treated with chrysoeriol and *M. suavis* crude extract.

| Treatments     | CarE<sup>a</sup> (CF)<sup>b</sup> | Activity | GST<sup>a</sup> (CF)<sup>b</sup> | Activity | AChE<sup>a</sup> (CF)<sup>b</sup> | Activity |
|----------------|-----------------------------------|----------|---------------------------------|----------|---------------------------------|----------|
|                | 24 h                              |          | 24 h                            |          | 24 h                            |          |
| Control        | 3.71 ± 0.09<sup>a</sup>           | –        | 2.06 ± 0.06<sup>a</sup>         | –        | 1.76 ± 0.12<sup>a</sup>         | –        |
|                | 3.72 ± 0.09<sup>a</sup>           | –        | 2.11 ± 0.06<sup>a</sup>         | –        | 1.78 ± 0.07<sup>a</sup>         | –        |
| Crude extract  | 3.58 ± 0.19<sup>b</sup>           | Inhibition| 1.70 ± 0.02<sup>b</sup>         | Inhibition| 1.23 ± 0.01<sup>b</sup>         | Inhibition|
|                | (1.03)                            |          | (1.21)                          |          | (1.44)                          |          |
| Chrysoeriol    | 3.21 ± 0.08<sup>b</sup>           | Inhibition| 1.47 ± 0.03<sup>b</sup>         | Inhibition| 1.17 ± 0.06<sup>b</sup>         | Inhibition|
|                | (1.15)                            |          | (1.40)                          |          | (1.51)                          |          |

The mean values followed by the same letter within the same column of each treatment are not significantly different (*P* > 0.05) using Tukey’s test.

<sup>a</sup> Unit of enzymes: CarE activity (nM p-nitrophenol/min/mg), GST activity (mM glutathione conjugated product/min/mg) and AChE activity (acetylcholinesterase/mg protein/min).

<sup>b</sup> CF the correlation factor (acetone-treated group/chrysoeriol-treated group).
All data are presented in Tables 1 and 2.

Availability of data and materials
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Declarations

Ethics approval and consent to participate
The Animal Ethics Committee of Kasetsart University approved all the methods of insect rearing (ACKU64-SCI-017).

Competing interests
The authors declare that they have no competing interests.

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