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Synthesis and Application of Some Pheromones and Insect Attractants in Sustainable Agricultural Development in Vietnam

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Abstract: This article supplies a review and evaluation of research concerning the synthesis and field application of pheromones and insect attractants in Vietnam, focusing on raising sustainable agricultural development. We present the attractants and pheromones widely tested in Vietnam and Southeast Asia, providing a useful reference for researchers and scientists. Next, we summarize the methods of pheromone synthesis, including compounds with optical and geometric isomeric structures. Finally, the article evaluates the practical effectiveness of using pheromones in pest control in the field, demonstrating the role of Vietnamese scientists in independent research and international cooperation. These results promote environmentally friendly biological solutions and support sustainable agricultural development in Vietnam.

Keywords: Insect pheromones; Sustainable agriculture; Integrated pest management; Optical isomers; Geometric isomers; Pheromone traps

1. Introduction

The serious consequences of chemical pesticides on human health, the environment, and ecosystems have prompted a shift towards sustainable pest management methods. In this context, Integrated Pest Management (IPM) stands out as a comprehensive solution, where the application of insect pheromones—known for their high selectivity and environmental friendliness—becomes an essential tool for agriculture and forestry.

Over the past three decades, Vietnam's research on pheromones has developed alongside the agricultural sector. This research focuses on technological advancements and is closely linked to production practices, contributing to improvements in the quality and efficiency of agricultural products.

Vietnam has had a diverse agricultural sector in recent years. However, the country's agriculture is also facing dual challenges, first of all ensuring food security for nearly 100 million people and then still needing to protect the integrity of the environment.

Farmers have been abusing synthetic pesticides because of the increasing demand for agricultural productivity. This has gradually caused many risks to biodiversity as well as public health. To address this challenging issue, the application of pheromones and insect attractants is gradually emerging as an effective pest control strategy, which is also in line with the country's vision of green and sustainable agricultural development.

Pheromones are chemicals secreted by males or females that can regulate the behavior and character of species. There are many pheromones in insects, including aggregation, sex, alarm, and trail pheromone... Sex pheromones, for example, play an important role in communication between individuals of the same species, being secreted outside the body and stimulating specific responses in other individuals. Some species produce only limited amounts of pheromones, while others produce more diverse ones. Nowadays, insect pheromones have been used to attract and kill male moths. This is a way that people use to break the life cycle of harmful insects in agriculture, thereby reducing the density of harmful insects without having to use pesticides that pollute the environment. Moreover, attractants such as kairomones and synthetic baits lure pests into traps, increasing pest control efforts while contemporarily protecting beneficial insect species.

Globally, the successful application of pheromones has been demonstrated in countries such as Japan, the United States, and the EU. Notable examples include Chow Y.S.'s work in 1977 on the sex pheromone of the diamondback moth (*Plutella xylostella*)[1], Heath R.R.'s find out 1986 on the sex pheromone of the sweet potato weevil (*Cylas formicarius*)[2], Hallett R.H.'s research in 1995 on the aggregation pheromone of the rhinoceros beetle (*Oryctes rhinoceros*)[3], and Hallett R.H.'s 1993 study on the aggregation pheromone of the palm weevil (*Rhynchophorus ferrugineus*)[4]. In Vietnam, although research began later, it has been highly specific due to the complex tropical ecosystem and the diversity of native pests, such as rice stem borers, vegetable webworms, and various beetles. The key distinction in Vietnam's approach is the optimization of synthesis methods for small-scale farmers—who make up 70% of the agricultural sector—by combining international knowledge with local experience to develop effective trapping systems.

This research is driven by two core objectives: (1) addressing the dual pressures of maintaining productivity while reducing reliance on pesticides, and (2) realizing the vision of ecological agriculture through technologies suited to Vietnamese conditions. The aim of expanding pheromone synthesis results and developing practical field application processes that are always linked to global scientific initiatives in local agricultural activities is a breakthrough in Southeast Asia. These help the region export clean agricultural products that comply with international standards.

Pheromones and attractants serve as "smart weapons" in IPM, laying the groundwork for the digitalization of pest management in Vietnam. From mating traps to kairomone monitoring systems, the integration of indigenous biological data with advanced synthetic technology promises to drive breakthroughs in ecological agriculture-key to establishing Vietnam as a model for sustainable development in the tropics.

2. Some Common Insect Pheromones in Vietnam

The classification and identification of insects along with their pheromone structures are very important in Vietnam. This contributes to proactively supporting the synthesis and application of pheromones and insect attractants in the forecasting and control of pests by a plant protection measure in modern agricultural production without polluting the environment and affecting public health as well as the quality of agricultural products.

2.1 Classification by characteristics

a. Sex pheromones

Purpose: Attracting opposing insects to mate, used in traps or breaking the reproductive cycle.

Examples:

+ Sex pheromone of the striped rice stem borer (*Chilo suppressalis*): Using traps to attract male butterflies, reducing the fertilization rate.

+ Sex pheromone of Diamondback moth (*Plutella xylostella*): Controlling pests on vegetables.

b. Aggregation pheromones

Purpose: Attract both sexes, often used to control termites and beetles.

Examples: The aggregation pheromone of Rhinoceros beetle (*Oryctes rhinoceros*), Rhynchophorus palm weevil (*Rhynchophorus ferrugineus*) used in coconut insect traps.

c. Attractants from plants (Kairomones)

- *Purpose*: Attract insects by the smell of plants

- *Examples*:

+ Methyl eugenol: Attract the fruit flies (*Bactrocera dorsalis*), used in fruit orchards (mango, orange, grapefruit).

+ Cue-lure: Used for the fruit cucurbit flies (*Bactrocera cucurbitae*).

2.2 Classification by target of damage

The chemical composition of pheromones and attractants of harmful insects on vegetables, colors, and fruit trees is very diverse, they can be geometric isomers, optical isomers... Most of the pheromones and synthetic pheromones of harmful insects on vegetables, colors, and fruit trees in Vietnam have the configuration of *E*-, and *Z*- geometric isomers with different ratios, with carbon numbers from 10-20 C.

- The diamondback moth (*Plutella xylostella*) *Z*11-16Ald:*Z*11-16OH:*Z*11-16Ac[5]; Oriental leafworm moth (*Spodoptera litura*) *Z*9*E*11-14Ac:*Z*9*E*12-14Ac[6]; beet armyworm (*Spodoptera exigua* Hübner) *Z*9*E*12-14Ac:*Z*9-14OH:*Z*9-14Ac:*Z*11-16Ac[7]; Cotton bollworm pheromone (*Helicoverpa armigera* Huber): *Z*11-16Ald:*Z*9-16Ald:*Z*3-6Ac[8].

- The sweet potato weevil (*Cylas formicarius* Fabricius) (*Z*)-3-dodecen-1-yl (*E*)-2-butenoate[2].

- The black cutworm pheromone (*Agrotis ypsilon* Hufnagel) *Z*9-14Ac:*Z*11-16Ac:*Z*7-12Ac[9].

- The cabbage borer damages cabbage and cruciferous vegetables, tomatoes, potatoes, etc. (*Trichoplusia ni* Hubner) *Z*7-12Ac[10].

- The striped flea beetle that damages vegetables (*Phyllotreta cruciferae* and *P. striolata*) with allyl isothiocyanate as an allomone[11].

- The fruit cucurbit fly damages gourds, cucumbers... (*Bactrocera cucurbitae* C.) with 4-(*p*-acetoxyphenyl)-2-butanone as a lure[12].

- The corn rootworm (*Diabrotica undecimpunctata howardi*, *Diabrotica virgifera virgifera*, and *Diabrotica longicornis*) 10me-13Kt and (2*S*,8*R*)-8-methyldecan-2-yl propionate[13,14].

- The fall armyworm (*Spodoptera frugiperda* Smith) *Z*9-14Ac:*Z*7-12Ac[15].

- The rice and sugarcane borers group: (the gold-fringed rice stemborer) Pyralidae (*Chilo auricilius* Dudgeon) *Z*7-12Ac:*Z*8-13Ac:*Z*9-14Ac:*Z*10-15Ac; (White rice borer), Pyralidae (*Scirpophaga nivella* Fabricius): *E*11-16Ald:*Z*11-16Ald:16Ald[16]; (Stem borer neonates), Pyralidae (*Proceras venosatus* Walker) *Z*13-18Ac:*Z*13-18OH:*Z*11-16Ac[17]; (Striped rice stem borer), Pyralidae (*Chilo suppressalis* Walker) *Z*11-16Ald:*Z*9-16Ald:*Z*13-18Ald[18]; (Purple stem borer), family Noctuidae (*Sesamia inferens* Walker) *Z*11-16Ac:*Z*11-16OH[19]; Paddy armyworm (*Mythimna separata* Walker) *Z*11-16Ald: *Z*11-16Ac[20]; Rice leaf folder (*Cnaphalocrocis medinalis* G.) *Z*11-18Ald : *Z*13-18Ald : *Z*11-18OH: *Z*13-18OH[21].

Since the late 90s and early 2000s, our research group has had research results and application experience on pheromones and attractants for insects that harm vegetables, crops, and food crops. Currently, pheromones and attractants for insects that harm vegetables and food crops continue to be an important research direction for our group.

Fruit trees are important plants that help develop the economy of Vietnamese farming families, especially in the Mekong Delta region. Many of Vietnam's fruit trees have export value such as lychee, grapefruit, dragon fruit, longan, mangosteen... Some important insect pests on fruit trees in Vietnam for which we have made pheromone traps and attractants:

-The fruit fly (*Bactrocera dorsalis* H., with methyl eugenol as a lure[22]), one of the major pests in the genus Bactrocera that damages wild and cultivated fruit trees, is the second most harmful species after *B. papayae*. This fly is a polyphagous insect because, in addition to guava, it also damages many other types of fruit trees, such as plum, apple, sapodilla, papaya, mango, dragon fruit, rambutan, soursop...and is a dangerous pest for fruit trees because the larvae live and cause damage in the fruit. In addition to direct damage, the fruit flies (*Bactrocera dorsalis* H.) are also subject to plant quarantine in many countries importing fresh fruit products.

-The yellow peach moth (*Conogethes punctiferalis* G., with *E*10-16Ald:*Z*10-16Ald as a female sex pheromones[23]) damages a variety of plants, including papaya, Queensland chestnut, mulberry, longan, peach, guava, cotton, corn, star fruit, rambutan, sunflower, sugarcane grass, and over 15 other secondary hosts. In the Mekong Delta, this fruit borer has also been observed damaging longan, guava, soursop, rambutan, and durian.

-The citrus flower moth (*Prays citri* M., with *Z*7-14Ald as a female sex pheromone[24]), also known as the orange and tangerine flower moth, primarily affects the flowers of citrus trees. The citrus pock caterpillar (*Prays endocarpa* Meyrick with *Z*7-14Ald:*Z*7-14Ac:*Z*7-14OH as a female sex pheromone combination[25]), which the larvae are pests of pomelo fruit. In the Mekong Delta, the citrus flower moth and the pock caterpillar mainly damage fruits, particularly grapefruit. The damage occurs when the fruit is still very small; if the damage is severe, the borer creates a lump on the fruit, which may cause the fruit to fall off.

-The rhinoceros beetle (*Oryctes rhinoceros* L.) primarily targets coconut trees (*Cocos nucifera*), oil palms (*Elaeis guineensis*), and coconut palms. Its secondary hosts include date palms, bananas, sugarcane, papaya, and pineapple. This species is distributed across coconut-growing regions in South Asia and Southeast Asia, extending from Pakistan to the Philippines, and it has since invaded many other countries worldwide.

-The rhynchophorus palm weevil (*Rhynchophorus ferrugineus* Oliv.) is a significant pest affecting coconut trees and oil palms. Its secondary hosts include rice, sugarcane, and bamboo. This pest is found throughout coconut and oil palm growing areas around the world, including regions in South America, Africa, the Middle East, South Asia, and Southeast Asia.

In recent years, insect pests damaging industrial and forest trees have caused considerable harm to Vietnam's economy. A significant area of forest has been damaged by the Mason pine caterpillar (*Dendrolimus punctatus* Walker), which uses a female sex pheromone combination of *Z*5,*E*7-12Ac and *Z*5,*E*7-12OH[26]. Additionally, thousands of hectares of coffee plantations in the Central Highlands have been affected by the coffee white stemborer (*Xylotrechus quadripes* Chevrolat), which emits a male sex pheromone combination of 2*S*-hydroxy-10-3Kt and 10-2,3Kt[27]. This infestation has negatively impacted both the quantity and quality of coffee produced for domestic consumption and export. Most recently, the tea mosquito bug (*Helopeltis theivora* Waterhouse, *Z*3-6Ac:*E*2-6OH as a pheromone[28]) has been affecting crops in Binh Phuoc and the Southern Central Highlands, and the black-headed caterpillar (*Opisina arenosella* Walker, with *Z*3,*Z*6,*Z*9-23Hy as a female sex pheromone[29]) has impacted the export of cashew nuts, tea, and coconut. Effective pest control will significantly reduce the economic damage caused by insects affecting industrial crops.

3. Synthesis of Pheromones and Insect Attractants: A Technological Marvel

The synthesis of pheromones and insect attractants demands a profound understanding of organic chemistry as well as the intricate molecular structures of these compounds. Vietnamese chemists have made significant strides in synthesizing pheromones and insect attractants aimed at key agricultural pests.

3.1 Main synthetic approaches and considerations

a. Stereoselective Synthesis

Many insect pheromones are composed of optical or geometric molecules that exist in two mirror-image forms or geometric configurations, with only one form being biologically active. Stereoselective synthesis techniques are essential for producing the correct optical or geometric isomer with high purity. This approach maximizes the effectiveness of the synthesized compounds in attracting insects.

b. Green Chemistry Methods

- Biosynthesis:

+ This method utilizes microorganisms or enzymes to synthesize pheromones, such as genetically modified yeast.

+ Advantages: Reduces the use of toxic solvents and is environmentally friendly.

- Organic Synthesis:

+ This involves the use of green metal catalysts (e.g., copper or palladium) and biological solvents (e.g., ethanol, water).

+ Example: The synthesis of rice stem borer pheromones via selective hydrogenation.

Vietnamese researchers are increasingly adopting green chemistry principles in the synthesis of pheromones and attractants. This includes minimizing waste, using renewable resources, and developing environmentally friendly reaction conditions to lessen the impact of the synthesis process on the environment. Specific strategies include:

- Utilizing green solvents (e.g., dimethyl carbonate, deep eutectic solvents).

- Employing green reagents and catalysts (e.g., palladium nanoparticles, enzymes, crown ether phase transfer catalysts, tetrabutylammonium bromide).

- Implementing green technical equipment (ultrasound and microwave technology).

Since 2004, we have successfully applied ultrasound techniques to various reactions, including Grignard reactions, coupling reactions, functional group removal and protection, and Wittig reactions. Microwave techniques have been used to enhance esterification reactions, significantly reducing reaction time and increasing efficiency in the synthesis of insect pheromones in Vietnam[30,31].

c. Scalability and Cost-Effectiveness with Nanotechnology

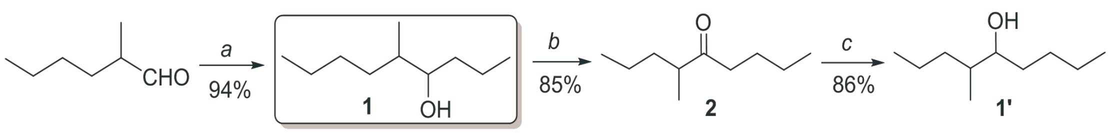
Scalability of the synthesis process is crucial for large-scale production and widespread application. In recent years, Vietnam's growing economy has allowed researchers to continuously optimize reaction conditions and develop new catalysts to improve yields and reduce costs, making these technologies more accessible to farmers. One example is microencapsulation, which involves encapsulating pheromones in biodegradable polymer materials to prolong their effectiveness, making these technologies more accessible to farmers. We are also implementing this technology. Another example is the use of palladium nanocatalysts in the selective reduction of triple bonds to double bonds in (*Z*)-alkenols, insect pheromone precursors, which we have effectively developed[32].

3.2 Results of insect pheromone synthesis in Vietnam

a. The insect pheromone group is an optical isomer

\+ Aggregation Pheromone of Rhynchophorus Palm Weevils (*Rhynchophorus ferrugineus* Oliv.)

In 2004, we synthesized the aggregation pheromone of Rhynchophorus palm weevils (*Rhynchophorus ferrugineus* Oliv.), specifically 4-methyl-5-nonanol **1**, from 2-methylpentanal and *n*-BuBr. We conducted a study on the threo:erythro configurational isomerism, which appeared in the NMR spectrum of the product in 2009, 2017, 2019, and 2021[33-37]. This research aimed to select suitable raw materials for preparing and testing the biological activity of this pheromone structure in the field. Therefore, we synthesized the racemic structure using the Grignard reaction from *n*-BuBr and 2-methylpentanal under ultrasonication. Additionally, we synthesized 4-methyl-5-nonanone (Ferrugineon) **2** through the oxidation of 4-methyl-5-nonanol (Ferrugineol) **1** (see **Scheme 1**).

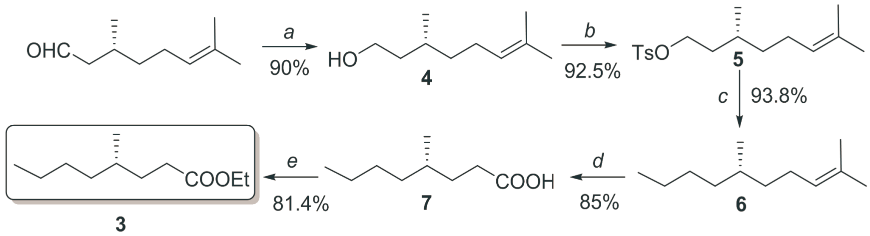


Reagents. a) 1-bromobutane/Mg, THF, 0 °C, ultrasound; b) $K_2Cr_2O_7$, H_2SO_4; c) $NaBH_4/CH_3OH$, ultrasound.

Scheme 1. Synthesis for racemic of 4-methyl-5-nonanol and 4 methyl 5 nonanone

\+ Aggregation Pheromone of Rhinoceros Beetles (*Oryctes rhinoceros* L.)

In 2003, we synthesized the aggregation pheromone of rhinoceros beetles (*Oryctes rhinoceros* L.), ethyl (*S*)-4-methyloctanoate **3**, from (*R*)-(+)-citronellal, which was extracted from the essential oil of lemon eucalyptus (*Eucalyptus citriodora* Hooker)[31,34,38]. We obtained (*S*)-4-methyloctanoic acid **7** through the oxidation reaction of (*S*)-2,6-dimethyl-2-decene (see **Scheme 2**).

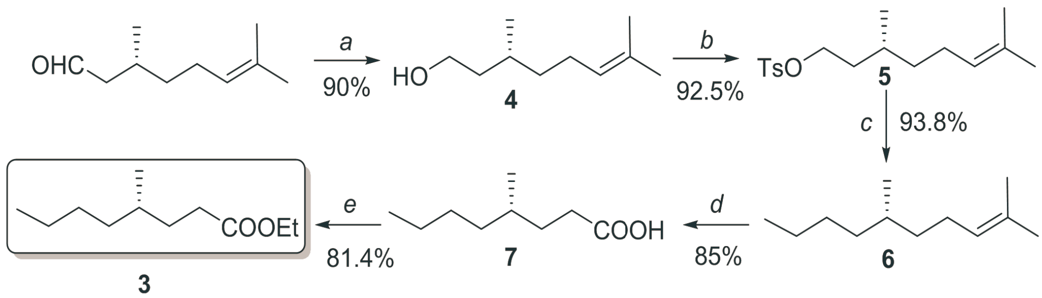


Reagents. a) $NaBH_4$/MeOH; b) TsCl/Py-$CHCl_3$, ultrasound; c) EtMgBr/THF/Li_2CuCl_4, -78 °C, ultrasound; d) $KMnO_4$-$FeCl_3$/acetone, - 78 °C; e) EtOH/PTSA, microwave.

Scheme 2. Synthesis of ethyl (*S*)-4-methyloctanoate from (*R*)-(+)-citronellal

Since the aggregation pheromones of both rhinoceros beetles and Rhynchophorus palm weevils in racemic form have been shown in foreign research to be effective in attracting insects, we developed and synthesized them using various simple raw materials.

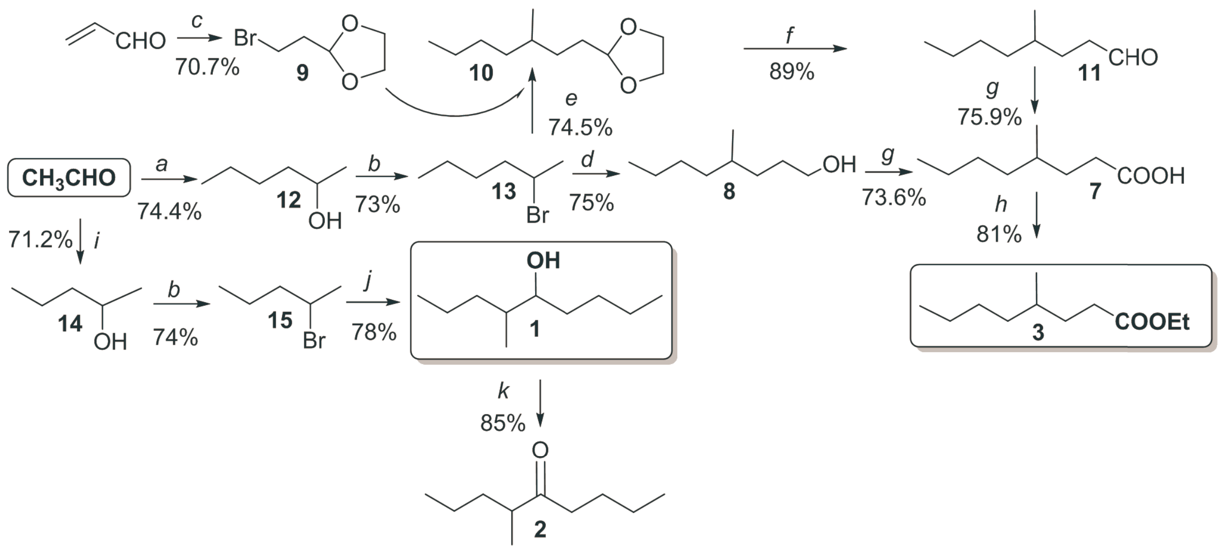
- We synthesized (±)-ethyl 4-methyloctanoate from 3-bromopropan-1-ol and 2-bromohexane through the Grignard reaction under ultrasonic conditions, achieving a yield of 53% (see **Scheme 3**).



Reagents. a) $NaBH_4$/MeOH; b) TsCl/Py-$CHCl_3$, ultrasound; c) EtMgBr/THF/Li_2CuCl_4, -78 °C, ultrasound; d) $KMnO_4$-$FeCl_3$/acetone, - 78 °C; e) EtOH/PTSA, microwave.

Scheme 3. Synthesis of ethyl (*S*)-4-methyloctanoate from (*R*)-(+)-citronellal

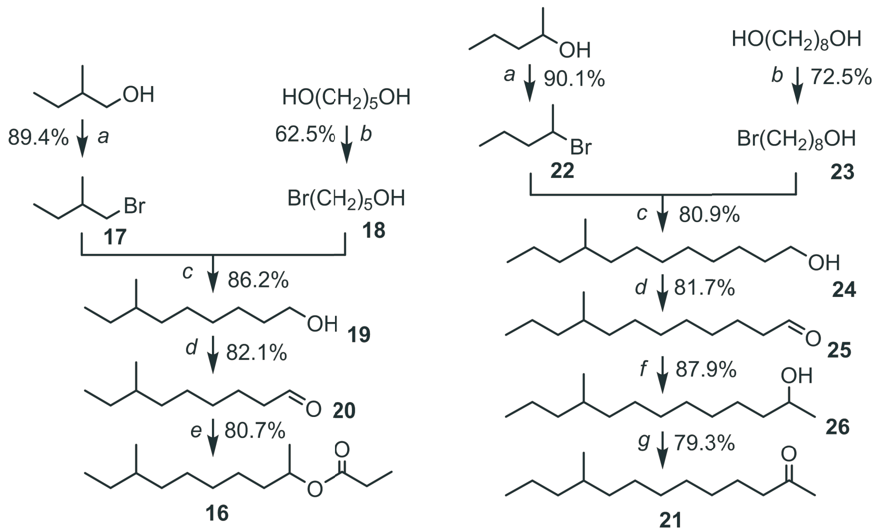
- By using acetaldehyde as the starting material and employing the Grignard reaction under ultrasonic conditions, we also successfully synthesized (±)-ethyl 4-methyloctanoate **3** and (±) 4-methyl-5-nonanol **1** (see **Scheme 4**)[33]. This research opens new opportunities for synthesizing pheromones of Rhinoceros beetles and Rhynchophorus palm weevils.



Reagents. a) $BuMgBr/Et_2O$, -10 °C, ultrasound; b) HBr; c) 1. $NaBr/H_2SO_4/CH_2Cl_2$, -10 °C, 2. ethyleneglycol, r.t, 8 hrs d) 1. Mg,THF 2. 3-bromopropan-1-ol, Li_2CuCl_4, 78 °C, ultrasound; e) 1. Mg,THF 2. 3 bromopropanal ethyleneglycol acetal, Li_2CuCl_4, 0 °C, ultrasound; f) AcOH 50 %; g) $KMnO_4$, Na_2CO_3, 0 °C. h) EtOH/PTSA, microwave; i) *n* $PrMgBr/Et_2O$, 0 °C, ultrasound; j) 1. Mg,Et_2O, ultrasound. 2. pentanal, 0 °C, ultrasound; k) $K_2Cr_2O_7$, H_2SO_4.

Scheme 4. Synthesis of (±) ethyl 4-methyloctanoate and 4-methyl-5-nonanol from acetaldehyde

+ Sex Pheromone of Southern Corn Rootworm (*Diabrotica longicornis*, *Diabrotica virgifera virgifera*, and *Diabrotica undecimpunctata*)



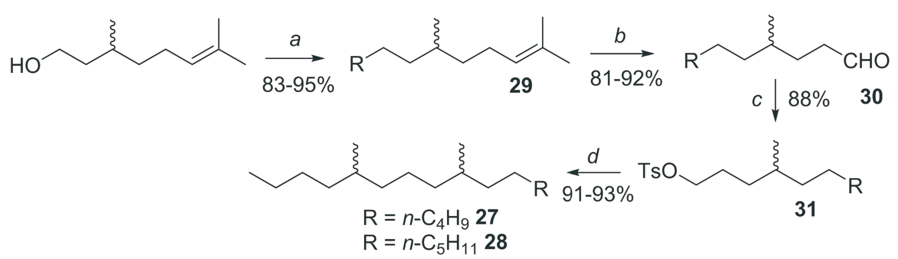
Reagents. a) Br_2, red P; b) HBr/petroleum ether-acetone; c) Mg, Li_2CuCl_4/THF, 0-5 °C, ultrasonic; d) PCC, CH_2Cl_2, ultrasonic; e) 1. CH_3MgI/THF, 0 °C, ultrasonic. 2. $(C_2H_5CO)_2O$/THF, ultrasonic; f) CH_3MgI/Et_2O, 0 °C, ultrasonic; g) $K_2Cr_2O_7$, H^+, ultrasonic.

Scheme 5. Synthesis of (±)-8-methyldecan-2-yl propionate and (±) 10-methyltridecan-2-one from 2 methylbutan-1-ol, pentan-1,5-diol, pentan-2-ol and octan-1,8-diol

In 2010, we synthesized the sex pheromone of southern corn rootworms (*Diabrotica undecimpunctata Howardi, Diabrotica virgifera virgifera, and Diabrotica longicornis*), which included (±)-8-methyl-2-decanyl propionate and (±)-10-methyltridecan-2-one. The synthesis of these compounds relied on the Grignard reaction as a critical step. We improved the synthesis of compounds **16** and **21** using the Grignard coupling method under ultrasonic conditions. Pentan-1,5-diol and octan-1,8-diol were used to generate (±)-8-methyldecan-2-yl propionate and (±)-10-methyltridecan-2-one. These diols were first converted to bromohydrins by reacting them with HBr in a petroleum ether-acetone solvent. The key step in the Grignard coupling reaction utilized Li_2CuCl_4 as a catalyst. Product 16 was synthesized directly via the Grignard reaction following Iwamoto's *in situ* method, while ketone **21** required an oxidation step with Jones reagent, yielding 35.7% and 33.5%, respectively (see **Scheme 5**)[39].

+ Sex Pheromone of Coffee Leaf Miner (*Leucoptera coffeella*)

Francke *et al*.[38] identified and synthesized the sex pheromone components of coffee leaf miner moth (*Leucoptera coffeella*), which include 5,9-dimethylpentadecane **27** and 5,9-dimethylhexadecane **28**. The synthesis of these racemic components from citronellol was described by Doan *et al*.[41] The Grignard coupling reaction with tosylate under ultrasonic conditions was a key step in the synthetic strategy. The alkene derivatives underwent oxidation and reduction to form tosylate synthons, which were then reacted with (2-methylhexyl)magnesium bromide to produce the pheromones with yields exceeding 90% (see **Scheme 6**).

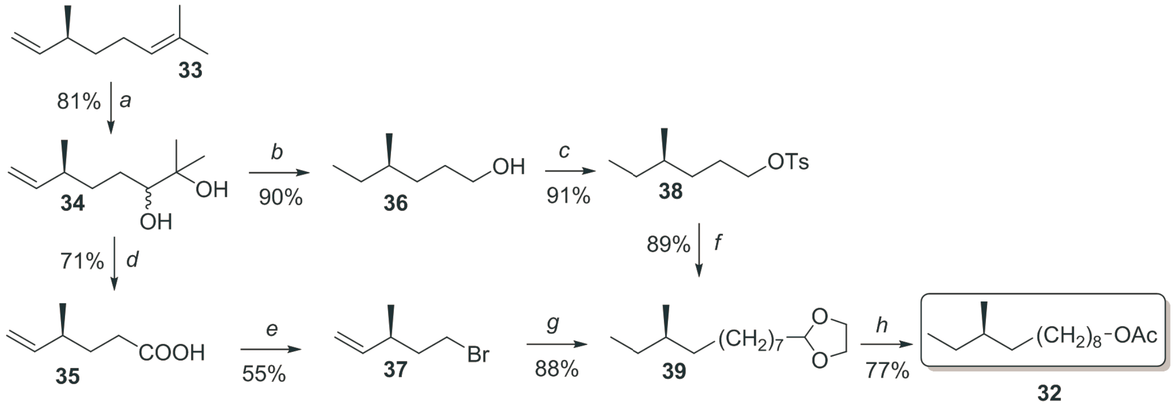


Reagents. a) 1. TsCl/Py, 2. $RMgBr/Li_2CuCl_4$, ultrasound; b) 1. Perphthalic acid, 2. HIO_4; c) 1. $NaBH_4$/MeOH, 2. TsCl/Py; d) $Me(CH_2)_4(Me)CHMgBr$, Li_2CuCl_4, ultrasound

Scheme 6. Synthesis of 5,9-dimethylpentadecane and 5,9-dimethylhexadecane from citronellol

+ Pheromone of the Tea Leaf-Eating Tortrix Caterpillar (*Adoxophyes* sp.)

The small tea tortrix caterpillar, (*Adoxophyes* sp.), is a significant pest of tea plants. The male sex pheromone consists of four components, with 10*R*-**32** identified as a minor component. Field trials indicated that the biological activity of 10*R*-**32** was higher than that of the *S*-isomer[42]. The synthesis of 10*R*-**32** involved two Grignard coupling methods between achiral and chiral units, with the chiral unit derived from the asymmetric diol produced by the selective peroxidation of (*S*)-citronellene[43]. This reaction generated diol **34**, which was further converted into tosylate **38** or bromide **37**, followed by esterification to yield the final product (see **Scheme 7**).



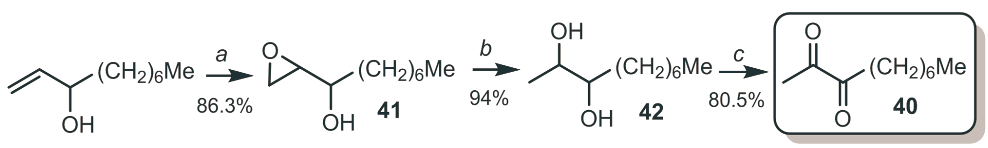
Reagents. a) m-PCBA; b) 1. HIO_4, 2.H_2/Ni; c) TsCl/Py; d) 1. H_2/Pd-C, 2. HIO_4, 3. Ag_2O; e) Br/HgO; f) $(CH_2O)_2C(CH_2)_5MgBr$, Li_2CuCl_4/-70 – 20 °C; g) $(CH_2O)_2C(CH_2)_6MgBr$, CuI/ -10 – 20 °C; h) 1. HCl 10%, 2. $NaBH_4$, 3. Ac_2O/Py

Scheme 7. Synthesis of (*R*)-10-methyldodecyl acetate from (*S*)-citronellene

b. Insect pheromones are geometric isomers

+ Pheromone of the Coffee White Stemborer (*Xylotrechus quadripes*)

In 2011, a component of the sex pheromone complex of the adult coffee white stemborer (*Xylotrechus quadripes* Chevrolat), specifically 2,3-decanedione **40** (which consists of two components: (*S*)-2-hydroxy-decan-3-one and 2,3-decanedione), was synthesized using three different methods. The first method involved the Wittig reaction with octanal as the starting material. The second method utilized the Grignard reaction starting from crotonyl alcohol. The third method employed the Sharpless K.B. reaction to asymmetrically epoxidize 1-decen-3-ol. Among these, the pathway starting from 1-decen-3-ol yielded the best results, achieving a yield of 65.3% after three steps (see **Scheme 8**)[44].

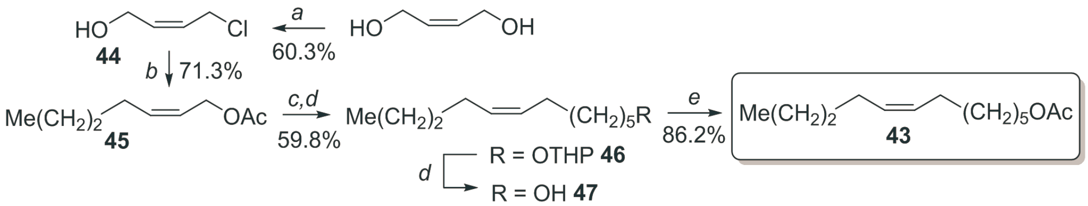


Reagents. a) Ti(*i*-PrO)$_4$, diisopropyl D-(-)-tartrate, *t* BuOOH, -20 °C; b) $LiAlH_4/Et_2O$; c) $K_2Cr_2O_7$.

Scheme 8. Synthesis of 2,3-decanedione from acrolein

+ Pheromone of the Cabbage Looper (*Trichoplusia ni*)

In 2013, the pheromone of the cabbage looper, commonly found in cruciferous vegetables, tomatoes, and potatoes (*Trichoplusia ni* Hubner), specifically (*Z*)-7-dodecenyl acetate **43**, was successfully synthesized from (*Z*)-2-butene-1,4-diol and pentan-1,5-diol[45]. This component is also significant in the pheromone complex of the rice stem borer, *Chilo auricilius* Dudgeon. The synthesis pathway, which utilized the Grignard reaction during the second and third key steps, involved forming *Z*-alkene **46** and subsequently *Z*-alkenol **47** before converting these into products according to Iwamoto *et al.*,[46] (see **Scheme 9**).

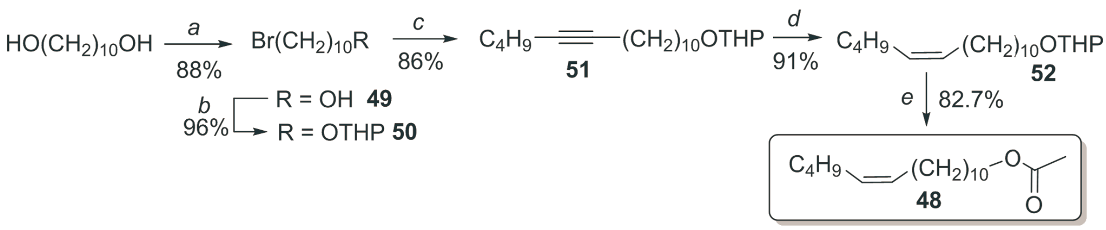


Reagents. a) $SOCl_2$, reflux, 2 hrs., b) 1, *n*-PrMgBr, THF, r.t,, 2. Ac_2O, 0 °C, c) $THPO(CH_2)_5MgBr$, CuI, THF, 0 °C, d) PTSA, MeOH, 50 °C, e) Ac_2O, Py, 0 °C.

Scheme 9. Synthesis of (*Z*)-7-dodecenyl acetate from (*Z*)-2-buten-1,4-diol and pentan-1,5-diol

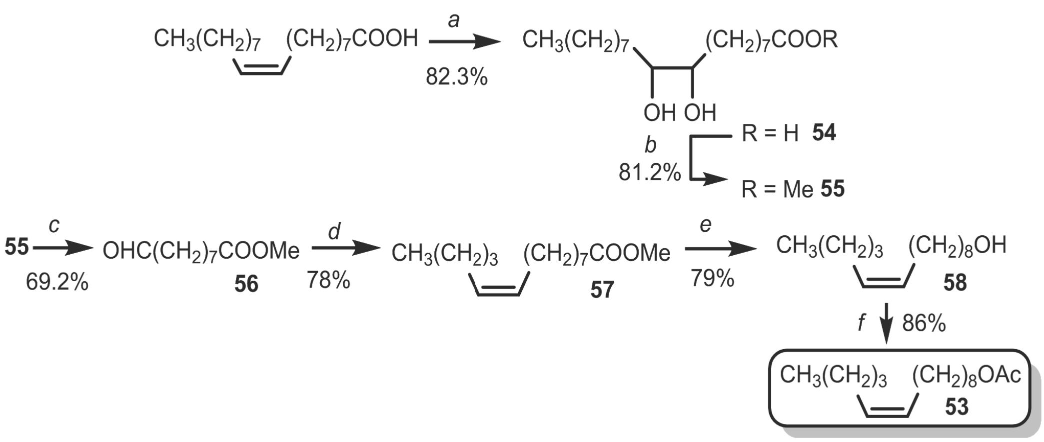
+ Pheromone of the Diamondback Moth (*Plutella xylostella*)

In 1995, Nguyen C.H *et al*., developed the synthesis of three components of the pheromone complex of the diamondback moth (*Plutella xylostella*): (*Z*)-11-hexadecenal, (*Z*)-11-hexadecen-1-ol, and (*Z*)-11-hexadecen-1-yl acetate **48**. This synthesis began with 11-undecenoic acid, utilizing the Wittig reaction catalyzed by dibenzo-18-crown-6 ether as a key step[47]. Experimental results indicated that the homemade bait produced outcomes nearly equivalent to the sample from Trecé, USA. In 2024, a new method was employed to synthesize acetate **48** from the same starting materials, 1,10-decanediol, and 1-hexyne, through a five-step process. This involved a $Pd_2(dba)_3$/DMF/KOH catalyst system, which provided high selectivity for the (*Z*)-alkene configuration and achieved a reduction efficiency of 91%, resulting in an overall yield of approximately 60% (see **Scheme 10**)[48].



Reagents. a) HBr/heptane, reflux 6 hrs.; b) DHP/*p*-TSA/CH_2Cl_2; c) 1. 1 hexyne/*n*-BuLi/THF, -78 °C; 2. KI, **(3)**/THF, reflux 16 hrs.; d) $Pd_2(dba)_3$/DMF/KOH, 145 °C, 6hrs; e) 1. pTSA/MeOH, 12 hrs.; 2. $(CH_3CO)_2O$/pyridine, 24 hrs.

Scheme 10. Synthesis of (*Z*)-11-hexadecen-1-yl acetate, the primary sex pheromone component of the diamondback moth (*Plutella xylostella*) from 1,10-decandiol and 1 hexyne.



Reagents. a) H_2O_2, $HCOOH/H_2O$, NaOH/HCl; b) MeOH/PTSA; c) $NaIO_4/CH_3CN$-CH_2Cl_2-H_2O; d) *n* $C_5H_{11}PPh_3Br$/NaH/DMSO; e) $LiAlH_4$/THF; f) Ac_2O/Py.

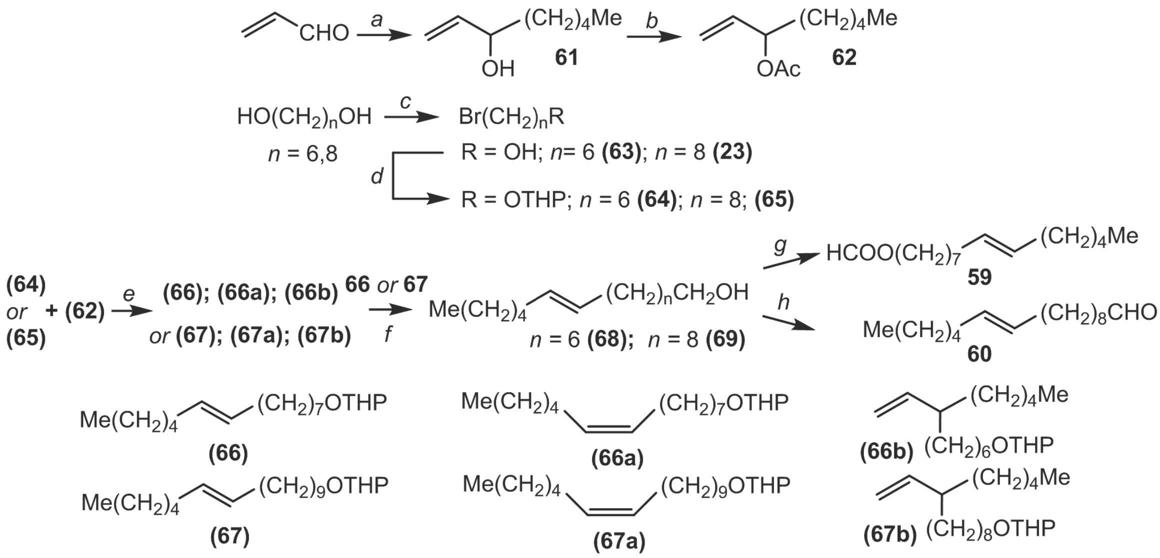
Scheme 11. Synthesis of (*Z*)-9-tetradecen-1-yl acetate from oleic acid

+ Pheromone of the Black Cutworm (*Agrotis ipsilon*)

The synthesis process began with the reaction of oleic acid with HCO_3H to form a peroxide acid, followed by alkaline hydrolysis to yield dihydroxy acid **54**. This dihydroxy acid was then esterified with methanol under a *p*-TSA catalyst, resulting in ester **55**. Ester **55** subsequently reacted with $NaIO_4$ in an AcCN-DCM-H_2O solvent to produce aldehyde-ester **56**. A Wittig reaction between aldehyde-ester **56** and ylide generated alkenyl-ester **57**, which was then reduced with $LiAlH_4$ to create alcohol **58**. Finally, alcohol **58** was acetylated to yield (*Z*)-9-tetradecenyl acetate **53**, achieved in a 32% yield from oleic acid (see **Scheme 11**)[49].

+ Pheromone of the Yellow Peach Moth (*Conogethes punctiferalis*)

In 2008, the sex pheromone and mimic pheromone of the yellow peach moth (*Conogethes punctiferalis*), namely (*E*)-8-tetradecenyl formate **59** and (*E*)-10-hexadecenal **60**, were synthesized from hexane-1,6-diol, octane-1,8-diol, and acrolein. The key reaction involved allyl rearrangement using a CuI catalyst (refer to **Scheme 12**)[50, 51]. Similarly, the pheromone of the sugarcane top borer (*Scirpophaga nivella* Fabricius), specifically (*E*)-11-hexadecenal, was synthesized from decane-1,10-diol in 2011[52].



Reagents. a) $C_5H_{11}MgBr$/THF, -10 °C, ultrasound. b)Ac_2O/Py, ultrasound. c) HBr/benzene. d) 3,4-dihydro-2H-pyran/P*p*TS, ultrasound. e) Mg/CuI, THF, 0 °C, ultrasound. f) 1. column chromatography (silicagel/$AgNO_3$), 2. HCl/MeOH, ultrasound. g) **68**, HCOOH, ultrasound. h) **69**, PCC, CH_2Cl_2

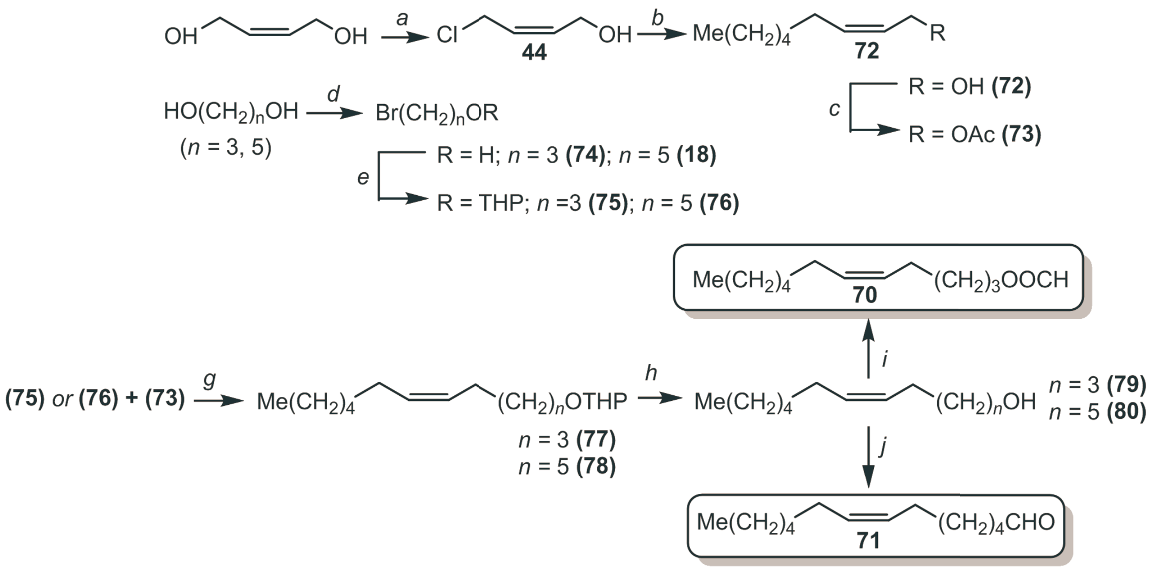
Scheme 12. Synthesis of (*E*)-8-tetradecen-1-yl formate and (*E*)-10-hexadecenal from acrolein, hexan-1,6-diol and octan-1,8-diol

+ Pheromone of the Citrus Flower Moth (*Prays citri*)

In 2005, the sex pheromone of the citrus flower moth (*Prays citri*), (*Z*)-7-tetradecenal **71**, was synthesized from (*Z*)-2-buten-1,4-diol and acrolein. In 2010, (*Z*)-5-dodecenyl formate **70** and (*Z*)-7-tetradecenal **71** were synthesized from (*Z*)-2-buten-1,4-diol, propane-1,3-diol, and pentane-1,5-diol (see **Scheme 13**). The steps for this synthesis were similar to those in **Scheme 9**[53].

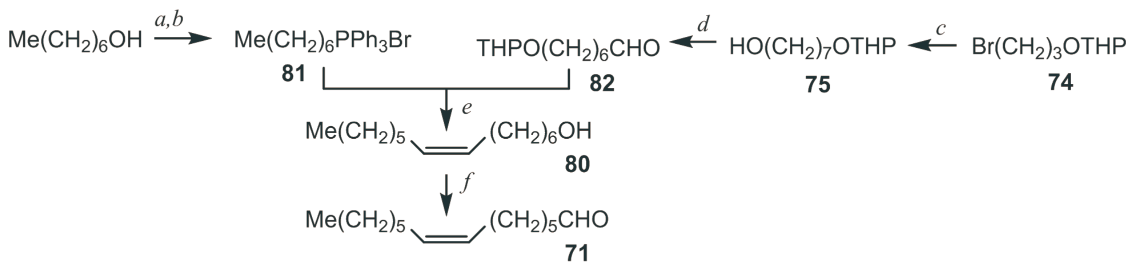
In 2009, using a key Wittig reaction with *t*-BuOK in a THF-CH_3CN medium, we successfully synthesized (*E*)-10-hexadecenal **60** from either decane-1,10-diol and hexanal, or 10-undecenoic acid and bromohexane. Additionally, we produced (*E*)-11-hexadecenol from 10-undecenoic acid and pentanal[54].

Additionally, in 2011, (*Z*)-7-tetradecenal was synthesized via the Wittig reaction, which involved a C7+C7 coupling; the necessary C7-phosphonium salt was prepared from heptyl bromide obtained from heptanol. Heptyltriphenylphosphonium bromide **81** was created by refluxing heptyl bromide with triphenylphosphine in a toluene solvent. A bifunctional C7 unit can also be easily prepared from C3-diol, another commercial material (see **Scheme 14**)[55].



Reagents. a) $SOCl_2$; b) $C_5H_{11}MgBr$, ether; c) Ac_2O, Py, ultrasound; d) HBr, benzene; e) 3,4-dihydro-2H-pyrane/P*p*TS, ultrasound; g) Mg/CuI, THF, -20 ^oC, ultrasound; h) 1. Silica gel/$AgNO_3$ (column chromatography); 2. MeOH, *p*-TSA, ultrasound; i) **79**, HCOOH, ultrasound; j) **80**, PCC, CH_2Cl_2.

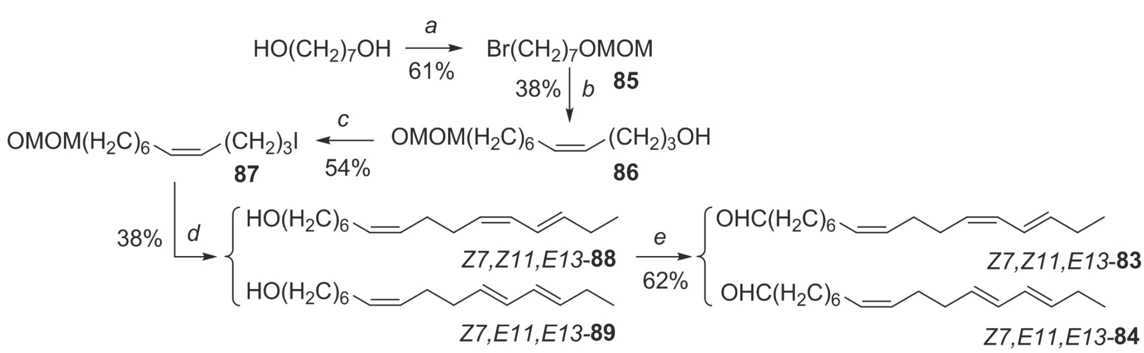
Scheme 13. Synthesis of (*Z*)-5-dodecenyl formate and (*Z*)-7-tetradecenal from (*Z*)-2-buten-1,4-diol, propane-1,3-diol and pentane-1,5-diol



Reagents. a) HBr, H_2SO_4; b) PPh_3, toluene; c) 1. $BrMg(CH_2)_3OTHP$/THF, ultrasound. 2. $Br(CH_2)_4OH$, Li_2CuCl_4, 0-5 ^oC, ultrasound; d) PDC/CH_2Cl_2; e) 1. Dimsyl anion, DMSO, ultrasound. 2. MeOH, PTSA, ultrasound; f) PDC/CH_2Cl_2.

Scheme 14. Synthesis of (*Z*)-7-tetradecenal from 3-bromoprop-1-yl tetrahydropyran-2-yl ether and heptan-1-ol

+ Sex Pheromone of the Citrus Leafminer (*Phyllocnistis citrella*)



Reagents. a) 1. HBr; 2. CH_2OMe_2/LiBr; b) 1. PPh_3/$NaN(SiMe_3)_2$; 2. $CHO(CH_2)_3OTHP$; 3. *p*-TsOH; c) PPh_3I/imidazole; d) 1. PPh_3/$NaN(SiMe_3)_2$; 2. (*E*)-2-pentenal; 3. HCl; 4. Preparative HPLC; e) PCC

Scheme 15. Synthesis of isomers of (7*Z*,11*Z*,13*E*)-hexadeca-7,11-13-trien-1-ol and (7*Z*,11*Z*,13*E*)-hexadeca-7,11,13-trienal from heptan-1,7-diol

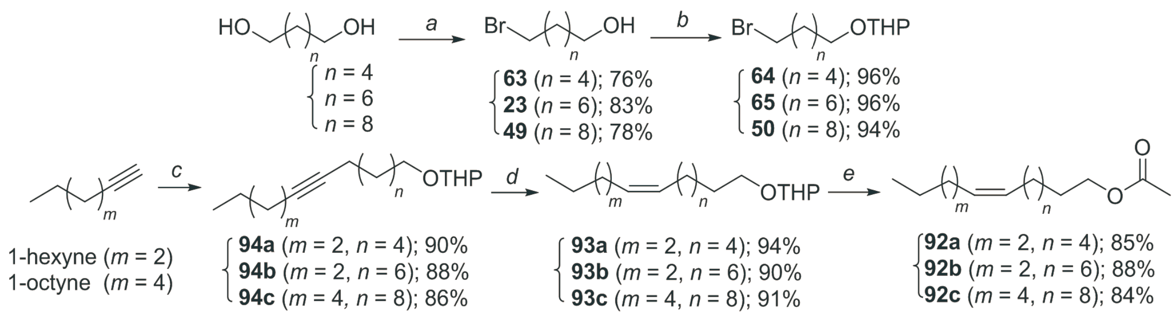
A study by Ando *et al*.[56] identified (7*Z*,11*Z*)-hexadeca-7,11-dienal as the sex pheromone of the citrus leafminer, *Phyllocnistis citrella*. Two other research groups demonstrated that a mixture of (7*Z*,11*Z*,13*E*)-hexadeca-7,11,13-trienal (*Z*7*Z*11*E*13-**83**) and (7*Z*,11*Z*)-hexadeca-7,11-dienal, at a ratio of 3:1, strongly attracted Citrus leafminer moths. Vang *et al*.[57] described the synthesis and biological testing of these two isomers. The Wittig reaction gave the major (*Z*) isomer an overall yield of 3%. The pure isomers were obtained by HPLC and oxidation by PCC (**see Scheme 15**).

+ Sex Pheromone of the Gold-Fringed Rice Borer (*Chilo auricilius* Dudgeon)

In 2011, we successfully synthesized two main components of the sex pheromone of the gold-fringed rice borer, *Chilo auricilius* Dudgeon. This mixture consists of four compounds: (*Z*)-7-dodecen-1-yl acetate (**43**), (*Z*)-8-tridecen-1-yl acetate (**90**), (*Z*)-9-tetradecen-1-yl acetate (**53**), and (*Z*)-10-pentadecen-1-yl acetate (**91**). These compounds are mixed in a ratio of 4:8:4:1 to create a trap for pests. The structures of these compounds were synthesized using the Wittig reaction with THF and *t*-BuOK as catalysts. In Vietnam, compound **91** is identified as the female sex pheromone of this caterpillar moth, while compound **53** is found in the pheromones of many other insects. We developed a synthesis method for compounds **53** and **91** via the Wittig reaction, using diols as starting materials, similar to the method described in **Scheme 14**[46].

+ Sex Pheromone of the Fall Armyworm (*Spodoptera frugiperda*)

In 2021, we synthesized the three main sex pheromone components of fall armyworm from diols, specifically 1,6-hexandiol, 1,8-octandiol, and 1,10-decandiol, along with 1-alkynes (1-hexyne and 1-octyne) according to **Scheme 16**[58]. This synthesis involved some important modifications compared to previous works. First, the alkylation of 1-alkynes was performed using KI as the nucleophile-exiting group, as described in the method[59]. Additionally, we used $Pd_2(dba)_2$ as a catalyst with KOH/DMF as a hydrogen source to reduce the alkyne to a *Z*-alkene in the pheromone synthesis (compounds **92a**, **92b**, and **92c**).



Reagents. a) HBr 48%, *n*-heptane, reflux, 3 hrs; b) DHP/PTSA/CH_2Cl_2, ultrasound; c) 1. *n*-BuLi/THF, -78 °C, 1 hr, 2. alkyl bromide (**64**, **65**, or **50**), KI, 80 °C, 16 hrs; d) $Pd(dba)_2$/KOH/DMF, 145 °C, 6 hrs; e) 1. PTSA/MeOH, 2 hrs, 2. Ac_2O/Py, 0 °C, 2 hrs

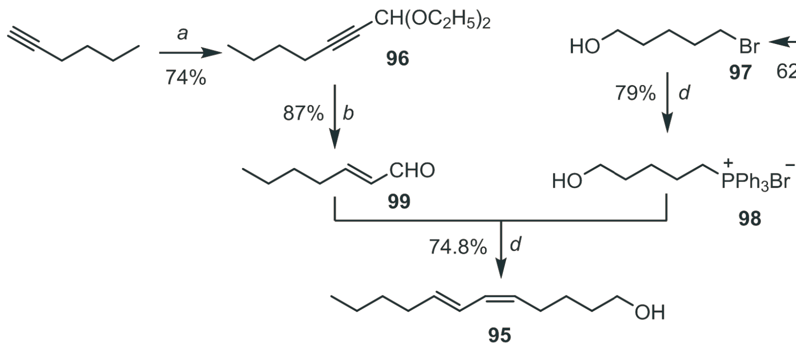
Scheme 16. Synthesis of main components of the sex pheromone of the fall armyworm (*Spodoptera frugiperda*), (*Z*)-7-dodecen-1-yl acetate (*Z*7-12Ac), (*Z*)-9-tetradecen-1-yl acetate (*Z*9-14Ac), and (*Z*)-11-hexadecen-1-yl acetate (*Z*11-16Ac)

+ Sex Pheromone of the Crucifer Flea Beetle and the Striped Flea Beetle (*Phyllotreta cruciferae* and *Phyllotreta striolata*)

The sex pheromone of the crucifer flea beetle and the striped flea beetle was isolated as allyl isothiocyanate from mustard seeds (*Brassica* sp). We also synthesized allyl isothiocyanate through the reaction of allyl iodide with potassium thiocyanate. Fleas are significant pests of cruciferous vegetables, particularly during the seedling stage. They inflict damage during both larval and adult stages. Our survey indicated a density of 11.5 ± 0.014 individuals per trap during the vegetable stage, which ranged from 35 to 63 days after sowing. Since it is challenging to determine the density of larvae and pupae in the soil, we used the adult population density as the survey index for assessing damage in the field[60].

+ Sex Pheromone of the Masson Pine Caterpillar (*Dendrolimus punctatus*)

In 2011, we synthesized the isomer (5*Z*,7*E*)-dodeca-5,7-dien-1-ol **95**, which is the main component of the female sex pheromone of the Masson pine caterpillar (*Dendrolimus punctatus* Walker). This was done using hex-1-yne and pentan-1,5-diol. In this synthesis, the key step was the Wittig reaction using KHMDS as the base agent, as illustrated in **Scheme 17**[61, 62]. The compound (*E*)-hept-2-enal **99**, an important synthon intermediate, was prepared from hex-1-yne via the Bodroux-Chichibabin reaction. The overall yield over three steps from hex-1-yne was 49.8%. (The sex pheromone complex of the pine moth consists of *Z*5*E*7-12Ac, *Z*5*E*7-12-propionate, and *Z*5*E*7-12OH).

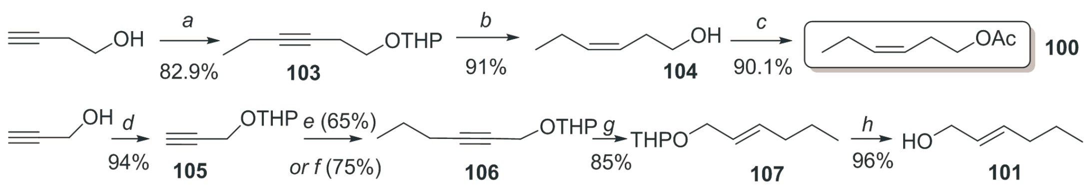


Reagents. a) 1. EtMgBr/THF, 2. $(EtO)_3CH$/Toluene, 90-100 °C; b) 1. $LiAlH_4$, THF, diglyme, 2. HCl 20%, CH_2Cl_2, 2 hrs.; c) HBr, benzene - acetone; d) PPh_3, CH_3CN, 110 - 130 °C; e) KHMDS, THF, 0 °C

Scheme 17. Synthesis of (5*Z*,7*E*)-dodeca-5,7-dien-1-ol from hex-1-yne and pentan-1,5-diol

+ Sex Pheromone of the Tea Mosquito Bug (*Helopeltis theivora* Waterhouse)

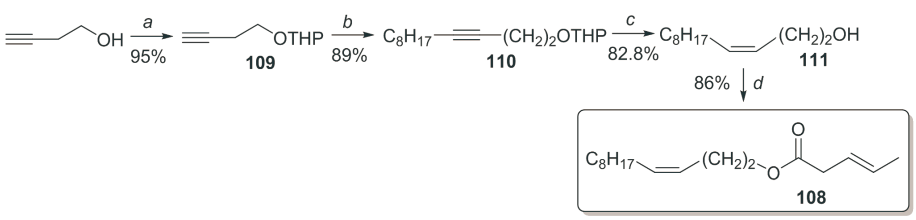
In 2017, we synthesized the sex pheromone of the tea mosquito bug (*Helopeltis theivora* Waterhouse), specifically (*Z*)-3-hexen-1-yl acetate **100** (*Z*3-6Ac), through two different routes. The most efficient method involved the reduction of alkyne-OTHP from but-3-yn-1-ol using a $Pd(OAc)_2$ catalyst and KOH/DMF as the hydrogen source, achieving an overall yield of 60% with stereoselectivity greater than 99% for the (*Z*)-isomer[63]. In 2019, we synthesized the remaining compound (*E*)-2-hexen-1-ol **101** (*E*2-6OH) from propargyl alcohol in four steps, with the best overall yield being 57.5% (as described in **Scheme 18**)[64].



Reagents. a) 1. 3,4-2*H*-dihydropyran, P*p*TS; 2. C_2H_5Br, *n*-BuLi, THF; b) 1. $Pd(OAc)_2$, KOH, DMF, 2. *p*-TSA, MeOH, ultrasound; c) Ac_2O, Py; d) 3,4-2*H*-dihydropyran/P*p*TS; e) 1. Mg/C_2H_5Br/THF; 2. $C_3H_7Br/FeBr_2$/O-TMEDA/THF, rt, 16 hrs; f) 1. Mg/C_2H_5Br/THF; 2. $C_3H_7Br/Pd_2(dba)_3/Ph_3P$/THF, 65 °C, 10 hrs; g) $LiAlH_4$/diglyme, 140 °C, 5 hrs; h) MeOH/PTSA

Scheme 18. Synthesis of (*Z*)-3-hexen-1-ol (*Z*3-6Ac) from propan-1,3-diol and but-3-yn-1-ol (**A**); synthesis of (*E*)-2-hexen-1-ol (*E*2-6OH) from propargyl alcohol (**B**)

+ Sex Pheromone of the Sweetpotato Weevil (*Cylas formicarius*)



Reagents. a) DHP/*p*-TSA/CH_2Cl_2; b) 1. *n*-BuLi/THF, -78 °C; 2. KI, $C_8H_{17}Br$/THF, reflux 16 hrs; c) 1. $Pd_2(dba)_3$/DMF/KOH, 145 °C, 6 hrs; 2. *p*-TSA/MeOH, ultrasound; d) crotonyl chloride/Py, 0 °C, 2 hrs.

Scheme 19. Synthesis of (*Z*)-3-dodecen-1-yl (*E*)-2-butenoate from 3-butyn-1-ol and 1 bromooctane

In Vietnam, in 1995, the sex pheromone of the sweet potato weevil (*Cylas formicarius*) was synthesized and tested in the field (Nguyen C.H, *et al.*)[65]. The pheromone, (*Z*)-3-dodecen-1-yl (*E*)-2-butenoate, was prepared from acetylene and $C_8H_{17}Br$ in the presence of *n*-BuLi and CuBr as catalysts. In 2016, Phan K.S synthesized (*Z*)-3-dodecen-1-yl (*E*)-2-butenoate (**108**) using the Wittig reaction from propan-1,3-diol[66]. In 2021, we selected 3-butyn-1-ol and 1-bromooctane as starting materials for the synthesis of pheromone **108** (**Scheme 19**). The reduction of the alkyne to the *Z*-alkene was accomplished using the $Pd_2(dba)_2$/DMF/KOH catalyst system, resulting in a yield of 92% with a nearly perfect *Z*-alkene configuration. The *n*-BuLi reagent was utilized to convert the triple bond (C≡C) between **109** and 1-bromooctane to **110** as another key step, which also yielded good results, achieving an overall yield of 60% over four steps from 3-butyn-1-ol[67].

c. Insect Attractants

Insect attractants are chemical compounds - either natural or synthetic - that can lure insects through smell, taste, or physical signals. Unlike pheromones, which are specific chemicals produced by insects to communicate with each other, insect attractants are not necessarily secreted by insects.

+ Oriental Fruit Fly Attractant (*Bactrocera dorsalis*)

In 2005, an attractant for the oriental fruit fly (*Bactrocera dorsalis*), known as methyl eugenol, was synthesized from eugenol using a K_2CO_3 catalyst in DMC solvent under microwave conditions. (*E*)-coniferyl alcohol was also synthesized from vanillin[68]. Test results indicated that the fruit fly attractants were effective on a variety of fruits, including apples, longans, plums, guavas, dragon fruits, and cherries. In addition to yellow sticky traps, we developed various types of fruit fly traps made from inexpensive and easily accessible materials, making them convenient for farmers to use.

+ Curcurbit Fruit Fly Attractant (*Bactrocera cucurbitae*)

The attractant for the fruit fly that affects squash and cucumber (*Bactrocera cucurbitae*) is 4-(*p*-acetoxyphenyl)-2-butanone, which was synthesized from anetol in 2007[69]. Results from tests on leaf miner traps showed effectiveness on commonly grown fruit-bearing vegetables, such as cucumbers, squash, and beans. Although the density of these flies is not as high on leafy vegetables, the damage can still be substantial, as evidenced by the number of damaged leaves.

Additionally, we have successfully developed sticky traps in various colors to capture flies and small insects that harm vegetables. Among these, yellow sticky traps have proven to be the most effective for catching striped flea beetles and leaf miners.

4. Applications of Insect Pheromones and Attractants in Vietnamese Agriculture

The use of insect pheromones and attractants in Vietnamese agriculture encompasses a wide range of pest management strategies:

4.1 Pheromone traps

- *Principle*: Pheromone traps are baited with specific pheromones designed to attract male insects. Once drawn in, the insects get trapped, thereby reducing their population and their ability to mate.

- *Application*: Pheromone traps have been extensively used to monitor and control various pests, including the Rhynchophorus palm weevil, rhinoceros beetle, black-headed caterpillar, diamondback moth, cotton bollworm, beet armyworm, oriental leafworm, striped flea beetle, and sweet potato weevil. These traps provide valuable insights into insect population dynamics and can help trigger timely control measures.

a. Pest Management in Rice

- Integrated Pest Management (IPM) Project:

+ Pheromone traps are combined with natural enemies, such as parasitic wasps, to manage stem borers and leaf rollers.

+ Results: This approach has led to a 30-50% reduction in pesticide use in the Mekong Delta.

b. Orchards

- Fruit Fly Traps:

+ Traps utilizing methyl eugenol and hydrolyzed protein (Success Appat) target mango and jackfruit flies.

+ Applicable Locations: Tien Giang, Ben Tre, Vinh Long.

c. Industrial Crops (Coffee, Pepper)

- Pheromone Traps for Stem Borers and Leaf Rollers:

+ Sex pheromones of *Xylotrechus quadripes*, *Zeuzera coffeae*, or *Xylosandrus compactus* are used to combat the coffee stem borer in the Central Highlands.

4.2 Mating disruption

- *Principle*: The method involves releasing large amounts of synthetic pheromones into the environment, which disrupts the mating behavior of male insects. These males become overwhelmed by the artificial signals and struggle to locate females, ultimately leading to reduced fertility and a decline in the insect population.

- *Application*: Mating disruption has been an effective strategy for controlling several key pests in Vietnam, including the coffee berry borer (*Hypothenemus hampei*) and the leaf roller. This technique is particularly effective in large-scale plantations where careful application and monitoring can be conducted.

4.3 Attract and kill techniques

- *Principle*: Attractants such as pheromone lures, food baits, and kairomones are used to entice insects into traps that contain insecticides. This targeted approach minimizes the impact on non-target organisms.

- *Applications*: Attract-and-kill techniques are becoming increasingly popular in Vietnam as a specific and effective method for controlling pests like the fruit fly and cucurbit fruit fly. These techniques are particularly useful for managing invasive species and pests that are difficult to control using traditional methods.

4.4 Push-pull strategy

- *Principle*: The push-pull strategy combines repellents (push factors) to deter insects from crops and attractants (pull factors) to lure them into trap locations or designated areas.

- *Applications*: This integrated approach has demonstrated promise in managing a variety of pests, including the southern corn rootworm, stem weevils, citrus flower moth, and the yellow peach moth. The push-pull strategy is particularly effective in agroecosystems where various crops are cultivated in proximity.

4.5 Monitoring and early warning system

- *Principle*: Pheromone traps can be utilized to monitor insect populations and detect infestations early. This information facilitates timely control actions and helps to prevent disease outbreaks.

- *Application*: Early warning systems using data from pheromone traps enable farmers to make informed pest management decisions, reducing their reliance on broad-spectrum pesticides.

4.6 Results of pheromone insect trap application

Pheromone traps are essential tools in integrated pest management (IPM). Currently, three common types of traps are effectively utilized: board traps, tube traps, and pitfall traps (see **Figure 1**).

- Board traps are primarily used to monitor and capture caterpillars that damage vegetables and forest trees. They are typically hung from tree branches or secured with nails in areas infested with insects.

- Tube traps are specifically designed for catching fruit flies and are often placed in fruit orchards.

- Pitfall traps are effective against beetles and weevils. These traps feature many small openings that are flush with the ground, allowing insects to enter while making it difficult for them to escape[70].

A B C

Figure 1. Types of traps: (A) Sticky board trap; (B) Tube trap; (C) Pitfall trap

The process of using pheromone traps involves the following steps:

1. *Preparation of Bait*: A specific pheromone is dissolved in a hexane solvent and then coated onto a porous material (such as rubber or polymer) to protect the compound from decomposition.

2. *Installation of Bait*: After the solvent evaporates, the bait is attached to the center of the trap and positioned in the target area.

3. *Control of Pheromone Release*: The bait is designed to release pheromones steadily, with the release rate depending on the chemical and physical properties of the carrier material, as well as temperature, humidity, and local weather conditions.

4. *Monitoring and Evaluation*: The traps are checked periodically (ranging from a few days to several weeks) to collect and record the number of insects caught. The effectiveness of the trap depends on selecting the appropriate pheromones for the biological characteristics of each target insect species.

4.6.1 The diamondback moth, plutella xylostella

Figure 2 illustrates the catches of diamondback moth males using pheromone traps tested at different dosages across various locations over a month-long period from 1994 to 1995.

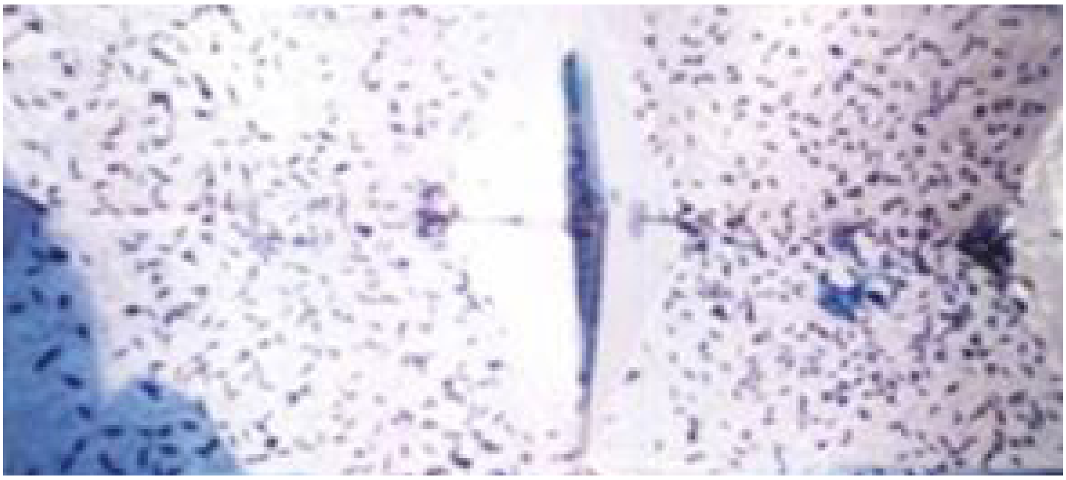


Figure 2. Sticky board trap caught diamondback moth, *Plutella xylostella*

Experimental Design:

- *Bait*: A synthetic pheromone mixture composed of three components: *Z*11-16OH (>98%, gas chromatography – GC), *Z*11-16Ac (99.2%, GC), and *Z*11-16Ald (95.5%, GC) in a ratio of 1:10:1, provided by AgriSense Company.

- *Trap Type*: Sticky board trap (see **Figure 2**)[69].

- *Test Area*: North: Tu Liem district vegetable field (Hanoi); Central Highlands: Da Lat (Lam Dong); South: Cu Chi and Hoc Mon (Ho Chi Minh City)

- *Research Focus*: The diamondback moth (*Plutella xylostella*), which primarily damages Cruciferae plants such as cabbage, cauliflower, and collard greens. The larvae feed on leaf tissue, causing significant harm in the seedling stage, leading to deformation and reduced yield.

- *Method*: A comparative study of the effectiveness of synthetic pheromones versus commercial bait was conducted from 1994 to 1995[65].

Results (see **Figure 3**):

1. *Geographical Differences*: The density of male moth captures in Da Lat and Cu Chi was significantly higher than in Tu Liem and Hoc Mon.

2. *Effect of Dosage*: The response from male moths increased dramatically with the concentration of synthetic pheromone. At a dose of 5 mg, trapping efficiency was comparable to that of commercial bait.

- *Remarks*: Synthetic pheromones demonstrate potential as substitutes for commercial bait in pest management strategies. The effectiveness of trapping is affected by the dosage of the pheromone and the specific ecological conditions of each region.

- *Application Significance*: This study contributes to enhancing integrated pest management (IPM) solutions for Brassica crops in Vietnam, helping to reduce economic losses caused by diamondback moths.

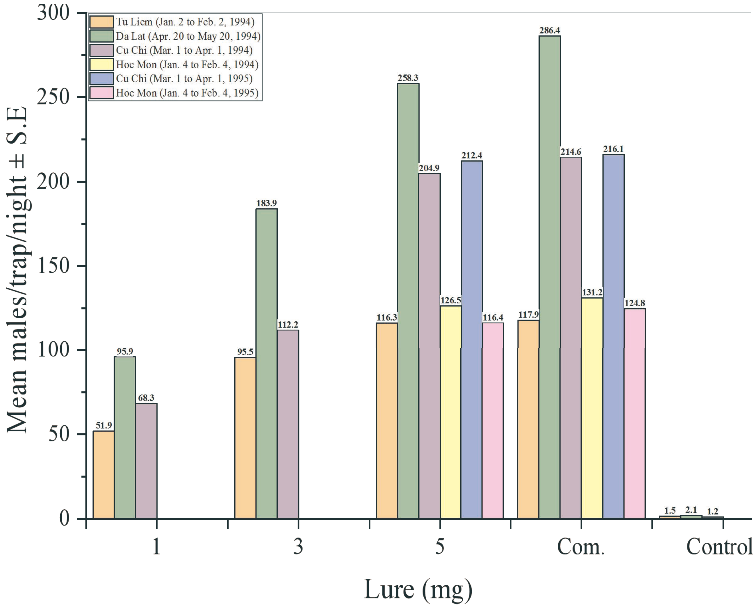


Figure 3. Pheromone trap catches of *P. xylostella* males were tested at different dosages across various areas for one month between 1994 and 1995[65].

4.6.2 The sweet potato weevil, cylas formicarius

A study was conducted to investigate the effect of insect attractant dosage on sweet potato weevils (*Cylas formicarius*) in a 1500 m² sweet potato field located in Tien Thuy commune, Chau Thanh district, Ben Tre province, Vietnam[67].

Bait Used:

- Synthetic pheromone bait **108** (99% purity, GC)
- Commercial bait sourced from Can Tho University (used as a control)

Trap Design:

Figure 4. A: setup pheromone traps of *Cylas formicarius* in the field; B: *Cylas formicarius* on the sweet potato leaf; C: *Cylas formicarius* caught with pheromone lures

We employed 2-liter plastic bottles with 8-10 windows (diameter of about 3 cm and approximately 10 cm from the bottle cap) (**Figure 4A**). The traps were labeled, covered, and placed throughout the field. A soap solution was filled to 2-3 cm from the trap windows, which was changed weekly to ensure the effectiveness of the decomposing individuals[67,71].

Baiting for Traps:

Rubber septa (1.5 cm diameter) were impregnated with the synthetic pheromone **108** dissolved in *n*-hexane. The evaporating solvent was carried out for 10 minutes. The impregnated septa were packed in aluminum bags, labeled, and stored at 0-5 °C until testing.

Effect of Attractant Dose:

Five treatment groups were randomly arranged and replicated three times with doses of 0.1, 0.2, 0.4, and 0.8 mg of pheromone **108**. Each dose included three traps and one control (using *n*-hexane)[67,72]. The baits were placed in opaque plastic bottles containing soap solution. A commercial lure (0.4 mg pheromone) was tested as well. The experimental period lasted four weeks, from February 22 to March 22, 2021, with sweet potatoes at 45 days of age during the study.

Effectiveness of Attractant Dosage:

- The number of weevils caught in traps at dosages of 0.1, 0.2, 0.4, and 0.8 mg of bait were 91.3 ± 3.22, 98.3 ± 1.53, 108.3 ± 1.53, and 132 ± 3.61 individuals/trap/week, respectively ($P < 0.05$).
- Results in the number of beetles captured indicated a significant difference at these dosages (**Figure 5**).
- The dosage of 0.4 mg of bait was found to be the most effective, averaging 108.3 ± 1.53 individuals/trap/week.

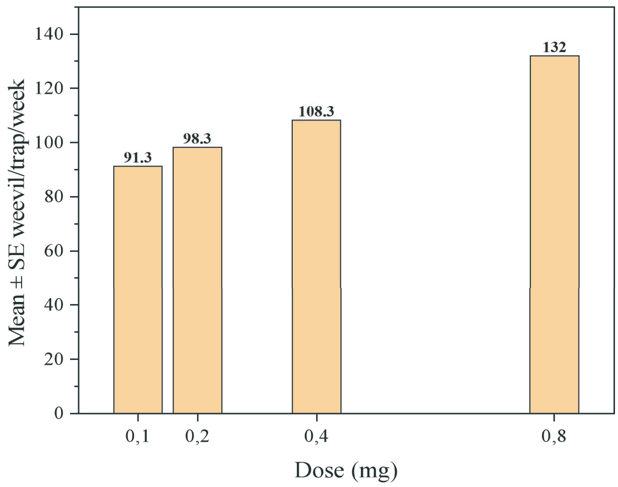


Figure 5. The field test result of sweet potato weevil with different doses

Comparison with Commercial Baits:

- Initial results indicated that the bait used in this study was approximately 30% more effective than the commercial bait obtained from Can Tho University[67].
- A previous study from Can Tho University with doses of 0.1, 0.3, 0.5, 0.7, and 1.0 mg reported average trapping rates of 23, 21.7, 27.3, 44, and 39 individuals/trap/week, respectively[73].
- The difference in attraction efficiency may be attributed to the stereoselectivity of the (*Z*) configuration synthesized by the Wittig reaction in the commercial bait.

In conclusion, this study found that the pheromone bait dosage of 0.4 mg was the most effective for trapping sweet potato weevils, outperforming the commercial bait. However, further testing is required to enhance the reliability of these findings.

4.6.3 Screening of sex attractants for moths in the Mekong Delta, Vietnam

A study conducted by Hai *et al*.[74] screened six typical attractants to assess pest populations in the Mekong Delta, Vietnam. The experiment took place in apple, guava, and longan orchards in Can Tho from December 1998 to November 1999, and in plum and guava orchards from January to December 2000.

Baits Used: The baits included a variety of synthetic and commercial compounds

- Monoenyl alcohol: *Z*7-12OH, *Z*11-14OH, and *E*11-14OH
- Monoenyl acetate: *Z*5-10Ac, *Z*5-12Ac, *Z*7-12Ac, *Z*9-12Ac, *Z*9-14Ac, *Z*11-14Ac, *E*11-14Ac
- Dienyl acetate: *Z*9*E*11-14Ac and *Z*9*E*12-14Ac
- Monoenyl aldehyde: *Z*11-14Ald
- Triene: *Z*3*Z*6*Z*9-18Hy, *Z*3*Z*6*Z*9-19Hy, *Z*3*Z*6*Z*9-20Hy, and *Z*3*Z*6*Z*9-21Hy
- Epoxydiene: racemic mixtures of various epoxy compounds

Trap Type: Sticky board traps measuring 30 × 27 cm were used.

Field results indicated that 19 Lepidopteran species were attracted to the traps, including 9 identified species and 10 unidentified species. The compound *Z*11-14Ac and its mixture were identified as significant attractants for Tortricid species such as *A. privatana, A. atrolucens*, and *M. furtive*. In contrast, several Noctuid species such as *A. signata, C. eriosoma, C. agnate, C. albostriata, A. ochreata*, and *S. pectinicornis* were primarily attracted to baits containing *Z*7-12Ac as the main component.

The study also observed a seasonal effect on capturing male Noctuid species. For example, the majority of pests were primarily captured during the dry season (January to March) and the latter part of the rainy season (September to December). In contrast, very few were captured between April and July. These observations may help us better understand the ecological behavior of pests in these regions.

4.6.4 Study on Rhynchophorus palm weevils, Rhynchophorus ferrugineus

- *Field Test Results (2006-2007)*

This study examined the effectiveness of pheromones and kairomones in trapping Rhynchophorus palm weevils over two seasons (rainy and dry) in two provinces (Hau Giang and Ben Tre) from 2006 to 2007[75].

Test Period:

- Dry Season: Hau Giang: April 1, 2006 - February 22, 2006; Ben Tre: July 12, 2006 - January 26, 2007

- Rainy Season: Hau Giang: July 1, 2006 - December 8, 2006; Ben Tre: August 3, 2006 - September 16, 2006

Experiments Conducted:

1. Dose Response of 4-methyl-5-nonanol (4Me5ol) and 4-methyl-5-nonanone (4Me5on): Three different doses of pheromone **1** (20, 30, 40, and 50 mg/trap) were compared with a mixture of pheromone **1** and pheromone **2** (1:1 ratio).

2. Interaction Between Pheromone and Kairomone: Three treatments were administered using kairomone, which is a mixture extracted from fresh coconut tissue (68% ethanol, 27% ethyl acetate, and 5% pentane). Prior studies at Dong Khoi Center indicated that storing bait in Eppendorf tubes increased the attraction efficiency of insects compared to using PVC tubes, so Eppendorf tubes were utilized for these trials.

Results:

- Capture Efficiency in Ben Tre (**Figure 6**):

During both rainy and dry seasons, the combination of pheromone and kairomone (P+K) proved significantly more effective than using either pheromone (P) or kairomone (K) alone. The 50 mg bait exhibited the highest capture efficiency in the rainy season. The 1:1 mixture of 4Me5ol and 4Me5on also demonstrated strong attraction, particularly in the dry season[75].

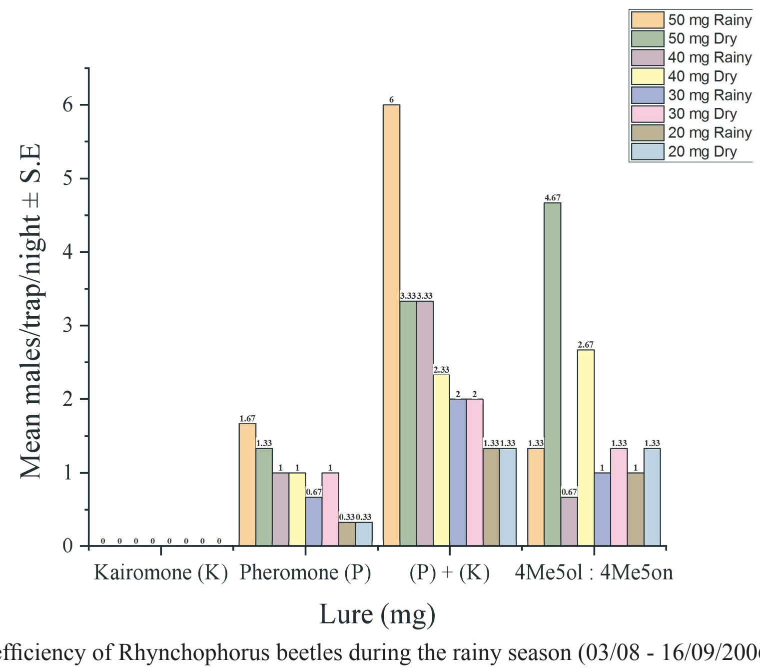


Figure 6. Catching efficiency of Rhynchophorus beetles during the rainy season (03/08 - 16/09/2006) and the dry season (07/12/2006 - 26/01/2007) in Ben Tre.

4-Methyl-5-nonanol (4Me5ol) and 4-methyl-5-nonanone (4Me5on) were used to test the 1:1 ratio.

The values within the same characters and column are not statistically different (at $P < 0.05$, Duncan's Test).

- Comparison of Capture Efficiency Between Provinces (**Figure 7**):

In both seasons, the total number of insects trapped in Ben Tre was higher than in Hau Giang, though the difference was not statistically significant. Notably, the number of female weevils caught was four times greater than that of males, especially during the rainy season[75].

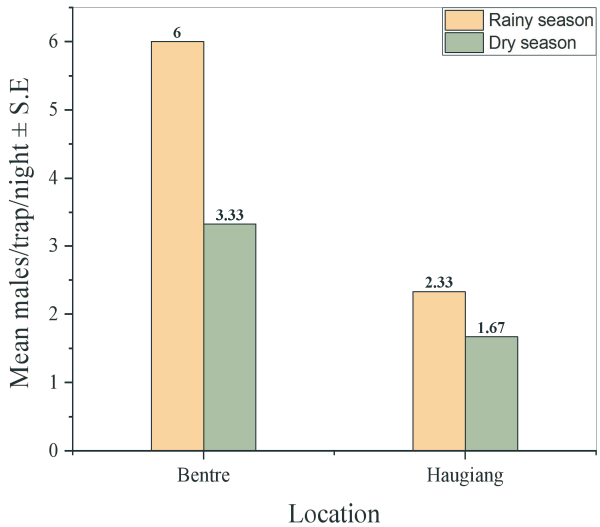


Figure 7. Comparison of Rhynchophorus capture efficiency during the rainy and dry seasons in two provinces (Hau Giang and Ben Tre) using 50 mg of pheromone, which reflects the combined effects of pheromone and kairomone. The values within the same characters and column are not statistically different ($P < 0.05$, Duncan's Test).

Rhynchophorus palm weevils are present year-round on coconut trees, with greater density observed at the onset of the rainy season and reduced numbers during the middle of the dry season. Capture efficiency improves with increased pheromone dosage. Additionally, trapping efficiency is influenced by various factors, including temperature, weather, environmental conditions, and insect density. The results can serve as a predictive tool for pest outbreaks based on sudden increases in captured insect numbers. In this study, an aggregation pheromone was utilized to attract both male and female weevils.

These demonstrated that the combination of pheromone and kairomone baits is the most effective method for trapping Rhynchophorus palm weevils. Trapping efficiency varies across seasons and locations, and its findings can be utilized to create more effective control measures for managing Rhynchophorus populations.

- *Another Field Test Results (2019)*

The main compounds studied for the pheromone composition of Rhynchophorus were (±)-4-methylnonan-5-ol (**1a**) and (±)-4-methylnonan-5-one (**2**). The experiment utilized traps with varying concentrations of each compound and their mixtures, referred to as Exp.1 to Exp.7[76]. The detailed results are presented below:

Number of weevils captured (x ± S.E) / 3 traps/week:

1. Effect of (±)-4-methylnonan-5-ol at a threo:erythro ratio of 2:1 (**1a**) – Exp.1: The concentration of 10 mg resulted in the highest number of insects captured in traps (2.6 ± 0.55 individuals/3 traps/week) and was significantly different from the concentrations of 0.5 mg to 5 mg ($P < 0.05$). Concentrations of 15 mg and 20 mg did not show significant differences compared to 10 mg. This indicated that the optimal concentration of (±)-4-methylnonan-5-ol (**1a**) was 10 mg.

2. Effect of (±)-4-methylnonan-5-ol with a threo:erythro ratio of 1:1 (**1b**) – Exp.2: There was no significant difference in the number of insects entering the traps between concentrations of 0.5 mg to 2.5 mg. However, concentrations of 15 mg and 20 mg (0.6 ± 0.54 individuals/3 traps/week) showed a significant difference compared to concentrations of 0.5 mg to 2.5 mg ($P < 0.05$). Nevertheless, the number of individuals attracted in Exp.2 was significantly lower than that in Exp.1 at the same concentration, indicating that the threo:erythro isomeric structure significantly influences attraction efficiency.

3. Effect of 4-methylnonan-5-one (**2**) – Exp.3: There was no significant difference in the number of insects entering the traps across concentrations from 0.5 mg

to 20 mg. This suggests that 4-methylnonan-5-one (**2**) is not the main component of the pheromone attracting coconut weevils.

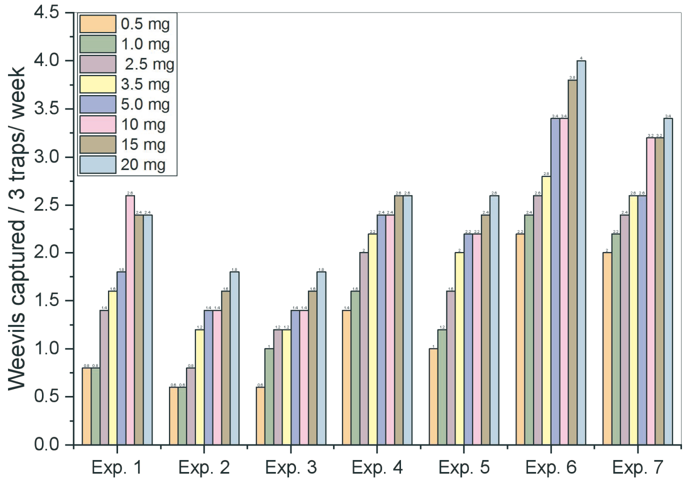


Figure 8. Average number of weevils captured in traps from Exp.1 to Exp.7.

4. Effect of mixtures (**1b**) and (**2**) – Exp.4 (rainy season) and Exp.5 (dry season):

- Exp.4 (rainy season): There was no significant difference between concentrations from 0.5 mg to 2.5 mg and 5 mg to 20 mg. However, the concentration of 5 mg (2.4 ± 0.55 individuals/3 traps/week) was significantly different from the concentrations of 0.5 mg to 2.5 mg ($P < 0.05$).

- Exp.5 (dry season): The concentration of 15 mg (2.4 ± 0.54 individuals/3 traps/week) differed from the concentrations of 0.5 mg and 1 mg, but not from the other concentrations. A comparison during the rainy season between Exp.4 and Exp.5 showed that the attraction efficiency is better than in the dry season.

5. Effect of mixtures (**1a**) and (**2**) – Exp.6 (rainy season) and Exp.7 (dry season):

- Exp.6 (rainy season): The concentration of 15 mg (3.8 ± 0.45 individuals/3 traps/week) showed a significant difference from the concentrations of 0.5 mg to 10 mg but not from 20 mg ($P < 0.05$).

- Exp.7 (dry season): Concentrations of 10 mg and 15 mg (3.2 ± 0.45 individuals/3 traps/week) were different from the concentrations of 0.5 mg to 2.5 mg but not from 20 mg ($P < 0.05$). A comparison between Exp.6 and Exp.7 indicates that attraction efficiency is higher in the rainy season than in the dry season.

6. General Comparison: The attraction effect during the rainy season is greater than that in the dry season (Exp.4 > Exp.5; Exp.6 > Exp.7). Furthermore, Exp.6 and Exp.7 (mixtures of (**1a**) and (**2**)) exhibited a higher attraction effect than Exp.4 and Exp.5 (mixtures of (**1b**) and (**2**)). This suggests that the pheromone mixture with a higher ratio of the *threo* isomer to the *erythro* isomer has better insect attraction capabilities.

Conclusion: Pheromone concentrations between 5 mg and 15 mg are important for practical applications, depending on the specific formulation. The compound 4-methylnonan-5-one (**2**) is included to increate the attraction of insects. The mixtures of pheromones (**1a**) and (**2**) (Exp.6 and Exp.7) demonstrated the strongest attraction effect, particularly when the mixture contains a larger ratio of the *threo* isomer compared to the *erythro* isomer.

4.6.5 The Rhinoceros beetle, Oryctes rhinoceros

Dang *et al*., investigated the damage caused by Rhinoceros beetles on palm trees in the Hau Giang and Ben Tre provinces of the Mekong Delta, Vietnam[31]. The research was carried out during the dry and rainy seasons of 2004 and 2005 in coconut fields aged 3 to 10 years.

Baits: The researchers used a combination of pheromone **3** and kairomone. The kairomone was extracted from fresh coconut tissue using a solvent mixture of 68% ethanol, 27% ethyl acetate, and 5% pentane.

Trap Type: Traps were made from 20-liter plastic buckets, featuring a window size of about 3 × 8 cm (**Figure 1**).

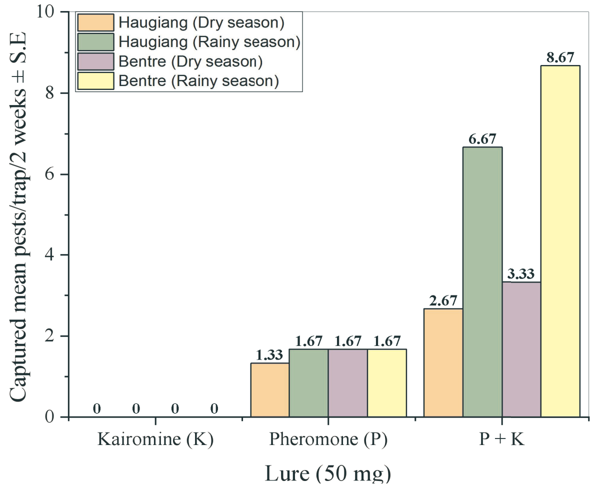


Figure 9. Trap catches of Rhinoceros beetles were tested in various areas during the dry and rainy seasons of 2004 and 2005[31].

Rhinoceros beetles cause significant damage to wild palm trees and economically important crops in Vietnam and Southeast Asia. The adult beetles feed on leaves and bore into the stems, leading to stunted growth. The results of the study indicated the following:

- The combination of kairomone increased the beetles' response to pheromone **3** in all trials.

- The number of Rhinoceros beetles captured did not differ significantly between the two provinces at the same time.

- Insect density was higher during the rainy season than in the dry season in both areas (**Figure 9**).

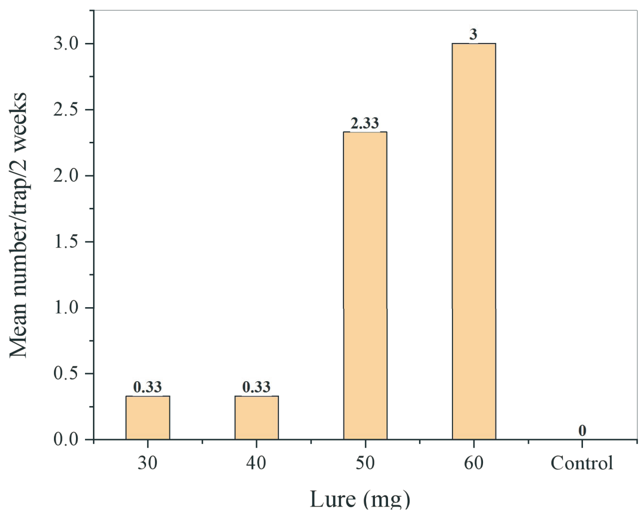


Figure 10. Trap catches of *Oryctes rhinoceros* beetles in Bentre province were tested with various dosages of the pheromone and kairomone from April 1 to April 15, 2005.[31]

- The yield of Rhinoceros beetles captured increased steadily with a higher release rate of pheromone **3** (**Figure 10**).

This study provides important information on using pheromone **3** and kairomone baits to control Rhinoceros beetles, helping to protect coconut trees and other economically important crops.

4.6.6 The Citrus Leafminer, Phyllocnistis Citrella

A study conducted by Vang *et al*., involved field trials of the citrus leafminer in citrus orchards located in Can Tho, Vietnam (from November 21, 2005, to March 12, 2006) and the Ogasawara Islands, Japan (from November 17, 2005, to April 5, 2006)[56].

Type of Pheromone Used: Two geometric isomers of synthetic compounds **32** and **33**, along with a commercial isomer of compound **34**.

Type of Trap: Sticky board trap (30 × 27 cm).

The citrus leafminer is a common pest in Asia and poses a significant threat to citrus crops in various regions worldwide, including East and South Africa. The larvae of this pest create winding tunnels on leaves or young shoots, leading to curled leaves and serious diseases affecting the trees.

The results of the study indicated that:

- In Vietnam, male citrus leafminers were not attracted to baits that contained only *Z*7,*Z*11-hexadecadienal.
- Males were effectively attracted to a mixture of *Z*7,*Z*11,E13-**83** and *Z*7,*Z*11-hexadecadienal in a 3:1 ratio.
- This attraction pattern was not observed in Japan.

From these findings, the authors concluded that the sex pheromone of the citrus leafminer in Vietnam differs from that in Japan.

4.6.7 The Citrus Rind Borer, Prays Endocarpa

Research by Vang *et al*., studied the citrus rind borer, a significant pest affecting grapefruit (*Citrus grandis* L.) orchards in Vietnam and Southeast Asia. The larvae of this pest bore into the fruit peel, causing tumors and potentially leading to the premature dropping of young fruit. This study was carried out in grapefruit orchards in Vinh Long province in 2007 and from April 4 to June 10, 2008[25].

Pheromones Used: (*Z*)-7-tetradecenol (**80**); (*Z*)-7-tetradecen-1-yl acetate (**80b**); (*Z*)-7-tetradecenal (**71**)

Trap Type: Sticky board trap (30 × 27 cm).

Gas chromatography-mass spectrometry (GC-MS) analysis of pheromone gland extracts from female moths revealed three monoenyl-C14 derivatives (**80**, **80b**, and **71**) in a 10:3:10 ratio. Field results demonstrated that:

- Male moths were attracted only to aldehyde **71**.
- The other two compounds (**80** and **80b**) did not attract male moths and did not exhibit a synergistic effect with aldehyde **71**.

The authors also showed that mass trapping experiments were as effective as pesticide application in controlling pests in grapefruit orchards.

5. Challenges and Future Directions

5.1 Challenges

In recent years, Vietnam agricultural scientists still face many challenges:

- Cost-effectiveness: Although synthesizing pheromones cost has decreased in recent years, the use of pheromones in plant protection is still a significant investment for small-scale farmers. Continuous development of more efficient methods of pheromone production and distribution to reduce costs is always necessary to encourage the wider application of pheromones and insect attractants.
- *Integration with Other Pest Management Strategies*: Effective use of pheromones and attractants often requires their integration with biological control and cultural practices as other pest management strategies. It is essential to develop and promote integrated pest management (IPM) approaches that incorporate these technologies.
- *Capacity Building and Knowledge Transfer*: Farmers often lack an understanding of pheromone application techniques. Enhancing the skills of researchers, extension officers, and farmers in the synthesis, application, and monitoring of pheromones and attractants is essential for sustainable pest management.

Solutions:

- Domestic Research: Institute of Chemical Technology - Vietnam Academy of Science and Technology is developing a process for synthesizing low-cost insect pheromones.
- Farmer Training: There is a need to enhance the development of safe fruit and vegetable projects, such as those supported by FAO, to provide guidance on using pheromone traps.

5.2 Future directions

- *Development of New Pheromones and Attractants*: Ongoing research is required to identify and synthesize new pheromones and attractants targeting emerging and invasive pests, such as the fall armyworm (*Spodoptera frugiperda*) and the black-headed caterpillar (*Opisina arenosella*), which have been affecting regions in Vietnam like Ben Tre and Tien Giang from 2022 to 2024[77].
- *Advances in Delivery Technology*: Innovative delivery systems, including controlled-release formulations and microencapsulation, can enhance the potency and shelf life of pheromones and attractants by using appropriate carrier materials (e.g., those used in

baits for Rhynchophorus palm weevils and fruit flies).

- *Integration with Precision Agriculture and IoT*: Combining pheromone and attractant technologies with precision agriculture techniques, such as thermal, remote, and GPS-based sensing systems, can optimize resource utilization and improve pest management efficiency. For example, using thermal, remote, and GPS-based sensing systems to monitor baits for Rhynchophorus palm weevils can be beneficial.

- *International Cooperation*: Vietnam can upgrade its capabilities in this area by exchanging green synthesis technologies with countries like Japan and South Korea.

- *Public Awareness and Education*: Growing awareness about the advantages of pheromone and attractant technologies with supporting education for farmers on their proper usage is necessary for widespread adoption.

Conclusion

The use of pheromones and insect attractants in plant protection in Vietnam has gradually proven its effectiveness in controlling harmful pests without polluting the environment, supporting sustainable agricultural development. Practical studies have shown that pheromones have the ability to attract and control insects selectively, helping to reduce dependence on chemical pesticides and protect biodiversity and public health. Despite these achievements, Vietnam still faces many challenges, including high production costs, integration with other pest management measures, and improving farmer knowledge. To overcome these challenges, it is necessary to invest in domestic research, adopt better production methods, and enhance farmer education.

Looking forward, develop of new pheromones combined with improved delivery technologies and precision agriculture systems will create new opportunities for more effective pest management. In addition, international cooperation and public awareness are also important in promoting the widespread application of these technologies. Thanks to that, Vietnam can affirm its position in the field of sustainable and environmentally friendly agriculture. Recent government policies, combined with the efforts of scientists in synthesizing and implementing the application of pheromones and insect attractants, not only protect crops but also conserve biodiversity. This serves the strategy of sustainable agricultural development, opening up bright prospects for pest management in Vietnam in the future.

List of abbreviations

10-2,3Kt:	2,3-decanedione
10me-13Kt:	10-methyltridecanone
10R-**32**:	(*R*)-10-methyldodecyl acetate
16Ald:	hexadecenal
2*S*-hydroxy-10-3Kt:	(*S*)-2-hydroxy-decan-3-one
4Me5ol:	4-methyl-5-nonanol
4Me5on:	4-methyl-5-nonanone
DMC:	dimethyl carbonate
*E*10-16Ald:	(*E*)-10-hexadecenal
*E*11-14Ac:	(*E*)-11-tetradecen-1-yl acetate
*E*11-14OH:	(*E*)-11-tetradecenal
*E*11-16Ald:	(*E*)-11-hexadecenal
*E*2-6OH:	(*E*)-2-hexen-1-ol
Exp. 1:	experiment No.1
KHMDS:	Potassium bis(trimethylsilyl)amide
n-BuBr:	n-butyl bromide
*Z*10-15Ac:	(*Z*)-10-pentadecen-1-yl acetate
*Z*10-16Ald:	(*Z*)-10-hexadecenal
*Z*11-14Ac:	(*Z*)-11-tetradecen-1-yl acetate

*Z*11-14Ald:	(*Z*)-10-tetradecenal
*Z*11-14OH:	(*Z*)-10-tetradecen-1-ol
*Z*11-16Ac:	(*Z*)-11-hexadecen-1-yl acetate
*Z*11-16Ald:	(*Z*)-11-hexadecenal
*Z*11-16OH:	(*Z*)-11-hexadecen-1-ol
*Z*11-18Ald :	(*Z*)-11-octadecenal
*Z*11-18OH:	(*Z*)-11-octadecen-1-ol
*Z*13-18Ac:	(*Z*)-13-octadien-1-yl acetate
*Z*13-18Ald :	(*Z*)-13-octadienal
*Z*13-18OH:	(*Z*)-13-octadien-1-ol
*Z*3,*Z*6,*Z*9-18Hy:	(3*Z*,6*Z*,9*Z*)-octadeca-3,6,9-triene
*Z*3,*Z*6,*Z*9-19Hy:	(3*Z*,6*Z*,9*Z*)-nonadeca-3,6,9-triene
*Z*3,*Z*6,*Z*9-20Hy:	(3*Z*,6*Z*,9*Z*)-icosa-3,6,9-triene
*Z*3,*Z*6,*Z*9-21Hy:	(3*Z*,6*Z*,9*Z*)-henicosa-3,6,9-triene
*Z*3,*Z*6,*Z*9-23Hy:	(3*Z*,6*Z*,9*Z*)-tricosa-3,6,9-triene
*Z*3-6Ac:	(*Z*)-3-hexen-1-yl acetate
*Z*5-10Ac:	(*Z*)-5-decen-1-yl acetate
*Z*5-12Ac:	(*Z*)-5-dodecen-1-yl acetate
*Z*5*E*7-12Ac:	(5*Z*,7*E*)-dodeca-5,7-dien-1-yl acetate
*Z*5*E*7-12OH:	(5*Z*,7*E*)-dodeca-5,7-dien-1-ol
*Z*5*E*7-12propionate:	(5*Z*,7*E*)-dodeca-5,7-dien-1-yl propionate
*Z*7-12Ac:	(*Z*)-7-dodecen-1-yl acetate
*Z*7-12OH:	(*Z*)-7-dodecen-1-ol
*Z*7-14Ac:	(*Z*)-7-tetradecen-1-yl acetate
*Z*7-14Ald:	(*Z*)-7-tetradecenal
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*Z*8-13Ac:	(*Z*)-8-tridecen-1-yl acetate
*Z*9,*E*11-14Ac:	(9*Z*,11*E*)-tetradeca-9,11-dien-1-yl acetate
*Z*9-12Ac:	(*Z*)-9-dodecen-1-yl acetate
*Z*9-14Ac:	(*Z*)-9-tetradecen-1-yl acetate
*Z*9-14OH:	(*Z*)-9-tetradecen-1-ol
*Z*9-16Ald:	(*Z*)-9-hexadecenal
*Z*9*E*12-14Ac:	(9*Z*,12*E*)-tetradeca-9,12-dien-1-yl acetate

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