

COMPOSITIONS AND METHODS FOR CONTROLLING INSECTS RELATED TO THE OCTOPAMINE RECEPTOR

FIELD OF THE INVENTION

5 The present invention relates to compounds, compositions and method for controlling insects.

BACKGROUND OF THE INVENTION

 Animals have chemosensory and mechanosensory systems that recognize a large array of
10 environmental stimuli, generating behavioral responses. Many behavioral studies have been conducted to understand the genetics of these systems. The olfactory system plays a crucial role in the survival and maintenance of species, particularly in insects.

 Biogenic amines serve a neurotransmitter or neuromodulator role in the olfactory system. The biogenic amine, octopamine, has a prominent role in insects and other invertebrates as it is
15 involved in the regulation of multiple physiological events, for example, effects on muscular systems, sensory organs, endocrine tissues as well as learning and behavior. Octopamine (OA) occurs in large amounts in the nervous systems of species representing the phylum Arthropoda, including the classes Insecta and Crustacea. OA has a broad spectrum of biological roles in insects acting as a neurotransmitter, neurohormone and neuromodulator. OA exerts its effects
20 through interaction with at least four classes of membrane bound receptors that belong to the family of G-protein coupled receptors (GPCRs). All members of GPCRs share the common motif of seven transmembrane (TM) domains.

 When a GPCR is activated, depending on its type and the protein to which it binds, changes in intracellular concentrations of cAMP, Ca^{2+} or both often take place. Since changes in
25 intracellular levels of cAMP or Ca^{2+} are the most commonly found cellular responses to biogenic amine treatments (e.g., serotonin, dopamine, octopamine, etc.), they are used to functionally

classify receptor subtypes. As a result of GPCR activation, intracellular cAMP levels can either be elevated or reduced. The cellular response strictly relies on the specificity of interaction between the receptor and the G protein (See e.g., Gudermann T, Kalkbrenner F, Schultz G. 1996, "Diversity and selectivity of receptor-G protein interaction," Annu Rev Pharmacol Toxicol 36: 429-459; and Gudermann T, Schoneberg T, Schultz G. 1997, "Functional and structural complexity of signal transduction via G-protein-coupled receptors," Annu Rev Neurosci 20: 399-427, both of which are incorporated herein by this reference). When the receptor binds to Gs-type protein, the activated G α s subunit will interact with adenylyl cyclase (AC) in the plasma membrane. This leads to an increase of AC activity and production of cAMP from ATP.

Several biogenic amine receptors are also known to inhibit AC activity. This effect is mediated by interaction of the receptor with inhibitory G protein (Gi). Interaction of AC with activated G α i subunits most likely competes with binding of activated G α s subunits and thereby interferes with AC activation.

Another pathway that is activated by several biogenic amine receptors results in a rise of intracellular Ca²⁺ levels. In such a scenario the amine-activated receptor binds to G proteins of the Gq/o family (See e.g., supra, Gudermann et al., 1996 and Gudermann et al., 1997). The activated G α q/o subunits bind to and stimulate phospholipase C (PLC) activity. The enzyme hydrolyzes a membrane-bound substrate, phosphatidylinositol 4,5-bisphosphate which gives rise to two second messengers IP3 and DAG. After binding of IP3 to its receptors, the calcium channel pore is opened and Ca²⁺ is released into the cytoplasm. Ca²⁺ ions play a vital role in the regulation of many cellular functions by binding to members of large family of Ca²⁺-binding proteins and/or directly controlling enzymatic or ion channel activities.

Multiple insect species have been utilized to understand the biological functions and pharmacological characteristics of octopamine receptors. Studies with *Periplaneta americana* (American cockroach) have provided insight into the pharmacology and second messenger

signaling of octopamine through octopamine receptors. For example, octopamine has been found to activate adenylate cyclase in certain cells in this species. Furthermore, octopamine has been found to increase inositol triphosphates in certain cells in this species.

As the octopaminergic system is believed to be unique to invertebrate physiology, this pathway has been proposed to offer a target for invertebrate pesticides with potential for low vertebrate toxicity. Formamidine-like chemicals have been found to be octopaminergic agonists and inhibit the uptake of sodium-sensitive octopamine in certain insects; for example, the formamidine pesticides chlordimeform and demethylchloridimeform were found to target the octopamine signaling pathway in certain invertebrates, including *Periplaneta americana*. To provide insight into the design of octopamine agonists that could be used as potential insecticides, structure function analyses have been performed with 2-(arylimino)oxazolidines and 2-(substituted benzylamino)-2-oxazolines in regard to activation of the octopamine sensitive adenylate cyclase in certain cells in *Periplaneta Americana*. More recently, it has been suggested that one site of action for the insecticidal activity of plant essential oils against *Periplaneta americana* is the octopaminergic system and that octopamine receptors may be targeted by these compounds, as described in Enan, E., 2001, "Insecticidal activity of essential oils: octopaminergic sites of action," Comp. Biochem. Physiol. C Toxicol. Pharmacol. 130, 325-327, which is incorporated herein by this reference.

Identifying plant essential oils and combinations thereof, having insect-controlling activity is particularly desirable given that many such compounds do not produce unwanted or harmful affects on humans, other animal species, and certain plants. However, identifying the most effective plant essential oils and combinations thereof requires random selection and use of tedious screening methods, which, given the vast number of plant essential oils and possible combinations thereof, is a substantially impossible task.

As such, there is a need in the art for an improved method for screening compounds and compositions for insect control activity.

SUMMARY OF THE PRESENT INVENTION

The present invention addresses the above identified problems, and others, by providing a screening method for identifying compounds and compositions that are effective insect control agents; a screening method for identifying compounds and compositions that are effective species-specific insect control agents; compounds and compositions isolated from the screening methods; cell lines expressing an octopamine receptor; and isolated nucleic acid molecule sequences.

DESCRIPTION OF THE DRAWINGS

Figure 1A is an alignment of the nucleic acid sequence and the translated amino acid sequence from Pa oa₁, of SEQ ID NO: 1 and SEQ ID NO: 2;

Figure 1B is the nucleic acid sequence from Pa oa₁ of SEQ ID NO: 1, with the seven putative transmembrane domains (TM) overlined and numbered 1 through 7, the stop codons (SC) underlined, and the initiation codon (M) underlined;

Figure 2 is an alignment of the translated amino acid sequences of Pa oa₁ of SEQ ID NO: 2 and OAMB of SEQ ID NO: 3, with the seven putative transmembrane domains (TM) overlined and numbered 1 through 7;

Figure 3A is saturation binding curve of ³H-yohimbine to Pa oa₁, where total binding is designated by the squares, nonspecific binding is designated by the triangle, and specific binding is designated by the inverted triangle;

Figure 3B is saturation binding curve of ³H-yohimbine to OAMB, where total binding is designated by the squares, nonspecific binding is designated by the triangle, and specific binding is designated by the inverted triangle;

Figure 4 is a hydropathy profile of Pa oa₁ with the transmembrane domains (TM) numbered 1 through 7;

Figure 5 depicts the similarity between octopamine and tyramine receptors from different insect species;

Figure 6 is a graph depicting the change of intracellular cAMP levels in HEK-293 cells expressing Pa oa₁ in response to treatment with various concentrations of either octopamine (OA) or tyramine (TA); and

Figures 7 is a graph depicting the change in intracellular calcium levels in HEK-293 cells expressing Pa oa₁ in response to treatment with either 100 nM octopamine (OA) or 100 nM tyramine (TA);

Figure 8 is a bar graph depicting the change in intracellular cAMP levels in HEK-293 cells expressing Pa oa₁ in response to treatment with 0, 100 nM, or 1 μ M octopamine (OA) in the presence and absence of 20 μ M BAPTA/AM, a calcium chelator;

Figure 9 is a bar graph depicting the cAMP response to octopamine through Pa oa₁ and OAMB expressed in HEK-293 cells where the cells expressing either receptor are treated with 10 μ M octopamine and the level of cAMP is determined;

Figures 10A and 10B are graphs depicting the calcium response to octopamine through Pa oa₁ and OAMB, respectively, expressed in HEK-293 cells;

Figure 11 is a depiction of the chemical structures of *p*-cymene [methyl(1-methylethyl)benzene], eugenol [2-methoxy-4-(2-propenyl)phenol], trans-anethole [1-methoxy-4-(1-propenyl)benzene], cinnamic alcohol [3-phenyl-2-propen-1-ol], α -terpineol [p-menth-1-en-8-ol], methyl salicylate [2-hydroxybenzoic acid methyl ester], 2-phenylethyl propionate, and geraniol [3,7-dimethyl-2,6-octadien-1-ol];

Figure 12 is a bar graph depicting the effect of certain plant essential oils on specific binding of ³H-yohimbine to Pa oa₁ and OAMB;

Figure 13 is a bar graph depicting the effect of certain plant essential oils on cAMP levels in HEK-293 cells expressing either Pa oa₁ or OAMB; and

Figures 14A-14F are graphs depicting the effect of certain plant essential oils on intracellular calcium $[Ca^{2+}]_i$ levels in HEK-293 cells either transfected with Pa oa₁ or OAMB.

DETAILED DESCRIPTION OF THE INVENTION

5 The present invention includes: a screening method for identifying compounds and compositions that are effective insect control agents; a screening method for identifying compounds and compositions that are effective species-specific insect control agents; compounds and compositions isolated from the screening methods; transfected cell lines; and isolated nucleic acid molecule sequences.

10 The present invention includes: an isolated nucleic acid molecule sequence which encodes a protein that binds a biogenic amine, resulting in changes in intracellular concentrations of cAMP, Ca^{2+} , or both, having a nucleotide sequence of SEQ ID NO: 1, or a fragment or derivative thereof and/or having an amino acid sequence of SEQ ID NO: 2, or a fragment or derivative thereof; an isolated nucleic acid molecule of having at least about 30% similarity to the nucleotide
15 sequence of SEQ ID NO: 1, wherein the isolated nucleic acid molecule encodes a protein, resulting in changes in intracellular concentrations of cAMP, Ca^{2+} , or both; an isolated nucleic acid molecule of having at least about 30% similarity to the nucleotide sequence of SEQ ID NO: 1, wherein the molecule encodes an octopamine receptor or a protein having an amino acid sequence of SEQ ID NO: 2, or a fragment or derivative thereof; and an isolated nucleic acid
20 molecule having a nucleotide sequence of SEQ ID NO: 1, or a fragment or derivative thereof, wherein the molecule encodes a protein designated Pa oa₁. SEQ ID NO: 1 and SEQ ID NO: 2 are shown in alignment in Figure 1A and SEQ ID NO: 1 is also provided in Figure 1B. Fragments and derivatives of the sequences shall include transmembrane domains (TM) 3, 5 and 6. Fragments and derivatives of the sequences may exclude, for example, portions upstream of TM
25 1, portions upstream of TM 2, or portions downstream of TM 7.

The present invention also includes: a strain of cells including a DNA vector having a nucleic acid sequence of SEQ ID NO:1; a strain of cells expressing an octopamine receptor cloned from an insect species of interest; a strain of cells expressing an octopamine receptor cloned from *Periplaneta Americana* (Pa oa₁); a strain of cells expressing a protein having an amino acid sequence of SEQ ID NO: 2, or fragments or derivatives thereof, wherein the fragments or derivatives thereof bind octopamine; a strain of cells expressing an octopamine receptor cloned from *Drosophila melanogaster* (OAMB); a strain of cells expressing a protein having an amino acid sequence of SEQ ID NO: 3, or fragments or derivatives thereof, wherein the fragments or derivatives thereof bind octopamine. The transfected cells may be mammalian cells or insect cells; for example, they may be African green monkey kidney COS-7 cells (COS-7 cells) or human embryonic kidney-293 cells (HEK-293 cells).

The present invention also includes a screening method of using a cell line expressing an octopamine receptor to identify compounds and compositions that are effective insect control agents. For example, the octopamine receptor expressed by the cell line may be Pa oa₁; or have an amino acid sequence of SEQ ID NO: 2, or fragments or derivatives thereof, wherein the fragments or derivatives thereof bind octopamine.

The present invention also includes a method of using multiple cell lines, wherein the cell lines are transfected with octopamine receptors from different insect species of interest, to identify compounds and compositions that are effective species-specific insect control agents. For example, a cell line expressing Pa oa₁ and a cell line expressing OAMB could be used to screen compounds and compositions having insect control activity which is specific to *Periplaneta Americana* or to *Drosophila melanogaster*.

The present invention also includes compounds and compositions having the ability to control target insects, which compounds and/or compositions are identified using the screening methods of the present invention. These compounds and/or compositions may include

compounds that are general regarded as safe (GRAS compounds) meaning that they do not produce unwanted or harmful affects on humans and other non-target animal species and that they are exempt from the Environmental Protection Agency's (EPA) pesticide registration requirements. The compounds and/or compositions of the present invention include certain plant
5 essential oils identified using the screening methods of the present invention.

The compounds and compositions of the present invention control insects by targeting an octopamine receptor, resulting in a disruptive change in the intracellular levels of cAMP, Ca^{2+} or both. For purposes of simplicity, the term insect has been and shall be used through out this application; however, it should be understood that the term insect refers, not only to insects, but
10 also to arachnids, larvae, and like invertebrates. Also for purposes of this application, the term "insect control" shall refer to repelling or killing an insect.

The present invention is further illustrated by the following specific but non-limiting examples.

EXAMPLE 1**PREPARATION OF STABLY TRANSFECTED COS-7 CELL LINES and HEK-293 CELL LINES WITH OCTOPAMINE RECEPTOR**5 **A. ISOLATION OF A cDNA ENCODING A G-PROTEIN-COUPLED RECEPTOR FROM *PERIPLANETA AMERICANA***

G protein-coupled receptors from insects and a tick that are demonstrated to be octopamine receptors or have significant DNA similarity to known octopamine receptors are aligned using the program DNASTar (Ma). The following degenerate oligonucleotides are designed based on this alignment: Transmembrane (TM) VI oligonucleotide 10 5'TACAAGCTTTG(C, T)TGG(C, T) (G, T) (A, C, G, T)CC(A, C, G, T)TTCTT3' (SEQ ID NO: 4), and TM VII oligonucleotide 5'CATGCGGCCGCTTT(A, C, G, T) (A, C) (A, C) (A, G)TA(A, C, G, T)CC(A, C)AGCCA3' (SEQ ID NO: 5). The underlined sequence corresponds to the TM 15 regions.

The TM VI oligonucleotide contains a *HindIII* site and the TM VII oligonucleotide contains a *NotI* site flanking the TM sequences. Total RNA from the heads of mixed sex adult American cockroaches that have the antennae excised is prepared by ultracentrifugation through cesium chloride, as described in Chirgwin *et al.*, 18 Biochemistry 5294-5299 (1979), and is 20 reverse transcribed into cDNA using random hexamers and murine leukemia virus reverse transcriptase (Applied Biosystems, Foster City, CA). The polymerase chain reaction (PCR) is performed on this cDNA using AmpliTaq polymerase (Applied Biosystems) and the TM VI and VII oligonucleotides at final concentrations of about 5 μ M. The reaction conditions are about 95 °C, about 5 min for about one cycle; about 95 °C, about 45 s, about 40 °C, about 2 min, about 25 72 °C, about 30 s for about three cycles; about 95 °C, about 45 s, about 55 °C, about 2 min; about 72 °C, about 30 s for about 37 cycles; and about 72 °C, about 10 min for about one cycle.

Products are digested with *HindIII* and *NotI* and ligated into pBK-RSV (Stratagene, La Jolla, CA). Inserts are sequenced and compared to known genes by searching the NCBI database with the Blast program.

To obtain the corresponding cDNA for an approximately 101 nucleotide fragment with the
5 highest similarity to octopamine receptors from other species, 5' and 3' rapid amplification of
cDNA ends (RACE) are performed using the SMART RACE cDNA amplification system
(Clontech, Palo Alto, CA). Poly(A) RNA is prepared from total RNA isolated from the head of
Periplaneta americana using an oligo-dT column as per the manufacturer's protocol (Amersham
Biosciences, Piscataway, NJ). The poly(A) RNA is used as template in the RACE reverse
10 transcription reaction for production of 5' and 3' RACE cDNA as per the manufacturer's
instructions. The gene specific oligonucleotides used for the RACE PCR are 5' RACE
oligonucleotide 5'CAGTAGCCCCAGCCAGAAGAGGACGGAGAAG3' (SEQ ID NO: 6), and 3'
RACE oligonucleotide 5'GCTGGCTGCCGTTCTTCACCATGTACCTGG3' (SEQ ID NO: 7). 5'
RACE and 3' RACE polymerase chain reactions are each about 50 µl and consist of about 2.5 µl
15 of the respective cDNA reaction, about 0.2 µM of the gene specific oligonucleotide and the
additional RACE components including Advantage 2 polymerase as per the manufacturer
(Clontech). The cycling conditions for the 5' RACE are about 95 °C, about 1 min for about one
cycle; about 94 °C, about 20 s, about 72 °C, about 3 min for about five cycles; about 94 °C, about
20 s, about 70 °C, about 10 s, about 72 °C, about 3 min for about five cycles; about 94 °C, about
20 20 s, about 68 °C, about 10 s, about 72 °C, about 3 min for about 32 cycles; and about 72 °C, about
10 min for about one cycle.

An approximately 1.9 kb product is gel purified and further, amplified using the same
oligonucleotides, Advantage 2 polymerase and cycling parameters of about 95 °C, about 3 min for
about one cycle; about 94 °C, about 20 s, about 68 °C, about 10 s, about 72 °C, about 3 min for

about 35 cycles; and about 72 °C, about 10 min for about one cycle. To facilitate T/A ligation, the product is A-tailed by precipitating with ethanol, resuspending in 1 x PCR Buffer II (Applied Biosystems), 2 mM MgCl₂, 1 mM dATP and 0.05 U AmpliTaq per µl and incubating at about 72 °C for about 15 min. The PCR product is ligated into pBK-RSV (Stratagene) that has been
5 digested with *SmaI* and T-tailed using dTTP and AmpliTaq. The insert is sequenced on both strands by automated fluorescent DNA sequencing (Vanderbilt Cancer Center).

The cycling conditions for the 3' RACE reaction are about 95 °C, about 1 min for about one cycle; about 94 °C, about 5 s, about 72 °C, about 3 min for about five cycles; about 94 °C, about 5 s, about 70 °C, about 10 s, about 72 °C, about 3 min for about five cycles; about 94 °C,
10 about 5 s, about 68 °C, about 10 s, about 72 °C, about 3 min for about 32 cycles; and about 72 °C, about 10 min for about one cycle. The product of this reaction is A-tailed, subcloned and sequenced as for the 5' RACE product.

15 B. GENERATION OF THE OPEN READING FRAME FOR OCTOPAMINE RECEPTOR (Pa oa₁)

Oligonucleotides used to amplify the open reading frame are a sense oligonucleotide 5' CAGGAATTCATGAGGGACGGGGTTATGAACGCTAG 3' (SEQ ID NO: 8), and an antisense oligonucleotide 5' GCTTCTAGATCACCTGGAGTCCGATCCATCGTTG 3' (SEQ ID NO: 9).

20 Sequences corresponding to the open reading frame are underlined. The sense oligonucleotide contains an *EcoRI* restriction site and the antisense oligonucleotide an *XbaI* restriction site. These oligonucleotides are used in a polymerase chain reaction that included the 5'RACE cDNA as template and VENT polymerase (New England Biolabs, Beverly, MA).

The product is subcloned into the plasmid pAc5.1/V5-His (Invitrogen Life Technologies,
25 Carlsbad, CA) at the *EcoRI* and *XbaI* restriction sites and sequenced. This plasmid is designated

pAc-Pa oa₁. For mammalian cell expression, a Kozak sequence is inserted using a sense oligonucleotide 5'ACAGAATTCGCCACCATGAGGGACGGGGTTATGAACGCTAG 3' (SEQ ID NO: 10) and an internal antisense oligonucleotide that contains an *XhoI* site 5' TTGACGGCGCTCGAGGACGTC 3' (SEQ ID NO: 11). The sense oligonucleotide contains an *EcoRI* site. These oligonucleotides are used in a polymerase chain reaction that includes pAc-Pa oa₁ as template and VENT polymerase. The product is inserted at *EcoRI* and *XhoI* sites into pAc-Pa oa₁, in which the corresponding *EcoRI* and *XhoI* fragment have been removed. The product is sequenced. The entire open reading frame is then transferred into pCDNA3 (Invitrogen Life Technologies, Carlsbad, CA) at *EcoRI* and *Apal* restriction sites, and this plasmid is designated pCDNA3-Pa oa₁.

C. AMPLIFICATION AND SUBCLONING OF OAMB, AN OCTOPAMINE RECEPTOR FROM THE FRUIT FLY, *DROSOPHILA MELANOGASTER*

The *Drosophila melanogaster* head cDNA phage library GH is obtained through the Berkeley Drosophila Genome Project (www.fruitfly.org). Phage DNA is purified from this library using a liquid culture lysate as described in Lech, Current Protocols in Molecular Biology, John Wiley & Sons, Inc., pp. 1 (2001). Oligonucleotides designed to amplify the open reading frame of *Drosophila melanogaster* OAMB consist of the sense oligonucleotide 5' CAGGAATTCGCCACCATGAATGAAACAGAGTCGGAGGATCTC 3' (SEQ ID NO: 12) and the antisense oligonucleotide 5' AATGCGGCCGCTCAGCTGAAGTCCACGCCCTCG 3' (SEQ ID NO: 13). Sequences corresponding to the open reading frame are underlined. A Kozak sequence is included in the sense oligonucleotide. In addition, the 5' oligonucleotide includes an *EcoRI* restriction site and the 3' oligonucleotide a *NotI* site.

For amplification by the polymerase chain reaction, about 200 ng of the GH library DNA is used as template with about 0.5 μ M of each oligonucleotide and VENT DNA polymerase (New

England Biolabs). Cycling conditions are about 95 °C, about 5 min for about one cycle; about 95 °C, about 30 s and about 70 °C, about 1.5 min for about 40 cycles; and about 70 °C, about 10 min for about one cycle. The product is digested with *EcoRI* and *NotI*, ligated into pCDNA3 and sequenced on both strands by automated fluorescent DNA sequencing (Vanderbilt Cancer
5 Center).

D. ISOLATION OF cDNA ENCODING OCTOPAMINE RECEPTOR (Pa oa₁)

A polymerase chain reaction with degenerate oligonucleotides corresponding to regions of
10 TM VI and TM VII of previously identified octopamine receptors is used to isolate an approximately 101 nucleotide fragment of cDNA from the head of *Periplaneta americana*. This cDNA fragment is used to design gene specific oligonucleotides to amplify the full-length cDNA of the corresponding gene by RACE. This method generates overlapping 5' and 3' segments that include the original cDNA fragment from TM VI to TM VII indicating these segments originate
15 from the same cDNA. The cDNA includes an approximately 1887 nucleotide open reading frame and 5' and 3' untranslated regions (Genbank accession number is AY333178). The predicted initiation codon is preceded by an in-frame stop codon, indicating that the 5' end of the open reading frame is included in the cDNA and that the encoded protein will be full length. This cDNA and encoded protein are designated Pa oa₁.

20 The open reading frame encodes a protein of approximately 628 amino acids with a predicted molecular mass of about 68,642 Da. Hydropathy analysis by the method described in Kyte *et al.*, J. Mol. Biol. 157, 105-132 (1982), with a window of about nine amino acids indicates about seven potential transmembrane spanning domains. In addition, a protein BLAST search finds similarity of Pa oa₁ to the rhodopsin family of 7 transmembrane G protein-coupled receptors
25 contained within the conserved domain database.

The BLAST analysis also indicates Pa oa₁ is most similar to other biogenic amine receptors. As mentioned above, all members of GPCRs share the common motif of seven transmembrane (TM) domains. Of these seven domains, TM 3, 5 and 6 comprise the binding sites. Compared to proteins with defined functions, Pa oa₁ is most closely related to OAMB, an octopamine receptor from the fruit fly *Drosophila melanogaster* and to Lym- oa₁, an octopamine receptor from the pond snail *Lymnaea stagnalis*. Sequence similarity is also detected with vertebrate α A adrenergic receptors and invertebrate tyramine receptors. Protein alignment indicates Pa oa₁ is about 51% identical to OAMB, 37% identical to Lym oa₁, and about 27% identical to both the insect tyramine receptors Tyr-Loc from *Locusta migratoria* and Tyr-Dro from *Drosophila melanogaster*. Sequence conservation between Pa oa₁, OAMB and Lym oa₁, is greatest within the TM domains, as shown in Figure 2. The regions of lowest similarity among these three proteins are in the amino terminus extending into TM 1, extracellular loop 2 (between TM IV and V), intracellular loop 3 (between TM V and VI) and the carboxyl termini following TM VII.

E. CELL CULTURE AND TRANSFECTION OF CELLS

Cell culture reagents may be obtained from Sigma-Aldrich (St. Louis, MO), or as otherwise indicated. African green monkey kidney COS-7 cells and human embryonic kidney (HEK)-293 cells are obtained from American Type Culture Collection (Manassas, VA). COS-7 cells are grown in Dulbecco's modified Eagle's medium (about 4.5 g glucose/l) and about 10% fetal bovine serum. HEK-293 cells are grown in Dulbecco's modified Eagle's medium (about 1 g glucose/l), about 5% fetal bovine serum and about 5% newborn calf serum. Both types of media are supplemented with about 100 U penicillin G/ml, about 100 μ g streptomycin/ml and about 0.25 μ g amphotericin B/ml) except during Lipofectamine 2000 transfections.

Lipofectamine 2000 and Opti-MEM I media may be obtained from Invitrogen Life Technologies (Carlsbad, CA). COS-7 cells are transiently transfected using Lipofectamine 2000. Cells are plated at about 1.5×10^6 cells per dish (about 55 cm^2) in about 10 ml growth medium without antibiotics the day before transfection. For each dish, about 30 μl Lipofectamine 2000 in
5 about 1 ml Opti-MEM I medium is mixed with about 12 μg plasmid DNA in about 1 ml Opti-MEM I medium and added to the cells after an approximately 20 min incubation at room temperature. The cells are harvested for membrane preparation 24 h following transfection.

For stable transfections of HEK-293 cells, about 1×10^6 cells in about 2.5 ml growth media without antibiotics are plated into dishes (about 10 cm^2) the day before transfection. For
10 transfection, about 10 μl Lipofectamine 2000 is added to about 250 μl Opti-MEM I medium. This is mixed with about 4 μg plasmid DNA in about 250 μl OptiMEM I medium. After an approximately 20 min incubation at room temperature, the approximately 500 μl of solution is added to cells in a single dish. Cells are split about 24 h after transfection into growth media containing about 0.8 mg G418 sulfate/ml (Mediatech Inc., Herndon, VA). Clonal lines are
15 selected and assayed for receptor expression with whole cell binding by incubating about 500,000 cells in about 1 ml phosphate buffered saline (PBS; 137 mM NaCl, 2.7 mM KCl, 10 mM Na_2HPO_4 , 1.4 mM KH_2PO_4 (pH 7.4)) with about 2 nM ^3H -yohimbine for about 30 min at about 27°C . Cells are pelleted by centrifugation, washed with PBS, and then transferred to scintillation vials. Nonspecific binding is determined by including about 50 μM phentolamine in the binding
20 reaction.

F. EFFICACY OF CELLS LINES TRANSFECTED WITH OCTOPAMINE RECEPTORS FOR SCREENING COMPOUNDS AND COMPOSITIONS FOR OCTOPAMINE RECEPTOR INTERACTION

All steps are performed at about 4 °C or on ice. Cells are harvested in growth media by scraping from the dishes and then rinsing dishes with PBS. The cells are centrifuged at about 1000g for about 3 min, washed with PBS and centrifuged again. The cells are suspended in ice cold hypotonic buffer (10 mM Tris-Cl (pH 7.4)), incubated on ice for about 10 min, and lysed
5 using a glass dounce homogenizer and tight glass pestle (Kontes Glass Co., Vineland, NJ) with about 10 strokes. Nuclei are pelleted by centrifugation at about 600g for about 5 min. The supernatant is decanted and centrifuged at about 30,000g for about 30 min to pellet a crude membrane fraction. The pellet is suspended, in binding buffer (50 mM Tris-Cl, 5 mM MgCl₂ (pH 7.4)). Protein concentration is determined by the Bradford assay (Bio-Rad Laboratories, Hercules,
10 CA). Membranes are frozen on dry ice and stored at about -75 °C in aliquots.

Antagonists and biogenic amines are obtained from Sigma-Aldrich (St. Louis, MO). Octopamine is the mixed isomeric form DL-octopamine. ³H-yohimbine is obtained from Perkin Elmer Life Sciences (Boston, MA). Radioligand binding is performed with about 7.5-15 µg membrane protein in about 250 µl binding buffer for about 30 min at about 27 °C while shaking at
15 about 100 rpm. Reactions are terminated by addition of about 3 ml ice cold binding buffer and filtered over GF/C filters (Whatman International, Maidstone, England) that have been soaked for about 30 min in about 0.3% polyethylenimine (Sigma-Aldrich). Filters are rinsed again with about 3 ml binding buffer. For the determination of K_d and B_{max}, a range of ³H-yohimbine is used from about 0.5 to 50 nM, and about 50 µM phentolamine is used as a competitor to determine
20 nonspecific binding. To determine K_i of different ligands, about 2 nM ³H-yohimbine is used with a concentration range of competitor that gives from 0% to 100% competition. Binding data is analyzed by nonlinear regression using the software GraphPad Prism (San Diego, CA).

For pharmacological binding experiments, Pa oa₁, is expressed in COS-7 cells by transient transfection. Membrane fractions are analyzed to determine total, nonspecific and specific

binding of ^3H -yohimbine, as shown in Figure 3A. The K_d and $B_{\max}$ for specific binding are determined to be about 28.4 nM and about 11.8 pmol/mg protein, respectively. Membrane fractions from COS-7 cells transiently transfected with empty pCDNA3 do not demonstrate specific binding. The high affinity binding of ^3H -yohimbine by Pa α_1 indicate that this is a suitable ligand to be used for competition binding experiments.

The octopamine receptor OAMB from *Drosophila melanogaster* is amplified by the polymerase chain reaction. Saturation binding analysis with ^3H -yohimbine is performed with OAMB expressed in COS-7 cells, as shown in Figure 3B. The K_d and $B_{\max}$ are determined to be about 43.0 nM and about 8.04 pmol/mg, respectively.

Competitive binding with various biogenic amines is utilized to determine the affinities for potential natural ligands of Pa α_1 . Referring now to Table A, below, DL-Octopamine has the lowest K_i (about 13.3 μM) for Pa α_1 followed by tyramine (about 31.0 μM). The decreasing order of affinity for the biogenic amines is octopamine > tyramine > dopamine > serotonin. The binding affinities for octopamine and tyramine are determined for this receptor. The K_i (mean $\pm$ standard deviation) of octopamine and tyramine for OAMB are about $8.20 \pm 2.60 \mu\text{M}$ and about $33.8 \pm 7.93 \mu\text{M}$, respectively. These values are similar to those obtained for Pa α_1 . The affinity of octopamine is about 2.3-fold higher than tyramine for Pa α_1 , and for OAMB, the affinity of octopamine is about 4.1-fold higher than tyramine, indicating that octopamine is the likely endogenous ligand for Pa α_1 .

Ligand	K_i (μM)
<i>Biogenic Amine</i>	
Octopamine	13.3 ± 2.4
Tyramine	31.0 ± 1.9
Dopamine	56.6 ± 8.0
Serotonin	77.4 ± 11.6
<i>Antagonist</i>	
Chlorpromazine	0.012 ± 0.003

Phentolamine	0.023 ± 0.009
Mianserin	0.048 ± 0.013
Metoclopramine	4.76 ± 1.32

Table A

In addition to using the affinity of octopamine receptors for specific antagonists as a method for classifying these receptors, antagonists may be used to analyze the effects of octopamine on adenylate cyclase activity in the brain, ventral nerve cord and hemocytes of *Periplaneta americana*. A pharmacological profile is developed for Pa oa₁ using these antagonists. With reference to Table A, in order of decreasing affinity, the profile of the antagonists is chlorpromazine > phentolamine > mianserin > metoclopramide.

EXAMPLE 2**STRUCTURAL FEATURES OF CLONED AMERICAN COCKROACH OCTOPAMINE RECEPTOR (Pa oa₁)**

The Pa oa₁ cDNA of 2268 bp which includes an 1887 nucleotide open reading frame and 5' and 3' untranslated regions is set forth in Figures 1A, 1B and SEQ ID NO: 1. With reference to Figure 1B, the predicted initiation codon (M) is preceded by an in-frame stop codon (SC). This indicates that the 5' end of the open reading frame is included in the cDNA and that the encoded protein would be full length.

With reference to Figure 4, hydropathy analysis by the method of Kyte and Doolittle with a window of 9 amino acids indicates that this sequence shares the common motif of 7 potential transmembrane scanning domains. See Kyte and Doolittle, 1982, J. Mol. Biol. 157, 105-132. A phylogenetic comparison of invertebrate biogenic amine receptor sequences reveals that both OAMB and Pa oa₁ sequences share ~ 45% similarity, which is illustrated in Figure 5. Pa oa₁ clusters with octopamine and tyramine receptors from different insect species. Similarity between

these receptors is analyzed using BLAST search and calculated based on protein alignment using DNASTAR software program. Pa oa₁ is used as a reference for comparisons with other receptors.

With reference to Figure 2, protein alignment indicates sequence conservation between Pa oa₁ and OAMB is greatest within the transmembrane domains (TMs). The regions of lowest similarity among these two proteins are in the amino terminus extending into TM1, extracellular loop2 between TM4 and TM5, intracellular loop between TM5 and TM6 and the carboxy termini following TM7.

EXAMPLE 3

EFFECTS OF TREATMENT WITH OCTOPAMINE ON CELLS EXPRESSING THE OCTOPAMINE RECEPTOR (Pa oa₁)

A. EFFECT OF TREATMENT ON [cAMP]

Twenty-four hours before cell treatment, about 300,000 HEK-293 cells are plated in about 1 ml media with about 0.8 mg G418/ml into multi-well dishes (e.g., 12-well, 4.5 cm²). For cell treatment, the media is aspirated and about 1 ml PBS with about 300 μ M IBMX and the test reagent is added. Cells are incubated at about 37 °C for about 20 min, and the PBS is then aspirated. Cells are incubated with about 70% ethanol for about 1 h at about -20 °C. The cellular debris is centrifuged and then the supernatant is removed and lyophilized to dryness. The amount of cAMP in the extract is determined by using a cAMP binding protein from the ³H-cAMP Biotrak assay system (Amersham Biosciences) as per the manufacturer's instructions. To test the effects of calcium chelation on cAMP levels, the cells are incubated with about 20 μ l 1 BAPTA/AM (Calbiochem Biochemicals, La Jolla, CA) for about 10 min before the addition of the test reagents.

Octopamine has been demonstrated to increase levels of the second messenger cAMP in brain, thoracic ganglion and hemocytes from *Periplaneta americana*. To determine which second messenger signaling pathways octopamine could affect through the Pa oa_1 receptor, HEK-293 cells are stably transfected with pCDNA3-Pa oa_1 or pCDNA3 without an insert as a control. In the control HEK-293 cells, neither DL-octopamine nor tyramine at concentrations up to about 100 μM has significant effects on cAMP levels.

A clone transfected with pCDNA3-Pa oa_1 having a high specific binding to ^3H -yohimbine is selected for second messenger analysis. Both octopamine and tyramine are able to increase the levels of cAMP in these cells in a dose dependent manner, as shown in Figure 6. The EC_{50}s for the octopamine and tyramine mediated increases in cAMP are about 1.62 and 97.7 μM , respectively ($p < 0.05$). Octopamine is more potent than tyramine in the cAMP response as a statistically significant increase in cAMP over the basal level (about 0.48 pmol cAMP) is first detected with about 10 nM octopamine (about 1.2 pmol cAMP) ($p < 0.05$). The cAMP concentration with about 10 nM tyramine is about 0.50 pmol cAMP, and therefore not statistically significant from the basal level ($p > 0.05$). A concentration of about 1 μM tyramine results in an increase in cAMP to about 1.2 pmol. In addition, about 100 μM octopamine leads to an approximately 911-fold increase in cAMP compared to an approximately 215-fold increase for about 100 μM tyramine. Since these assays are performed in the presence of the phosphodiesterase inhibitor IBMX, the increases in cAMP is determined to be through activation of adenylate cyclase. As such, it appears that the Pa oa_1 receptor is an octopamine receptor, the Pa oa_1 receptor may be targeted to effect a disruptive change in intracellular levels of cAMP, controlled targeting of the receptor allows for insect control, and the cell lines stably expressing the Pa oa_1 receptor may be used to screen compounds and compositions for insect control activity.

B. EFFECT OF TREATMENT ON cAMP AND $[Ca^{2+}]$

To determine cAMP levels in cells, about 24-hours before cell treatment, 300,000 HEK-293 cells are plated in 1 mL media with 0.8 mg G418/mL into multi-dishes (4.5 cm²). For cell treatment, the media is aspirated and 1 mL PBS with 300 μ M IBMX and the test reagent is added. Cells are incubated at 37°C for 20 min, and the PBS is then aspirated. Cells are incubated with 70% ethanol for 1 hour at -20°C. The cellular debris is centrifuged and then the supernatant is removed and lyophilized to dryness. The amount of cAMP in the extract is determined by using a cAMP binding protein from the ³H-cAMP Biotrak assay system (Amersham Biosciences, Piscataway, NJ) as per the manufacturer's instructions.

To determine Ca^{2+} levels in the cells, HEK-293 cells are washed once with Hank's balanced salt solution (137 mM NaCl, 5.4 mM KCl, 0.3 mM Na₂HPO₄, 0.4 mM KH₂PO₄, 4.2 mM NaHCO₃, 1 mM CaCl₂, 1 mM MgSO₄, and 5.6 mM glucose (pH 7.4)) (HBSS). Cells are collected by scraping and are suspended at about 750,000 cells/ml in HBSS with about 5 μ M Fura-2 AM (Sigma-Aldrich). Cells are incubated at about 37 °C for about 1 h in the dark, centrifuged, suspended in HBSS at about 750,000 cells/ml and used for calcium measurements. A spectrofluorometer with Felix software from Photon Technology International (Lawrenceville, NJ) is used for the fluorescence measurements and data collection.

Octopamine has been demonstrated to modulate intracellular calcium levels in cultured hemocytes of *Malacosoma disstria*. Also, in hemocytes from *Periplaneta americana*, octopamine lead to an increase in inositol triphosphate which likely will lead to increases in calcium in these cells as well. The ability of both octopamine and tyramine to modulate calcium levels in the HEK-293 clone expressing Pa oa₁ is determined. Neither about 10 μ M octopamine nor about 10 μ M tyramine modulates intracellular calcium levels in control HEK-293 cells transfected with pCDNA3 lacking an insert. However, when about 100 μ M octopamine is added to the Pa oa₁

expressing HEK-293 cells, a rapid increase in intracellular calcium is detected, as shown in Figure 7. In these same cells, about 100 nM tyramine does not modulate intracellular calcium levels, as shown in Figure 7.

Testing of these amines at additional concentrations indicates that the lowest concentration of octopamine that increases intracellular calcium levels is about 10 nM. Tyramine is found to increase intracellular calcium when a concentration of about 1 μ M or higher is tested. These increases in intracellular calcium by about 10 nM octopamine and about 1 μ M tyramine are to a similar level, both of which is lower than the increase in calcium mediated by about 100 nM octopamine. This result is similar to that obtained with the cAMP assay in that an approximately 100-fold increase in tyramine concentration compared to about 10 nM octopamine is required to give a similar level of response.

As such, it appears that the Pa oa_1 receptor is an octopamine receptor, the Pa oa_1 receptor may be targeted to effect a disruptive change in intracellular levels of Ca^{2+} , controlled targeting of the receptor allows for insect control, and the cell lines stably expressing the Pa oa_1 receptor may be used to screen compounds and compositions for insect control activity.

Octopamine is found to increase both cAMP and calcium in HEK-293 cells expressing Pa oa_1 and the calcium increase is detected immediately upon octopamine addition. As such, the possibility that calcium is leading to a secondary increase in cAMP levels in the cells expressing Pa oa_1 is tested. The intracellular calcium chelator BAPTA/AM is used. BAPTA/AM at about 20 μ M is found to inhibit the increase in free intracellular calcium when about 1 μ M octopamine is added to the Pa oa_1 -expressing cells. Octopamine-mediated changes in cAMP levels are compared in the absence and presence of about 20 μ M BAPTA/AM. cAMP levels following treatment with either about 100 nM or about 1 μ M octopamine, as well as basal cAMP levels, are not found to be statistically different, whether in the absence or presence of about 20 μ M BAPTA/AM, as shown

in Figure 8. This indicates that the increase in cAMP by octopamine results from direct coupling of Pa oa₁ to a G protein that leads to activation of adenylate cyclase, making the expression of Pa oa₁ in HEK-293 cells a good model for adenylate cyclase-modulated insect control through this receptor and the cell lines stably expressing the Pa oa₁ receptor useful for screening compounds and compositions for insect control activity.

EXAMPLE 4

RECEPTOR BINDING AND CHANGES IN cAMP AND INTRACELLULAR CA²⁺ IN RESPONSE TO OCTOPAMINE TREATMENT

For radioligand binding studies, the binding of ³H-yohimbine to membranes isolated from COS-7 cells expressing Pa oa₁ and octopamine receptor (OAMB) from *Drosophila melanogaster* are performed. See Bischof and Enan, 2004, *Insect Biochem. Mol. Biol.* 34, pp. 511-521, which is incorporated herein by this reference. The data shown in Table B demonstrates that the affinity of Pa oa₁ to the radioligand is about 1.5 fold higher than OAMB. Radioligand binding using ³H-yohimbine is performed on membranes expressing either Pa oa₁ or OAMB. For the determination of K_d and B_{max}, a range of ³H-yohimbine is used from 0.5 to 50 nM, and 50 μM phentolamine is used as a competitor to determine nonspecific binding. To determine K_i of octopamine, 4 nM ³H-yohimbine is used with a concentration range of octopamine that gives from 0 to 100% competition.

OAR Species	K _d (nM)	B _{max} (pmole receptor/mg protein)	K _i (μM)
OAR species	28.4	11.80	13.30
OAMB	43.0	8.04	8.20

Table B

With reference to Figure 9, OA (10 μM) increases the level of cAMP in HEK-293 cells permanently expressing either OAMB or Pa oa₁. With reference to Figures 10A and 10B, OA (10

μM) increases the level $[\text{Ca}^{2+}]_i$ in HEK-293 cells permanently expressing either OAMB or Pa oa_1 , where HEK-293 cells expressing either receptor are incubated for 30s before the addition of 10 μM octopamine (OA). The arrow in the figures indicates addition of the amine. The fluorescence ratio determined from excitation with 340 and 380 nm is plotted to indicate changes in $[\text{Ca}^{2+}]_i$ levels. These increases are mediated through the OAR as judged by the insignificant changes in cAMP level and $[\text{Ca}^{2+}]_i$ in cells transfected with an empty vector then treated with 10 μM OA (data not shown).

EXAMPLE 5

EFFECTS OF TREATMENT WITH PLANT ESSENTIAL OILS ON CELLS EXPRESSING THE OCTOPAMINE RECEPTOR

In this example, membranes isolated from COS-7 cells expressing the receptor are used for receptor binding studies and HEK-293 cells are used for cAMP and $[\text{Ca}^{2+}]_i$ studies. Plant essential oils, including: *p*-cymene [methyl(1-methylethyl)benzene], eugenol [2-methoxy-4-(2-propenyl)phenol], trans-anethole [1-methoxy-4-(1-propenyl)benzene], cinnamic alcohol [3-phenyl-2-propen-1-ol], α -terpineol [p-menth-1-en-8-ol], methyl salicylate [2-hydroxybenzoic acid methyl ester], 2-phenylethyl propionate, and geraniol [3,7-dimethyl-2,6-octadien-1-ol], are obtained from City Chemical (West Haven, CT) and tested for insect control activity. The chemical structures of these compounds are set forth in Figure 11.

A. RECEPTOR BINDING ACTIVITY

The binding activity of ^3H -yohimbine to membranes expressing Pa oa_1 or OAMB is performed in the presence and absence of three structurally related plant essential oil monoterpenoids, which are selected based on their insecticidal activity, the absence or presence and location of the hydroxyl group and a spacing group within the molecule. Membrane protein (10 μg) expressing Pa oa_1 is incubated with 4 nM ^3H -yohimbine in the presence and absence of 50

μM of the test chemical. The specific activity is calculated as the difference between counts in the presence and absence of test chemical. Specific binding is calculated by determining nonspecific binding with 50 μM tested plant essential oils and subtracting nonspecific binding from total binding.

5 With reference to Figure 12, depicting specific binding of ^3H -yohimbine to Pa oa_1 and OAMB, while eugenol and cinnamic alcohol decrease the binding of ^3H -yohimbine to membranes expressing either Pa oa_1 or OAMB as compared to the corresponding control, trans-anethole decreases the ^3H -yohimbine binding activity to only Pa oa_1 . It is also found that eugenol and trans-anethole are more potent inhibitors against Pa oa_1 than OAMB, while cinnamic alcohol is
10 more potent against OAMB than Pa oa_1 . The data suggested insect species differences in receptor binding in response to monoterpenoids.

B. EFFECTS OF TREATMENT ON [cAMP]

Figure 13 depicts the effect of certain plant essential oils on cAMP levels in HEK-293
15 cells expressing either Pa oa_1 or OAMB. HEK-293 cells stably expressing either receptor are treated with 300 μM IBMX and the effect of tested plant essential oils (50 μM) on basal cAMP levels is measured.

Eugenol (50 μM) significantly decreases the cAMP level (24%) in cells expressing Pa oa_1 but slightly decreased cAMP level in cells expressing OAMB. A 22% increase in cAMP level in
20 cells expressing OAMB is found in response to treatment with (50 μM) trans-anethole. Cinnamic alcohol (50 μM) induces slight increase in cAMP level in both cell models.

C. EFFECT OF TREATMENT ON INTRACELLULAR CALCIUM MOBILIZATION

25 To address whether changes in $[\text{Ca}^{2+}]_i$ in octopamine receptor-expressing cells in response to 25 μM of tested plant essential oils is mediated specifically through the receptor, cells

transfected with an empty plasmid (pCDNA3) are treated with either test chemicals or solvent only and changes in $[Ca^{2+}]_i$ are monitored. In cells transfected with an empty plasmid, none of the test chemicals induce remarkable changes in $[Ca^{2+}]_i$ levels as compared with cells treated with the solvent (data not shown).

5 On the other hand, changes in $[Ca^{2+}]_i$ level in cells expressing either OAMB or Pa oa_1 in response to test chemicals is remarkably high. Figures 14A-14F, depict the effect of cinnamic alcohol (Figures 14A and 14B), eugenol (Figures 14C and 14D), and t-anethole (Figures 14E and 14F) on intracellular calcium $[Ca^{2+}]_i$ levels in HEK-293 cells either transfected with Pa oa_1 or OAMB. HEK-293 cells are incubated for 30s before the addition of 25 μ M tested agents. The
10 arrow in the figures indicates addition of tested agents. The fluorescence ratio determined from excitation with 340 nm and 380 nm is plotted to indicate transient increase in $[Ca^{2+}]_i$ levels.

Generally, changes in $[Ca^{2+}]_i$ in cells expressing OAMB is more pronounced than changes in cells expressing Pa oa_1 . Based on increased $[Ca^{2+}]_i$ level in cells expressing OAMB, cinnamic alcohol is the most potent agent tested in this example, followed by eugenol and trans-anethole.

15 In cells expressing Pa oa_1 , eugenol is the most potent agent tested in this example, followed by cinnamic alcohol then trans-anethole. The data suggest that elevation pattern of $[Ca^{2+}]_i$ levels is chemical-dependent. While application of octopamine induces an immediate but transient peak (~20 sec) in $[Ca^{2+}]_i$ level, as shown in Figure 9, the peaked $[Ca^{2+}]_i$ level is slower in onset and has a longer recovery time (more than 3 min) in response to treatment with tested plant essential oils.

20 In cells expressing OAMB, the increase in $[Ca^{2+}]_i$ level in response to cinnamic alcohol is slower than the other two chemicals. In Pa oa_1 -expressing cells, the increase in $[Ca^{2+}]_i$ in response to trans-anethole is slower than eugenol and cinnamic alcohol. Thus, the efficacy of coupling of both cloned octopamine receptors to different second messenger signaling varies with the chemical used.

25 D. SUMMARY OF THE EFFECTS OF TREATMENT WITH CERTAIN PLANT ESSENTIAL OILS

The present example studies the molecular interaction of plant essential oils with octopamine receptors from different insect species. Based on the characteristic features of octopamine receptors from American cockroach and fruit fly, the example characterizes certain molecular basis for insect species differences in response to plant essential oils. Although trans-anethole does not have a significant effect on binding to OAMB while eugenol and cinnamic alcohol do (Figure 12), only trans-anethole increases cAMP level (Figure 13) and $[Ca^{2+}]_i$ (Figures 14A-14F) through OAMB. These findings suggest that, in the case of trans-anethole, ionic interaction between the tested agent and the receptor is not critical for the activation of signaling down stream to OAMB.

On the other hand, while both eugenol and cinnamic alcohol decrease the binding activity to Pa oa₁ (Figure 12), only eugenol decreases cAMP levels through this receptor (Figure 13). However, these two chemicals increase $[Ca^{2+}]_i$ through Pa oa₁ and OAMB (Figures 14A-14F). The data demonstrates that activation of Pa oa₁ by trans-anethole and cinnamic alcohol is not primarily coupled to cyclic nucleotide system. It appears that it is coupled to IP₃-system, which activates the release of Ca^{2+} ions from internal stores. Activation of Pa oa₁ by eugenol is found to be coupled to both adenylate cyclase/cAMP and IP₃/ Ca^{2+} signaling cascades. Therefore, the current changes in cellular responses suggest that tested plant essential oils differing by only a single hydroxyl group or methoxy group in their chemical structure are capable of differentially coupling each octopamine receptor to different second messenger systems. The data also suggest that, activation of single GPCR such as Pa oa₁ or OAMB, may potentially couple to multiple second messenger systems. Thus, a single receptor may have a different pharmacological profile depending on which second messenger system is activated. The variability of the transmembrane regions and N-termini of Pa oa₁ and OAMB might determine the selectivity of tested monoterpenoids. In addition, conservation of certain transmembrane motifs and the variability of

the intracellular loops might enable Pa oa₁ and OAMB to discriminate among the various G-protein subtypes upon treatment with tested monoterpenoids.

Protein alignment indicate that the regions of lowest similarity among these two proteins are in the amino terminus extending into TM1, extracellular loop2 between TM4 and TM5, intracellular loop between TM5 and TM6 and the carboxy termini following TM7 (Figure 2). On the other hand, protein alignment indicates sequence conservation between Pa oa₁ and OAMB is greatest within the transmembrane domains (TMs).

EXAMPLE 6

TOXICITY TESTING AGAINST CERTAIN INSECT SPECIES

Toxicity bioassay against the wild type *Drosophila melanogaster* fly and American cockroach is performed to address insect species specificity in response to certain plant essential oils and to determine whether the cellular changes in Pa oa₁ and OAMB cell models in response to treatment with tested essential oils correlate with their insecticidal activity.

Drosophila melanogaster wild type strain is purchased from Carolina Biological Supply Company (Burlington, NC). Flies carrying the inactive (*iav*) mutation that exhibit low locomotor activity and poor mating success, both of which are associated with a deficiency in octopamine synthesis are obtained from Bloomington *Drosophila* Stock Center (flybase ID FBa10005570, stock# BL-6029 *iav*).

Plant essential oils, including: *p*-cymene [methyl(1-methylethyl)benzene], eugenol [2-methoxy-4-(2-propenyl)phenol], trans-anethole [1-methoxy-4-(1-propenyl)benzene], cinnamic alcohol [3-phenyl-2-propen-1-ol], α -terpineol [p-menth-1-en-8-ol], methyl salicylate [2-hydroxybenzoic acid methyl ester], 2-phenylethyl propionate, and geraniol [3,7-dimethyl-2,6-octadien-1-ol], are obtained from City Chemical (West Haven, CT) and tested for insect control activity. The chemical structures of these compounds are set forth in Figure 11.

Acetonic solutions of plant essential oils are prepared and different concentrations of each, that give from 10% - 100% mortality, are applied by topical application. Controls are treated with the same volume (0.5 µl/insect) of acetone. Replicates, with 5 insects per replicate, are used for each concentration. The mortality is calculated 24 hours after treatment. Data are subjected to

5 probit analysis to determine LD₅₀ value for each compound. See Finney, 1971, Probit Analysis, 3rd Ed., Cambridge University Press, London, pg. 333.

To determine whether the octopamine/octopamine receptor (OA/OAR) system is involved in the toxicity of tested plant essential oils, octopamine synthesis mutant (iav) *Drosophila melanogaster* strain is topically treated with a dose equivalent to the determined LD₅₀ for wild

10 type strain. For this study, the LD₅₀ values of eight monoterpenoid plant essential oils (p-cymene, eugenol, trans-anethole, cinnamic alcohol, α-terpineol, methyl salicylate, phenylethyl propionate, and geraniol) are determined against wild type as described above and being used to treat the octopamine mutant (iav) fruit fly. Controls are treated with the same volume (0.5 µl/fly) of acetone. The mortality is calculated 24 hour after treatment. Multiple replicates and 5 flies per

15 replicate are used for the bioassay of each chemical. Data are subjected to probit analysis to determine LD₅₀ value for each chemical. See Finney, 1971.

To determine insect species differences in response to plant essential oil monoterpenoids, the toxicity of certain monoterpenoids is determined against fruit fly and American cockroach. Based on the calculated LD₅₀ values, shown in Table C, cinnamic alcohol is the most toxic chemical

20 tested in the example (LD₅₀ = 1.65 µg/fly) against wild type fruit fly strain, followed by eugenol (LD₅₀ = 1.90 µg/fly), and trans-anethole (LD₅₀ = 6.00 µg/fly). Eugenol is about 2-fold and about 27-fold more toxic against American cockroach than cinnamic alcohol and trans-anethole, respectively.

Plant essential oil	LD ₅₀ , µg/insect	
	<i>D. melanogaster</i>	<i>P. Americana</i>

Cinnamic alcohol	1.65	98
Eugenol	1.90	47
Trans-anethole	6.00	1300

Table C

To determine whether the OA/OAR system mediates the toxicity of certain plant essential oil monoterpenoids, fruit flies carrying the *iav* mutations, which are highly susceptible to the octopamine analogue *p*-cresol, are used in parallel with wild type fruit fly strain in the toxicity bioassay test. The toxicity of cinnamic alcohol, eugenol, trans-anethole and 2-phenylethyl propionate is remarkably increased when they are topically applied to the *iav* strain, as shown in Table D.

Chemical name	Wild/type LD ₅₀ values (μg/fly)	%Mortality at LD ₅₀ of wild/type <i>Drosophila melanogaster</i> strain	
		Wild/type	<i>iav</i>
cinnamic alcohol	1.65	30.0%	80.0%
eugenol	1.90	53.3%	80.0%
trans-anethole	6.00	40.0%	100.0%
methyl salicylate	7.50	40.0%	46.6%
geraniol	10.50	60.0%	60.0%
α-terpineol	13.00	46.6%	60.0%
2-phenylethyl propionate	14.50	53.3%	80.0%
<i>p</i> -cymene	25.00	40.0%	40.0%

Table D

However, mutation of the octopamine synthesis does not affect the toxicity of *p*-cymene, methyl salicylate, and geraniol. Therefore, the current data suggests a correlation between agents inducing cellular changes in clonal cells expressing octopamine receptors and their insecticidal activity. The data also suggests that the insecticidal activity of cinnamic alcohol, eugenol, trans-anethole and 2-phenylethyl propionate is mediated through the octopamine/octopamine receptor system. From these data it can be concluded that the increase in the insecticidal activity of these chemicals results from the deficiency of octopamine synthesis in *iav* mutants because low octopamine levels may be unable to compete against the toxic effect of these chemicals.

As mentioned above, the toxicity data demonstrates significant differences between the toxicity of the tested chemicals against each insect (Table C). The toxicity data also demonstrates differences between the two insects in response to each chemical. The toxicity data against wild type and octopamine mutant (*iav*) fruit fly suggests that the toxicity of cinnamic alcohol, eugenol and trans-anethol is mediated through octopamine/octopamine receptors system. Among certain other plant essential oils tested against both strains of fruit fly only the toxicity of 2-phenylethyl propionate is mediated through octopamine receptors. Collectively the data suggest a correlation between cellular changes and toxicity of certain plant essential oils.

In the present example, chemical-structure relationships of plant essential oil monoterpenoids against wild type fruit fly suggest certain structural features required for chemical-receptor interaction. Among these features are the presence and location of a hydroxyl group, and a spacing group such as methoxy group. The rank order of toxicity demonstrates that cyclic alcohols and phenolic compounds are more toxic than other monoterpenoids such as acyclic alcohols and esters. The efficacy of each compound is found to be determined by the presence and location of the spacing group on the benzene ring. For example, although the phenolic derivative, eugenol, and propenyl benzene, trans-anethol, contain the same spacing group (-

OCH₃) on position 2 and 1, respectively, eugenol is 3-fold more toxic against wild type flies than trans-anethole (Figure 11 and Table D).

In summary, the similarities and differences between both Pa oa₁ and OAMB sequences are determining features in the toxicity differences of certain plant essential oil monoterpenoids.

5 Additionally, it appears that the octopamine receptor mediates the insecticidal properties of cinnamic alcohol, eugenol, trans-anethole and 2-phenylethyl propionate and, in part, the toxicity of α -terpineol against *Drosophila melanogaster* fly. Furthermore, it appears that the presence of an electronegative group such as hydroxyl group, and different spacing groups, may be required for the insecticidal activity of plant essential oils through octopamine receptor.

10 ***

It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. It is intended that the Specification and Example be considered as exemplary only, and not intended to limit the scope and spirit of the invention. The references and publications cited herein are
15 incorporated herein by this reference.

Unless otherwise indicated, all numbers expressing quantities of ingredients, properties such as reaction conditions, and so forth used in the Specification, Examples, and Claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the Specification, Example, and Claims are
20 approximations that may vary depending upon the desired properties sought to be determined by the present invention.

CLAIMS

What is claimed is:

1. A strain of cells comprising a DNA vector having a nucleic acid sequence consisting essentially of SEQ ID NO: 1.

5

2. The strain of cells of claim 1, wherein the cells are COS-7 cells or HEK-293 cells.

3. A strain of cells expressing a protein having the amino acid sequence of SEQ ID NO: 2, or a fragment or derivative thereof, wherein the fragment or derivative thereof binds octopamine.

10

4. A strain of cells expressing a protein having the amino acid sequence of SEQ ID NO: 2.

15

5. The strain of cells of claim 4, wherein the cells are COS-7 cells or HEK-293 cells.

6. A strain of COS-7 cells or HEK-293 cells expressing a protein having the amino acid sequence of SEQ ID NO: 3.

20

7. An isolated nucleic acid molecule sequence encoding a protein that binds a biogenic amine, resulting in changes in intracellular concentrations of cAMP, Ca^{2+} , or both, having a nucleic acid sequence consisting essentially of SEQ ID NO: 1.

25

8. A molecule of claim 7, wherein the protein has an amino acid sequence consisting essentially of SEQ ID NO: 2.

9. An isolated nucleic acid molecule sequence having at least about 30% similarity to SEQ ID NO: 1, wherein the molecule encodes a protein that binds a biogenic amine, resulting in changes in intracellular concentrations of cAMP, Ca^{2+} , or both.

5

10. The isolated nucleic acid molecule of claim 9, wherein the molecule encodes an octopamine receptor.

11. The isolated nucleic acid molecule of claim 10, wherein the molecule encodes a protein having an amino acid sequence consisting essentially of SEQ ID NO: 2, or a fragment or derivative thereof.

12. An isolated nucleic acid molecule sequence of SEQ ID NO: 1, or a fragment or derivative thereof, wherein the molecule encodes an octopamine receptor.

15

13. The isolated nucleic acid molecule of claim 12, wherein the molecule encodes a protein having the amino acid sequence set forth in SEQ ID NO: 2, or a fragment or derivative thereof.

14. A method of screening compounds and/or compositions for insect control activity, comprising:

providing cells expressing a protein having the amino acid sequence of SEQ ID NO: 2; or a fragment or derivative thereof, wherein the fragment or derivative binds a biogenic amine;

adding said compounds and/or compositions to the cells; and

measuring the effects of the compounds and/or compositions.

15. The method of claim 14, wherein the step of measuring the effects of the compounds and/or compositions includes measuring the binding affinity of said compounds and/or compositions to the receptor.

16. The method of claim 15, and additionally comprising: selecting compounds and/or compositions having an affinity for the receptor.

17. The method of claim 14, wherein the step of measuring the effects of the compounds and/or compositions includes: extracting intracellular cAMP and/or Ca^{2+} from the cells; determining the intracellular cAMP and/or Ca^{2+} levels; and comparing the intracellular cAMP and/or Ca^{2+} levels in cells treated with said compounds and/or compositions to the intracellular cAMP and/or Ca^{2+} levels in untreated cells.

18. The method of claim 17, and additionally comprising: selecting compounds and/or compositions, the treatment with which, causes a change in intracellular cAMP and/or Ca^{2+} levels.

19. A method of screening compounds and/or compositions for species-specific insect control activity, comprising:

providing first cells expressing a first octopamine receptor cloned from a first insect species-of-interest;

providing second cells expressing a second octopamine receptor cloned from a second insect species-of-interest;

adding said compounds and/or compositions to the first and the second cells; and

measuring the effects of the compounds and/or compositions.

20. The method of claim 19, wherein the step of measuring the effects of the compounds and/or compositions includes measuring the binding affinity of said compounds
5 and/or compositions to the first and the second receptor.

21. The method of claim 20, and additionally comprising: selecting compounds and/or compositions having a desired relative affinity for one of the receptors.

10 22. The method of claim 19, wherein the step of measuring the effects of the compounds and/or compositions includes: extracting intracellular cAMP and/or Ca^{2+} from the first and the second cells; determining the intracellular cAMP and/or Ca^{2+} levels; and comparing the change in intracellular cAMP and/or Ca^{2+} levels in the first cells and the second cells.

15 23. The method of claim 22, and additionally comprising: selecting compounds and/or compositions, the treatment with which, causes a desired relative change in intracellular cAMP and/or Ca^{2+} levels in one of the cells.

20 24. The method of claim 19, wherein one of the octopamine receptors has an amino acid sequence of SEQ ID NO: 2, or a fragment or derivative thereof.

25 25. The method of claim 24, wherein one of the octopamine receptors has an amino acid sequence of SEQ ID NO: 3, or a fragment or derivative thereof.

26. A method of testing the effects of compounds on cells, said method comprising:

providing cells expressing a protein having the amino acid sequence of SEQ ID NO: 2; or a fragment or derivative thereof, wherein the fragment or derivative binds a biogenic amine;

adding said compounds and/or compositions to the cells; and

5 measuring the effects of the compounds and/or compositions.

27. A method of testing the effects of compounds on cells, said method comprising: providing first cells expressing a first octopamine receptor cloned from a first insect species-of-interest;

10 providing second cells expressing a second octopamine receptor cloned from a second insect species-of-interest;

adding said compounds and/or compositions to the first and the second cells; and

measuring the effects of the compounds and/or compositions.

15 28. A report produced by a method, comprising:

providing cells expressing a protein having the amino acid sequence of SEQ ID NO: 2; or a fragment or derivative thereof, wherein the fragment or derivative binds a biogenic amine;

adding said compounds and/or compositions to the cells; and

20 measuring the effects of the compounds and/or compositions.

29. A report produced by a method, comprising:

providing first cells expressing a first octopamine receptor cloned from a first insect species-of-interest;

providing second cells expressing a second octopamine receptor cloned from a second insect species-of-interest;

adding said compounds and/or compositions to the first and the second cells; and
measuring the effects of the compounds and/or compositions.

5

30. A compound and/or composition for controlling insects identified by a method, comprising:

providing cells expressing a protein having the amino acid sequence of SEQ ID NO: 2; or a fragment or derivative thereof, wherein the fragment or derivative binds a biogenic amine;

10

adding said compounds and/or compositions to the cells; and
measuring the effects of the compounds and/or compositions.

31. A compound and/or composition for controlling insects identified by a method comprising:

15

providing first cells expressing a first octopamine receptor cloned from a first insect species-of-interest;

providing second cells expressing a second octopamine receptor cloned from a second insect species-of-interest;

20

adding said compounds and/or compositions to the first and the second cells; and
measuring the effects of the compounds and/or compositions.