

Perspectives: Olfactory Targeting of Integrated Vector Management

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This volume has reviewed some of the most recent developments in our understanding of how insects detect and interpret odors. The general picture that emerges is that insects are highly dependent on odor reception for most, if not all, of the aspects of their lives. Phylogenetically conserved systems accomplish much in insects, representing remarkably economical use of biochemistry. The biology is fascinating, but so is the potential to take advantage of olfactory systems to accomplish better insect management. Just as insects are guided to oviposition sites, mates, and food by olfactory signals, humans can target insects more precisely by using repellents and attractants.

Insect Pest Management (IPM) is a concept that was born of the necessity of using very simple tools to protect crops and people. Whether tenting citrus to apply gaseous hydrogen cyanide or using the arsenical Paris green to poison mosquito larval sites, methods tended to be expensive, labor intensive, or of limited efficacy. Understanding the insect was seen as the key to getting the most effectiveness from methods of lower efficacy. This gave rise to intensive study of taxonomy, biology, and methods for surveillance.

The invention of synthetic insecticides beginning in the late 1930s revolutionized insect control. DDT was invented in 1939 and, because of World War II, was rushed into widespread use against fleas, lice, and mosquitoes to control plague, typhus, and malaria. It was wildly successful, earning its inventor, Herman Mueller, the Nobel Prize in 1948. DDT was just the beginning, as other organochlorine insecticides became common in the 1950s. A series of new compounds were developed in response to resistance, environmental concerns, effectiveness, and commercial interests. Today, there are 30 different modes of action recognized among insecticides, creating a varied chemical armamentarium.

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The principles of IPM and the tool box of chemistry have emphasized agricultural application, where the use of entomological interventions is required for adequate production. Very few new chemicals were developed exclusively for public health, though many of the agricultural chemicals have been adapted to protection of people and animals from arthropod vector species that transmit pathogens. From a health standpoint, vector control can make a huge improvement by decreasing the incidence of disease. Applied systematically, vector control has had a history of some major successes, like the suppression of yellow fever to build the Panama Canal, the complete elimination of the *Aedes aegypti* mosquito from Brazil in the 1930s, and about a 50% decrease in malaria deaths and incidence in Africa between 2000 and 2015.

Vector control also faces challenges in its application. Possibly the most basic challenge is that the commercial market is very weak, especially in the places that have the highest levels of transmission. As a result, the funds for product development are scarce compared to agriculture. Another challenge is that suppression of a vector to stop transmission is an indirect means of stopping disease, which is the real objective of the activity. This means that measurement of effectiveness is either based on faith in simple indices of abundance, based on complex measurements of entomological transmission levels, or based on even more complex measurements of disease incidence. Finally, the arthropods that transmit diseases mostly live near human or animal hosts. This simple idea means that people and domestic animals are likely to be exposed to many of the chemical interventions, narrowing the safety margin considerably.

Applications

Understanding the olfaction system in vectors could lead to solutions for these challenges in several ways. Three of the requirements for good IPM – surveillance, targeted control, and careful monitoring – can take advantage of olfaction. Improvements in these three areas would tend to lower costs and increase the predictability of effective programs, ultimately resulting in better disease control.

Surveillance is the activity undertaken to find out where there is a problem and to evaluate the severity of that problem. In many cases in human health, surveillance starts following first detection in a person. This is an effective way to find where the disease problem is located and to quantitate severity, but it inevitably occurs after transmission. If the incubation period of the pathogen in a human is longer than a week, the current entomological situation is unlikely to be the same as when the pathogen was transmitted. Sampling the arthropods themselves can give nearly real-time information on transmission potential, especially when there is a field method for determining presence of the pathogen in the arthropod. Anything that could increase yield and selectivity of traps would improve this process.

Olfactory attractants based on host odors have been used for surveillance for a long time, especially carbon dioxide for flying vectors and for ticks. More recent

products supply octenol or a blend of skin odors that are effective attractants of some species. Precise application of olfactory signals could greatly improve surveillance in a several ways. Mosquitoes, for example, respond to different chemical signals for different aspects of their lives. For example, receptive female mosquitoes can be sensitive to odors produced from the male cuticle; whereas, older females respond to odors from oviposition sites. Simultaneous collection based on both attractant systems would not only produce measures of abundance, but also a measure of population-wide age. Older females have had time to develop infectious levels of pathogens so that a higher ratio of ovipositing mosquitoes to mate-seeking mosquitoes might be a good indication of transmission potential.

Olfaction is important for various attract-and-kill products and concepts. Traps and intoxication devices are already on the market for *Aedes aegypti* and *albopictus* based on visual and olfactory attraction to oviposition sites. Attractive targeted sugar baits (ATSBs) are being developed that appear to have great impact on mosquito populations. Host odors are involved in the action of systemic insecticides fed or topically applied to animals for the purpose of killing ticks, fleas, and biting flies. Recently, there has been interest in developing so-called “endectocides,” drugs given to people so that arthropods attracted to them are killed when they take a blood meal.

Area repellents have been used for years to provide some relief from biting insects and topical (on the skin) repellents are familiar products. In these cases, the objective is to disrupt the olfaction process. Most of the commercial chemicals used as repellents were discovered either by screening or by molecular modeling of known active chemicals. Plants have been rich sources of repellent compounds, including one of the major commercial active ingredients (para-menthane diol or PMD, an extract of the lemon eucalyptus tree). Recent work based on screening compounds through cellular assays, where transgenic cells expressed mosquito odorant binding proteins, resulted in a series of compounds that appear to be much more repellent than current chemicals. This raises the ground-breaking possibility of repellent systems that use much less active ingredient, greatly improving the possibilities for formulation.

Trapping and repellency have been combined successfully in a strategy call “push-pull.” The concept is to repel mosquitoes from where they are normally attracted and then attract them to lethal traps. A successful trial of such a system was recently completed using host-seeking attractants in the traps.

A small number of pheromones are known from mosquitoes. None of them have been used in a confusion technique to suppress essential functions, as has been done so successfully for some agricultural pests. Another possibility for the confusion technique would be to release host odors, floral odors, or even male mating odors. Another speculative use of the olfaction system for vector control could be to poison the insect through the olfaction system. A toxic compound that bound to an odorant binding protein and that could not be degraded in the reception cell might be active at very low concentrations as it was literally pulled into the insect.

The third aspect of IPM in which olfaction could play a part is monitoring and evaluation of effectiveness. Such efforts use many of the same tools as surveillance,

but in contrast to targeting control methods, monitoring must be good at documenting a negative. That negative might be the desired outcome of disease reduction, lower vector populations that do not increase to their former levels, or pathogen-free vectors. Traps made more sensitive by the addition of olfactory factors and traps selective for the most likely vectors are just two of the possibilities for improvements.

Conclusion

The oldest mosquito fossil is some 90 million years old and it has been estimated that the origins of the family date back over 200 million years. The implication is that mosquitoes have been using olfaction to find food sources that have changed drastically over evolutionary time. The oldest estimate places the first mosquitoes before the development of flowering plants, suggesting that they had to find sugar sources from other plant parts. The original vertebrate hosts would also have been very different. This suggests that the genetic and physiological architecture for mosquito olfaction rests on a broad range of evolutionary experience. It is possible that the distinctive way mosquitoes show preferences for sugar sources and blood hosts, yet switch to non-preferred hosts when necessary, is a result of the adaptable genetic architecture that resulted from many series of selective events over millions of years?

To say that arthropod vectors are highly dependent on olfaction is an obvious statement; however, the human concern with these species is reflected in the term “vector,” implying directed movement. The direction is accomplished by olfaction in most cases. It is usually hard to predict the practical significance of basic biological research, but the likelihood of finding something useful in olfaction must be greater than in some other areas that are not so clearly linked to the damage caused by arthropods. Those useful findings can be very difficult to translate into available products with real impact, just like most other practical discoveries that have to be led through optimization, regulatory approval, social acceptance, large scale production and distribution, and successful competition in small markets. Olfactory attractants have an advantage over other technologies in this field because they will reduce costs of application, improve efficacy, and lead to sustainable solutions. Ironically, much of the work is to understand the world from the arthropods’ perspective so that we can kill them more effectively.

Glossary

- ³H-labeled pheromone** A synthetic pheromone with a hydrogen atom exchanged by tritium (³H, the radioactive isotope of hydrogen) used in pioneering biochemical studies in order to measure the pheromone concentration using the beta radiation
- Acetylcholine** (*Ach*) An organic neurotransmitter chemical that functions in the brain of many organisms including human and insects
- Acheta domestica*** (house cricket) A study model for neurogenesis in the brain
- Actinobacter*** A genus of Gram-negative bacteria belonging to the class of Grammaproteobacteria known to occur in pairs
- Active core (FxPRL-NH₂)** A specific motif in the PBAN pentapeptide that is active in inducing pheromone production
- Acyrtosiphon pisum*** (pea aphid) A sap-sucking insect in the Aphididae family
- ADAR** (adenosine deaminase acting on RNA) An enzyme that recognizes specific RNA duplexes and affects RNA sequence through adenosine (A)-to-Inosine (I) mutations
- Aedes aegypti*** The yellow fever mosquito that is responsible for epidemiological diseases such as Dengue, Chikungunya and Zika
- Aggregation pheromone** An odor that attracts members of the same species (con-specifics) to the same location for mate selection or defence against predators
- Agrotis ipsilon*** (black cutworm moth) A long-lived migrant species of moth (Noctuidae), polyphagous, widespread, damaging particularly in the Northern hemisphere and known to postpone its activities linked to pheromone production and reproduction
- Agrotis segetum*** (turnip moth) An owlet moth of the family Noctuidae, largely spread particularly in Europe, species of the same genus than *A. ipsilon* with whom interspecific hybrids can be obtained in laboratory conditions
- Alarm pheromone** A highly volatile odor pheromone chemical used to alert nest-mates for danger (predator) and colony defense
- Aldehyde oxidase** A metabolic enzyme that catalyzes the oxidation of aldehydes into carboxylic acids

- Allelochemical** (*allelo* = “another”) A chemical produced by an organism that has an effect on individuals of another species when released (e.g. toxic chemicals released by the plants in response to herbivorous attacks)
- Alpha-helix** A basic structure in the protein characterized by a rod-like spatial configuration
- Alternative splicing** A regulated process of intron removal during gene expression that results in a single gene coding for multiple protein isoforms
- Anopheles gambiae** The primary mosquito vector for the transmission of Malaria
- Anosmia** Inability to sense an odor or a perfume scent
- Ant** An eusocial (from Greek *Εὔ* = “good”) insect that lives in colonies (nests) similarly to bees and wasps with whom they share common ancestry (order Hymenoptera)
- Antagonist** An organism that competes with another (one species is negatively affected); A drug or chemical that binds to a receptor and blocks (or alters) the biological response by interfering with the interaction to the natural compound at the same receptor site
- Antennal lobe** The region of the insect brain which receives the input from the antennae
- Antheraea polyphemus, A. pernyi** A giant silkworm (Saturniid) with large, double-combed male antennae, with one cm² outline area and 60,000 sensilla trichodea, each 300 μm long
- Antimicrobial Peptide** (host defense peptide) A 12–50 amino acids-long peptide with the potency to kill microbes and/or modulate the immune system as part of the innate immune response found among the whole class of life, including insects
- Aphrodisiac** An odor released by the male to facilitate its acceptance by the female as found in pyralid moths
- Apis cerana** The common Asiatic or Eastern honey bee
- Apis mellifera** The common European or Western honey bee
- Apoptosis** (from ancient Greek ἀπόπτ[= “falling off”) The process of programmed cell death that occurs in all multicellular organisms
- Arbovirus** (arthropod-born virus) An informal name in modern medicine to refer to viruses that are transmitted by arthropod vectors of infectious diseases
- Arthralgia** (arthro = “joint”, algos = “pain”) A pain in one or more joints symptomatic of epidemiological diseases vehiculated by insects
- Arthropod** An invertebrate organism having an external skeleton (exoskeleton), a segmented body, and paired jointed appendages (insects, arachnids, myriapods and crustaceans)
- Atmosphere** (from Greek *atmos* = “vapour” and *sphaira* = “sphere”) A layer of gases such as argon, carbon dioxide, nitrogen and oxygen surrounding Earth, held in place by the gravity of Earth and maintained if this gravity exerted by Earth is high and the global layer temperature is low enough, among others
- Bacillus** A genus of gram-positive aerobic, motile rod-shaped bacteria (firmicute, the most heat-resistant organism known on earth)
- Bacillus thuringiensis** A soil-dwelling *Bacillus* bacterium naturally occurring in the gut of caterpillars and commonly used for insect pest control

- Base pair mismatch** A typo change in the genetic sequence that causes a point mutation
- Bemisia tabaci*** The sweetpotato whitefly, principal threat to green vegetation worldwide
- Beta sheet** Another major type of conformation (formed by β -strands) observed in protein structures
- Bimodality** The simultaneous use of two distinct conditions, modalities or systems
- Biocontrol** The aim of controlling insect pest species using other insects or organisms
- Biologically relevant odorant** An odor molecule (or chemical signal) that can induce specific behavioral changes
- Biopesticide** A naturally occurring substance (or pesticide) from animals, plants, insects or bacteria or even a mineral that can affect the physiology and thereby the behavior of an insect pest species
- Biosensor** (biological sensor) A device, used for the analysis of a particular substrate; it combines a biological component (enzyme, antibody or nucleic acid) with a transducer that converts the recognition event (or molecular reaction) into a measurable signal
- Biotransformation enzyme** An enzyme that mediates a specific change of a drug or molecule within a given tissue of a living organism
- Bitter taste sensation** An acrid biting sensation in the gustatory modality that is associated to activation of bitter taste receptors
- Bombykol** (*E,Z*)-hexadecadien-1-ol, the first ever described sex pheromone, discovered by Butenandt et al. (1959), that is released by the female silkworm moth to attract specifically the male silkmoth
- Bombyx mori* L.** (in French *le ver à soie*) The silkworm of the mulberry tree, symbol of Asia and primary producer of silk and model organism in the study of genetics, neurobiology, olfaction and pheromone
- Ca²⁺ channel** An ion channel which has selective permeability to calcium (Ca²⁺) ions
- Calcium influx** A massive entry or arrival of Ca²⁺ ions inside the cell
- Calling** The behavior associated to pheromone release; at a precise moment of the night, female moths immobilize on a vertical support such as the stem of a green plant and devaginate a (pheromone) gland located at the abdominal tip; this is accompanied by continuous vigorous wing fanning presumably to help disperse the odor
- Calmodulin** (calcium-modulated protein) A multifunctional intermediate Ca²⁺-binding protein that mediates various metabolic processes in insect and other eukaryotic cells
- Calyx** (from Greek *kálux* = “husk or pod”) A flattened cap of neuropiles in the insect brain where most sophisticated computations occur for signal recognition
- cAMP** (3',5'-cyclic adenosine monophosphate) A second messenger important for signal transduction in many organisms, including insects
- Capacitance** The ability of the neural circuit to collect and store energy in the form of an electrical charge

- Carbamate** An organic (toxic) compound derived from carbamic acid (NH_2COOH)
- Carbon** The key ingredient for most life on Earth, the elemental composite of the cell
- Carbon dioxide** A colorless gas made of a carbon atom attached to two oxygen atoms (CO_2) that occurs naturally in earth's atmosphere and water resources since Precambrian period (about 600 Mya)
- Carbon world** An unstable ancient world that has influenced evolution and perhaps can be found in the modern time rich in carbon samples, molecules and emissions
- Carboxylesterase** (carboxylic-ester hydrolase) An enzyme that utilizes two substrates (carboxylic ester and water) to release two products (alcohol and carboxylate)
- Central olfactory pathways** A combination of multiple interconnected olfactory structures in the insect brain that processes odor information and triggers specific odor-guided behavior
- Chain shortening** The process by which a long carbon fatty-acyl (lipid) chain precursor is subjected to selective two-carbon chain reduction to produce a specific sex pheromone
- Chemical barrier** A fatty acid, a protein, a secretion or another substance that helps defend the body against pathogens
- Chemical defence** A life history strategy of insects, plants and many other organisms to produce toxic or repellent molecules against predatory attacks; it also includes chemicals that reduce plant (or insect) digestibility to avoid consumption
- Chemoreception** The sensory modality tuned to volatile and non-volatile chemical stimuli molecules
- Chemosensory organ** An organ that is able to detect the presence of specific chemicals or relates to the perception of chemical substances – In mammals including human it includes the main olfactory epithelium (MOE) and the vomeronasal organ (VNO); in insects it includes the antennae, legs and proboscis, but not essentially the gut, the fat body, the dermis (immune organ) or the pheromone gland
- Chemosensory Protein (CSP)** A family of small soluble proteins (four-Cys) ubiquitously expressed throughout the whole insect body, also in arthropods and bacteria, highly abundant in chemosensory organs as well as in other tissues, tuned to fatty acids and xenobiotic chemicals for multiple functions including development, digestion, metabolism, pheromone production and immune defense
- Chronobiology** The study of the periodic (cyclic) phenomena, of the biological rhythms and of the effects of time on living organisms
- Cicadella** (green leafhopper) A jumping insect pest known to consume sugar on leaves of trees and many various other plant cultures
- Circadian clock** (*circa diem* = “about a day”) An internal clock whose biochemical, genetic and molecular components drive specific changes in the insect behavior depending on rhythms with a period close to 24 h
- Circadian clock gene** A gene that encodes a protein involved in circadian clock oscillation

- Circadian rhythm** A 24 h cycle in a physiological process within a living organism such as an insect or a plant
- Circadian rhythm of pheromone production/emission** A 24 h cycle in the regulation of pheromone production and release in mating behaviors of insects (moths)
- Cis-7-dodecenyl acetate (Z7-12:Ac)** A crucial pheromone chemical for male response to female sexual odors in moths (*Agrotis* noctuids)
- Cis-9-tetradecenyl acetate (Z9-14:Ac)** A second crucial pheromone chemical for male response to female sexual odors in *Agrotis* noctuid moths
- Cis-11-hexadecenyl acetate (Z11-16:Ac)** A third crucial pheromone chemical for male response to female sexual blend of odors in *Agrotis* noctuid moths
- Cockroach** (*blatta* = “insect that shuns the light”) A very ancient type of insect (320 Mya) closely associated to food residues and human habitats (since Antiquity); it can adapt to various kinds of external environments such as cold and heat, adopt a social organization, a kin recognition, a group or swarm behavior, a collective decision-making for food choice, and a very peculiar courtship ritual in which the female (*Periplaneta*) eventually climbs on the male’s back to devour the abdominal tergal gland, site of production for the sexual pheromone
- Cognate ligand** A ligand that is strictly required for protein interaction and function
- Coleopteran** An insect or species that belongs to the order Coleoptera (beetles)
- Consensus** A motif of conserved amino acid residues in a protein gene family
- Contact pheromone** (cuticular pheromone) A non-volatile odor or pheromone detected by direct contact with chemoreceptors on the antennae or tarsi of insects and thereby closely related to social insect species such as ants and termites
- Courtship** (“*faire la cour*”) An attempt or a specific behavior of the male to seduce the female in a purpose of mating for reproduction
- Cricket** (gryllid) A type of nocturnal insect known for the song of males in search for mates and for a sophisticated hearing tympanic system (eardrums) on the front legs
- CRISPR/Cas9** (Clustered Regularly Interspaced Short Palindromic Repeats/Cas) A system or technology for gene/genome editing based on archaeal and bacterial prokaryotic defense mechanisms against foreign viral DNA contamination
- Crop protection** A field research in agronomy and agricultural sciences for sustained development and high-throughput production of food supply, transgenic plants and leguminous cultures resistant to insects
- C-terminal pentapeptide motif** The region of PBAN with pheromonotropic activity
- Current clamp recording** An electrophysiological method for measuring the voltage across a cell membrane at a fixed current across the membrane
- Cuticle** (exoskeleton) The outermost part (the external armor) of the insect body, also in all arthropod invertebrates, involved in many functions such as defence against toxic chemicals and prevention of water loss
- Cycle** The time necessary for a sequence of a recurring succession of biological events or phenomena such as those associated to diapause and reproduction to be completed

- Cysteine** ((R)-2-Amino-3-mercaptopropionic acid) The amino acid residue (Cys) that harbors a sulfur atom and helps build disulfide bridges in specific protein structures
- Cytochrome P450 (CYP450)** A superfamily of enzymes that use a variety of small and large molecules as substrates in various chemical reactions from the electron transfer chain and exogenous toxic chemical degradation
- Cytoplasmic incompatibility** A phenomenon caused by bacteria living in the cytoplasm of gamete cells that results in sperm and eggs being unable to lead to viable offspring
- Damage** The harm, injury, impairment, loss or destruction in biological function or economic value of a sensory cell or an agricultural parcel
- Danaus plexippus*** (monarch butterfly) An iconic pollinator species known on the American continent for winter mass migration
- DDT** (dichloro-diphenyl-trichloro-ethane) An organochlorine (chlorinated hydrocarbon) insecticide molecule known to be associated with Alzheimer's disease
- DEET** (N,N-diethyl-meta-toluamide) A renown insect (mosquito and tick) repellent molecule with some known secondary toxic effects on human
- Dengue hemorrhagic fever** A severe outcome of dengue disease resulting in bleeding, low levels of blood platelets and blood plasma leakage
- Dengue shock syndrome** A severe outcome of dengue disease, where dangerously low blood pressure occurs
- De novo* pheromone biosynthesis** (*de novo* = "from a new") The particular biochemical pathways in which specific metabolites (pheromone products) are newly biosynthesized typically from acetyl coenzyme A in the (moth) pheromone gland
- Desaturase** (fatty acid desaturase) An enzyme that removes two hydrogen atoms from a fatty acid, *de novo* producing a specific carbon/carbon double bond pheromone molecule
- Detoxification** The process of removing exogenous foreign toxic (xenobiotic) substances from an organism, a tissue or a cell
- Deutocerebrum*** (from greek deuteros = "second") A part of the insect brain with numerous glomeruli (ball-like structures) where the axons of antennal receptor neurons end and connect with interneurons and with neurons projecting to higher brain centers; within a glomerulus the receptor neurons of similar odorant specificity converge, there is e.g. one glomerulus for CO₂ receptor neurons, pheromone receptor neurons converge in the macroglomerular complex
- Development** (simple or incomplete metamorphosis) The biological process that all insects must undergo from eggs to the adult stage and reproductive status
- Diapause** A physiological state dormancy; a delay in development in response to regularly and recurring periods of adverse environmental conditions
- Dipteran** An insect or species that belongs to the order Diptera (flies and mosquitoes)
- Disparlure** A specific noctuid sexual pheromone (2-methyl-7,8-epoxyoctadecane) released by female gypsy moths, *Lymantria dispar*

- Disulfide bridge** A linkage (or bridge) enrolling a disulfide (S–S) bond usually derived by the coupling of two thiol (R–SH) groups within the same protein and/or two different molecular complexes or protein units
- Drosophila melanogaster*** The common fruit fly or vinegar fly, most widely used model organism for biological research in immunology, genetics, life history evolution, trait inheritance, microbial pathogenesis, neurophysiology, olfaction, vision and neurorobotics
- Drosophila suzukii*** The spotted wing *Drosophila*, major fruit, grape, cherry and berry crop pest species worldwide; it is the rare fly that infests fruit and berry during the ripening stage, in contrast to most species of flies that infest only rotting fruit
- Duplication** (gene or chromosomal duplication) A major mechanism through which new genetic (DNA) material is generated during molecular (genome) evolution through unequal crossing-over (misalignment of chromosomes) and/or retrotransposition event
- Dysgeusia** The alteration in taste and recognition of gustatory molecules
- Eciton hamatum*** A species of army ant (Dorylinae) known to prey on the larvae of other social insects such as wasps and ants of genera *Dolichoderus* and *Camponotus*
- Ecodrug** A drug, chemical, agent or reagent with eco-safe property (see ORSA), which needs to be considered for insect control and ecosystem preservation; the required alternative to insecticides and other environmental pollutants
- Ecosphere** An Earth closed ecological system; The part of the atmosphere in which it is expected to breathe naturally without aid, cure or protection
- Electroantennogram (EAG)** A recording from insect antennae with both electrodes located within the hemolymph (blood space) but at different regions on the antenna; the voltage changes observed upon odor stimulation reflect mixed responses of many receptor neurons, including temperature effects
- Electroantennography** An electrophysiological technique for measuring EAG, the average output (sum of responses of many olfactory neurons activated) of an insect antenna exposed to a given odor
- Encephalitis** An infectious disease in human characterized by a sudden onset inflammation of the brain or the brain tissue
- Endectocide** Insecticide applied to the host to kill an endo- or exoparasite
- Entomopathogen** A chemical drug or a bacterial organism that can cause disease specifically in insects
- Entrainability** The ability of oscillators (or clocks) to be synchronized with an external periodic signal such as seasonal variation and/or day length (photoperiodism)
- Enzyme kinetics** The study of the chemical reactions and reaction rates that are catalysed (governed) by specific enzymes
- Euarthropoda** The phylum of “true” arthropods (arachnids, crustaceans, insects and myriapods); their cuticle is periodically shed to allow for continued growth
- Exon** A part of a gene that will encode a part of the protein (block or motif) after introns have been removed by RNA splicing

- Fairyfly** (fairywasp) A family of almost invisible beautiful very tiny insects with a feathery appearance, the most primitive family within Chalcidoidea (100 Mya), which has a very short lifespan at the adult stage; females have the antennae tipped with club-like segments (clava), while the male antennae are filiform and look like a long soft cotton fiber thread
- Fatty acyl reduction** The chemical process involving the gain of electrons in a fatty acid to yield a fatty alcohol (via a fatty aldehyde intermediate)
- Food choice** An impact that food, plant or prey selection has on the environment, health and life of many organisms
- Food trail pheromone** An odor chemical that builds a narrow and precise route for the (insect) organism to reach specific food sources
- Formica rufa*** The red wood (or horse) ant that sprays formic acid from their abdomen
- Free-running period** A period or rhythm that is not adjusted to 24 h cycle nor to any other artificial photoperiodic cycle
- Glutathione-S-Transferase (GST)** (ligandins) A family of metabolic enzymes that catalyze the conjugation of the reduced form of glutathione (GSH) to foreign xenobiotic substances, participating thereby to cell or tissue detoxification
- GABA** (gamma-aminobutyric acid) A neurotransmitter that acts at inhibitory synapses by binding specific receptors in the membrane of both pre- and postsynaptic neuronal processes; it regulates brain and nerve cell (neuron) activity by decreasing the number of neurons firing in the insect (and human) brain
- Genetic code** Building blocks of life (Watson and Crick 1953); Genetic information in DNA conveyed solely by the linear sequences of four (nucleotide) bases (A, T, G and C) in a triplet codon alphabet that is used by living cells to translate gene/RNA into protein (most of all amino acids in the protein are specified by more than one codon or nucleotide base triplet in the DNA = degeneracy of the genetic code)
- Genome** A complete set of DNA (genes, exons and introns) that contains all the information necessary to build an organism and lead its activity through expression of a complete and specific repertoire of proteins
- Glomerulus** (*glomus* = “ball of yarn”) A globular structure or neural network of entwined vessels, fibers and nerve cells (neurons)
- Glutamate** An excitatory neurotransmitter in the (insect) brain essential for normal brain function, learning and memory
- Glycine** (aminoacetic acid) The simplest possible amino acid residue (Gly) that has a minimal side chain (one single hydrogen atom) and therefore can fit into any hydrophilic (attracted to water) or hydrophobic (not attracted, even repulsed by water) medium; it has a repeated role in the modulation of alpha-helical motifs in many various proteins
- G-Protein Coupled Receptor (GPCR)** A protein located in the cell membrane compartment (seven transmembrane domains) that binds extracellular substances and transmits specific signals through an intracellular relay molecule called G-protein (guanine nucleotide-binding protein)
- G protein-coupled receptor kinase 2 (GPCRK2)** A family of protein enzymes that regulate the activity of GPCRs by phosphorylation/dephosphorylation process

Guillain-Barre syndrome (GBS) A rare disorder caused by the immune system damaging the peripheral nervous system (= nerves outside the brain and spinal cord)

Gustation One of the five senses that belongs to the gustatory (taste) system

Haplotype A group of genes that are inherited together from a single parent

Heliothis virescens (tobacco budworm) A species of noctuid moths whose larvae are addicted to gluttony on cotton, pea, soybean and tobacco with extremely high resistance to a large panoply of insecticides

Hemocyte A cell from the hemolymph that plays a role in the immune system of insects (analogous to human phagocyte)

Hemolymph A transport fluid from the circulatory system that fills in the body cavity and all tissues in insects as well as in other arthropods (rather analogous to human lymph, not to human blood); it does not help carrying oxygen, it helps fighting infections and removal of waste toxic products

Histamine A biogenic amine inhibitory neurotransmitter in the insect brain

Honey bee (*Apis mellifera*) The most beneficial insect for human; building most intimate interactions with flowers, it provides human with honey, beeswax and crop pollination

Host plant odor A specific odor profile released by a plant most suitable for the moths or butterflies that need to lay eggs on it

Host preference The choice of an insect to find most suitable individual, organism, species, nest or plant for blood meal, food source, egg-laying and/or reproduction

Host selection The use of both olfactory and visual cues in (plant) host location

Hyalophora cecropia (cecropia moth) A giant silk moth with beautiful feathery antennae used to detect pheromonal odors from miles away. Also known for the discovery and extraction of juvenile hormone (1956) and as a symbol of North-American natural fauna

Hydrophobic semio-chemical A chemical signal used a mean of communication between organisms that can dissolve in the air, but not in the water

Hymenopteran An insect or species that belongs to the order Hymenoptera (ants, bees, sawflies and wasps)

IMD (immune deficiency) A key component of the immune response to infection specifically in the insect gut

Immunity The ability of an organism (including insects) to resist an infectious agent, a pathogen, a toxin or toxic xenobiotic substance by the action of the immune system

Inhibition of receptor neurons Nerve impulse firing possibly inhibited (i) by poisons affecting the nerve impulse generation (e.g. permethrin), (ii) by antagonistic ligands blocking odorant receptor molecules (e.g. presumably decanoyl-thio-1,1,1-trifluoropropanone selectively inhibiting pheromone-sensitive neurons of moth species), and (iii) by odorants that produce receptor potentials of opposite polarity thereby decreasing the spontaneous nerve impulse firing (e.g. linalool that inhibits some olfactory receptor neurons but excites others)

Inositol 1,4,5-triphosphate (IP3) (combined with diacylglycerol or DAG) A secondary intracellular messenger molecule used in sensory signal transduction and

lipid signalling that is known to diffuse through the cell to release intracellular calcium stocks

Insect (*insectum* = “with a divided body”: head, thorax, abdomen) The largest group within Arthropods (a profusion of species); The most diverse kind of arthropod, characterized by a pair of antennae erected on the head, six legs and one or two pairs of wings at the adult stage- A panoply of developmental and reproductive variations- A set of sophisticated appendages or glands to make sounds or odors – A set of remarkable very sensitive and specialized organs of sensory perception- An example of parasitism or essential beneficial role- Their appearance and survival coincide with first Earth’s terrestrial ecosystems (500 Mya)

Insect antennae Paired head appendages carrying numerous sense organs (sensilla) for detecting stimuli of various modalities: odorants, CO₂, taste compounds, mechanical stimuli (e.g. touch, vibration, sound), temperature

Insect behavior A very wide range of innate activities from pheromone communication to reproduction and migration, also including a whole panoply of diverse responses to environmental (toxic chemical) changes

Insect growth regulator A chemical substance that inhibits the life cycle of an insect

Insect pest An insect species that causes specific damages on crops or food supplies or poses a real threat to human health

Insertion mutation A type of base (or amino acid) mutation characterized by the insertion of one or few nucleotide base pairs to a DNA or RNA strand and/or the insertion of one or few amino acid residues (Glycine) to a protein motif or structure

Intron The silent (non-expressed) part of a gene, laying between two exons; it helps assemble exons but is removed from RNA after maturation before protein synthesis

Inversion mutation A type of base (or amino acid) mutation characterized by the removal of a length of DNA or a pair of amino acids which is then reinserted in the opposite direction in a protein motif or structure

Iodobenzene An organic compound with a benzene ring and one iodine atom

Ion channel A protein of the cell membrane serving as a gate for ion currents across the membrane; it may be opened upon specific (odor or neurotransmitter) ligand binding

Ionotropic receptor (ligand-gated ion channel) A family of ion-channel proteins located in the cell membrane which allow ions (Na⁺, K⁺, Ca²⁺ and/or Cl⁻ to enter the nerve cell in response to the selective binding of a chemical messenger neurotransmitter (or ligand)

Ipsdienol The aggregation pheromone ((4S)-2-methyl-6-methylideneocta-2,7-dien-4-ol) of bark beetles

Juvenile hormone (JH) A (main) hormone in insects, secreted by two tiny translucent endocrine glands near the brain (*corpora allata*), which play a crucial role in controlling most of the key processes in the insect physiology from development and molt to growth and reproduction through chemical communication, migration and oviposition

- Juvenile hormone binding protein (JHBP)** A protein that interacts with or helps the transport of JH in the hemolymph or in different compartments of the target cell to control specific gene expression
- Kenyon cell** An intrinsic nerve cell (or neuron) from the mushroom body of insects
- Labial palp pit organ glomerulus** The part of the insect brain tuned to CO₂ detection
- Lamellocyte** A large flat cell of the insect immune system that is known to function as a plasmatocyte (hemocyte)
- Lateral horn** (*lateral protocerebrum*) One of the two areas in the insect brain (the other area is the mushroom body) where projection neurons of the antennal lobe send their axons and specific odor information
- Lepidopteran** An insect or species that belongs to the order Lepidoptera (butterflies and moths)
- Leucophaea maderae*** (Madeira cockroach) The first organism where an endogenous circadian clock was identified
- Ligand-induced internalization** An uptake of a material into a different compartment
- Ligand-induced internalization of Ca⁺⁺ into a receptor neuron** A mechanism (desensitization process) controlling odorant receptor signaling to ensure the appropriate cellular responses to a specific odor molecule
- Linked gas chromatography-electrophysiology** A technology that combines separation of pheromone volatile chemicals vaporized without decomposition (gas chromatography) and recordings from single olfactory neurons (electrophysiology) to screen for biological natural active novel compounds
- Lipids** A group of (oil, fat, wax and other ester) organic compounds strictly insoluble in water (highly hydrophobic); it is (with carbohydrates and proteins) the primary structural component of living cells
- Local neuron** (interneuron) A broad class of nerve cells that enable communication between sensory neurons and the central nervous system in the insect brain
- Locomotor activity rhythm** (*locō* = “from a place”) A strong regular repeated pattern of movement from one place to another, largely under the control of a persistent endogenous timing mechanism of circadian frequency
- Locust** A solitary or gregarious insect (grasshopper) that can migrate in gigantic swarms and cause immense damages on cultures, vegetations and crops
- Locusta migratoria*** The migratory locust that can change characteristics or traits (phenotype; from solitary to gregarious) in response to population density and build swarms of 40–80 millions individuals
- Log₁₀-unit of stimulus intensity** A step of factor ten in stimulus strength
- Lymantria dispar*** (gypsy moth) The most destructive pest (*Lymantriidae*) of hardwood trees in US and North-America
- Lymph emulsion** A water-in-oil emulsion; a suspension of lipid droplets of oil in a water environment with which the oil will not mix
- Maculopapular rash** A type of rash characterized by a flat, red area on the skin that is covered with small confluent bumps

- Mamestra brassicae*** (cabbage moth) An invasive noctuid species of moth known to feed (at the caterpillar stage) on many various fruits, vegetables and crops (cabbage, broccoli, Brussels sprouts, tobacco, tomato, sunflower, etc.)
- Management** The process of dealing with or controlling insect pests
- Manduca sexta*** (hawk moth; in French *le sphinx*) A species of moth (Sphingidae) that feeds on flowering plants (Solanaceae or nightshades) from agricultural crops, medicinals, spices, weeds and ornamentals, and a common model organism in odor neurobiology
- Mating** The action of pairing for intersexual interaction or reproduction
- Microcephaly** A medical condition present at birth or later during the first few years of life in which the brain does not develop properly resulting in an abnormally small head
- Microfilaria** An early stage in the life stage of parasitic nematodes (worms) that can be taken up from an individual (host) by blood-feeding insects and develop to infective larvae transmitted to a new host prone to cause epidemic diseases
- Migration** Seasonal flights or movements of insect species such as beetles, butterflies, dragonflies, locusts and moths (most damaging) in response to environmental changes
- Molecular receptive range** The agonist (excitatory) and antagonist (inhibitory) characteristics of an odorant receptor
- Mosquito** A long-legged buzzing dipteran fly with aquatic larvae and female that feeds on human blood transmitting a series of serious epidemiological infectious diseases (Chikungunya, Dengue, Malaria, Zika, etc)
- Moth** A crepuscular or nocturnal insect species with gluttonous herbivorous (phytophagous) larvae, females with pheromone gland at the abdominal tip and males with prominent hairlike or feathery antennae which flies at night to find the females that emit the odor over kilometers distance
- Multiglomerular structure** A (brain) structure that affects, contributes or pertains to multiple glomeruli
- Musca domestica*** (house fly) The most common species found on cattle farms, a nuisance that can transport vector-mediated diseases; it is also a key element in ecological chain for breaking down and recycling organic matters
- Mushroom body** (*corpora pedunculata*) A pair of nervous structures in the insect brain known to play a key role in olfactory learning and odor memorization
- Mutation** A change, not necessarily an alteration, in the DNA, RNA or protein sequence that helps produce a new gene, RNA or protein isoform, prelude to new function in a given gene protein family in responses to specific external environmental changes
- Myalgia** A pain in one or more muscles
- Mymar pulchellum*** A genus of fairyflies in Euathropoda Insecta Hymenoptera Mymaridae (only ten species described)
- Mythimna separata*** The rice-ear cutting caterpillar; the major pest of maize in Asia
- Negative staining** The staining of the background used in transmission electron microscopy in order to increase contrast to the specimen

- Nerve impulse (of sensory neuron)** An action potential elicited (or suppressed) by the receptor potential reaching the impulse generator zone; this zone is thought to be located in the soma (cell body with nucleus) of the neuron, nerve impulse may also be spontaneously generated
- Neuropile** An area in the insect brain or any nervous system composed mainly of nerve fibers (only a few nerve cell bodies) that forms a synaptically very dense region
- Niemann-Pick type C2 protein (NPC2)** A small soluble β -stranded protein important for cholesterol, fatty acid and sphingolipid transport in the lysosome of animal cells and the sensory lymph of ant workers
- Noxious compound detection** The sensory perception of chemicals that are harmful, eventually destructive and difficult to control or eliminate (toxicants)
- Noxious compound protection** A mechanism in the insect defense system that allow them to cope with the toxic secondary compounds from the plant for specialization, selection and specific adaptation to a potentially new habitat (host)
- Nuptial gift** A piece of food, twig of wood, tuft of grass or very precious bowl of silk that is given by the insect male to the female prior to mating
- Octopamine** The insect noradrenaline; it regulates aggression, behavioral development, reproduction, sleep, flight and odor memorization in various insect species, modulating specific neural signals in olfactory learning and memory as well as circadian rhythms of sleep and activity for instance in honey bees, fruit flies and crepuscular moths
- Odonatan** An insect or species that belongs to the order Odonata (damselies, dragonflies and Libellulidae)
- Odor** A scent, a stench, a bad or neutral smell that is caused by one or more in a bouquet airborne chemical volatiles all perceived by the sense of olfaction (i.e. the human nose or the insect antennae); it eventually refers to fragrance (a flower aroma, a perfume, a good positive enjoyable smell) for the positive aspect of life
- Odor discrimination** The perceptual ability (of the brain) to detect and describe differences between odors or perfume scents
- Odor perception** The brain's interpretation of the activation responses of many peripheral sensory neurons from the human nose or insect antennae which are differentially sensitive to a wide variety of molecules or chemical odorants
- Odorant-binding protein (OBP)** A small soluble α -helical protein that binds to odor molecule (odorant) at the periphery of olfactory receptors in the insect antennae
- Odorant clearance** The process of removing (eliminating, cleaning out, washing out etc.) any residual odorant molecule from the human nose or the insect antennae
- Odorant-Degrading Enzyme (ODE)** An enzyme that mediates the metabolism of volatile signal molecules crucial to sustained sensitivity and specificity in the insect olfactory system
- Odorant inactivation** (odorant deactivation) A chemical alteration of odorant molecules by specific enzymes (ODEs) that stop them interacting with receptor molecules

- Odorant Reception Suppressing Agent (ORSA)** An airborne volatile or non-volatile synthetic odor pheromone chemical structural analog with a subtle modification in the native molecular stretch for the ability to block specifically the functional binding sites of target olfactory proteins and/or to counteract with specific odor receptor activation
- Odorant receptor (OR)** (olfactory receptor) A seven-(pass)-transmembrane domain protein expressed in the cell membrane of olfactory (receptor) neurons that need to be activated by specific odor molecules before the sense of smell
- Olfaction** The sense of smell; the primary sense tuned to odor detection and recognition; One of the most ancient and primordial modality to sense the environment
- Olfactory co-receptor (ORCO)** A co-expressed and co-localized olfactory receptor protein that complexes with odorant receptor to form an odorant-sensing unit
- Olfactory receptor neuron (ORN)** (olfactory sensory neuron, OSN) The cell that transduces chemical odor signals into electric neural messages that are sent out to the brain for odor sensing (ten million in human, thousands to ten thousands in insects)
- Ophthalmotropic** (from greek ophthalmos = “eye” and tropic = “turned towards”) An insect species (moths or flies) that have developed feeding habits and mouth parts typically tuned to animal eye secretion
- Optic lobe** A structure or pair of structures (left and right) found in the microbrain of insects that integrate sensory information from the eyes and certain auditory stimuli
- Organophosphate** The common name for phosphate esters or esters of phosphoric acid; it includes DNA, RNA and ATP but also most common insecticide phosphorous chemical
- Orthopteran** An insect or species that belongs to the order Orthoptera (crickets, grasshoppers, katydids and locusts)
- Ostrinia nubilalis** (in French *la pyrale du maïs*) The European corn borer (*E* and *Z* strains); A grass moth (Crambidae) pest of grain, known for hairbrushes or hairpencils (aphrodisiac organs) in the middle and lower abdomen that the male opens out like a fan during courtship to facilitate its acceptance by the female
- Oviposition** The act or behavior related to lay eggs in insects
- Palindrome** A DNA or protein sequence that is spelled the same way forwards or backwards
- Parasitoid** An insect (usually a wasp) whose larvae feed and develop within or on the body of another insect species (usually a moth caterpillar): an example of endoparasitism (when the parasite lives inside the host organism)
- Patch clamp recording** A voltage or current clamp recording with the mouth of the recording electrode tightly sealed (GOhm seal) to a small patch (piece) of the neuron plasma membrane containing one or a few ion channels
- Pathogen** An agent such as a virus or a bacterial microorganism that can cause infectious disease
- Pattern recognition receptor (PRR)** A protein expressed by the (insect) innate immune system that plays a role as a host-sensor; it detects molecules specific to pathogens

- PBAN agonist** A peptide molecule that can bind to and activates a PBAN receptor to induce (or stimulate) a PBAN response
- PBAN/pyrokinin family** (FxpRL amides) A large family of neuropeptides (PBAN, diapause hormone, melanization and reddish coloration hormone-MRCH, myotropin, etc.) that bear the same amidated C-terminal tail (FxpRL) and regulate multiple various physiological functions in insects (Lepidoptera), i.e. development, cuticular coloration, flight, mating, muscle contraction, pheromone production and wing tanning
- PBAN receptor (PBANR)** A G-protein coupled receptor with seven-(pass)-transmembrane domains which triggers a specific signal transduction in the female moth pheromone gland leading to pheromone production in response of PBAN activation
- Pedunculus** (Peduncule) A stemlike structure that collects nerve fibres and thereby connects different regions from the central nervous system of the insect brain
- Peptidomimetic** A subtly modified peptide chain that mimics the effect of the natural peptide or a system similar to peptides (poly-N-substituted glycines or peptoids and amyloid β , A β or A β peptides)
- Period** A gene that is expressed in a circadian pattern to associate specific behaviors with circadian rhythms, the primary circadian pacemaker in the insect brain
- Peripheral clock** A functionally autonomous local oscillator in circadian timing active not in the brain but in many peripheral organs or tissues such as the gut and antennae of the insect influenced by light, temperature, hormonal regulation and/or fasting-feeding cycle
- Periplaneta americana*** (American cockroach) The largest pest species of common cockroach with ability of limb regeneration at the nymphal stage, a cosmopolitan plague that can live more than a year, reproduces over six hundred days and leads to more than ~150 progenies/a year
- Perireceptor event** The interaction between two or more molecular elements (ligand, transport protein, scavenger protein, enzymes) at the periphery of the receptor protein with central or pivotal function (i.e. odor receptor in the olfactory system)
- Perireceptor event in insect olfaction** The extracellular processing of the odor molecule before and after its interaction with the receptor protein, such as binding to soluble odorant binding protein, transport and degradation by odorant-degrading enzyme
- Peritrophic matrix** A semi-permeable envelope of chitin microfibriles that surrounds food metabolites in the insect midgut essential for digestion and infection by pathogens
- Permian** The geologic period of time and system which spans about 50 million years from the Carboniferous period (about 300 Mya) to the beginning of Triassic (about 250 Mya); it corresponds to the largest mass extinction of life recorded in the history of Earth (also called the Great Dying: 96% of species died out), the end of Paleozoic era
- Pherokine** A molecule related to both pheromone and immunological systems

- Pheromone** (from Greek *phérein* = “carry”, and *hormáo* = “to set in rapid motion, stir up”, “hormone”) A secreted or excreted odor molecule, an odorant factor or chemical signal that triggers a specific behavioral response in individuals of the same species
- Pheromone Biosynthesis Activating Neuropeptide (PBAN)** A neuropeptide (33 amino acids) with functional C-terminal FxPRL-NH₂ tail produced in the insect head (suboesophageal ganglion) secreted via *corpora cardiaca* (neurohemal organs of insects) and released into the hemolymph (and/or the ventral nerve cord) for the induction and stimulation of *de novo* pheromone biosynthesis in the lepidopteran female moth pheromone gland at some crucial time of the night
- Pheromone blend** A few or multiple pheromonal odors aimed at combining different molecules into a species-specific uniform whole odorant signal
- Pheromone degrading enzyme (PDE)** An enzyme that specifically mediates pheromone degradation (catabolism) and/or the conversion of pheromone molecules into inactive (or less active) forms
- Pheromone gland** A primary source and reservoir for sequestering *de novo* biosynthesized chemical compounds with pheromone function (e.g. the sex pheromone gland of female moths); it is usually covered by pines on the gland surface to facilitate pheromone emission and/or odor release
- Pheromonogenesis** The genesis of *de novo* (sex) pheromone chemicals via multiple key biosynthetic enzymes from the uptake of fatty acid, lipid or thioester precursor molecules to the final product of specific pheromone biosynthetic pathway
- Pheromonostasis** A mechanism or a peptide molecule mediating arrest or suppression of pheromone production in the sex pheromone gland; it naturally occurs in female moths after mating thanks to a number of humoral (male factors, sex peptides) and neural cues, it can also be induced by a family of biosynthetic sex peptide analogs inhibitors of sex pheromone production in selected insect pest species
- Phospholipid** A large biological polymer of the lipid family with hydrophobic “legs” (fatty acid) and hydrophilic “head” (phosphate) that plays a crucial role in the formation of cell membranes and all membranes surrounding organelles (= cell organs, differentiated structures within a cell that performs a specific function, e.g. mitochondria from the insect cell)
- Phosphorylation** The reversible process of attaching a phosphate group to a molecule (mainly on Serine, Threonine or Tyrosine amino acid residue) to help lead a protein to trigger a specific physiological mechanism (opposite: dephosphorylation); it is certainly one of the most important post-translational modification in various protein structures, including enzymes and receptors
- Photoperiod** The length of day or night in a cycle of time (24 h)
- Photoperiodic clock** An endogenous (internal) clock or timekeeping network that allows insects as well as many various organisms to align a specific physiological system with a changing external environment in order to perform most adapted biologically relevant important behavior

- Photoperiodic response** A functional physiological and/or behavioral change in response to a change in the length of day and night
- Photoperiodism** The physiological reaction of insects (and plants) to a photoperiod
- Physical barrier** An environmental, induced or natural condition that interferes in communication or interaction between two cells, individuals, organisms or species
- Physiology** The discipline of biology concerned with the functioning of living organisms
- Pit organ** A temperature- infrared- CO₂- and odor-sensitive organ on the antennae, or antenniform legs of insects (beetles, hymenoptera, moths), the small Haller's organ on the forelegs of ticks and varroa used to detect heat and pheromone chemical odors released by host (honey bee); it is formed by a ring-shaped cuticular ridge surrounding a pit (a hollow or indentation in the leg surface) containing five or six raised pore openings within each two to five sensilla are exposed
- Plant-herbivore insect interaction** A range of adaptations evolved by plants and insects for co-evolution: the responses of the plant to herbivore insect attack, the responses of the insect to plant defense, host-plant resistance, insect resistance, survival dynamics
- Plant semiochemical** (from Greek semeion = "signal") A chemical substance released by plants to defend themselves against herbivore insect attack by repelling the assailant and/or by attracting natural enemies (predators) of the herbivore (tritrophic interactions)
- Plasmodium falciparum** A unicellular protozoan parasite transmitted by *Anopheles* mosquitoes that is the main cause of malaria (anemia) disease in humans
- Poison avoidance** The act of avoiding (keeping away) from toxic chemical element possibly ingested (by insects) through food and nutrients
- Poisson statistics** Statistics of random events as e.g. arrival of single stimulus molecules on olfactory sensilla at a weak stimulus concentration
- Proboscis** The insect tongue (the sucking organ of a bee, a butterfly, a fruitfly or an hawk moth); an appendage, elongation or extension at the front of the insect mouth whose vital function remains elusive in most adult moths as most adult moths do not feed and do not suck nectar: proboscis should be absent when superfluous
- Projection neuron** An afferent (arriving to the brain) or efferent (exiting the brain) axonal projection fiber nervous cell uniting the insect brain with lower parts, peripheral nervous system, suboesophageal ganglion (SOG) and other ganglia of the ventral nerve cord that innervates (for instance) the pheromone gland in moths
- Proline** (pyrrolidine-2-carboxylic acid) The only amino (imino) acid residue (Pro) with a pyrrolidine (or tetrahydropyrole) and amine function for side chain, which confers an exceptional conformational rigidity in protein structure; it is usually found at the beginning of alpha-helices and in the edge strands of beta-sheets: polyproline motifs are essential for protein phosphorylation, protein assembly and signalling
- Protein** The core of life in cells (with lipids and other molecules); a short or very elongated soluble or trans-membrane macromolecules consisting of one or mul-

multiple chains of amino acid residues (such as Cysteine, Glycine and Proline) that combine to build the (primary) structure dictated by the nucleotide sequence of the corresponding gene on the basis of the genetic code (Watson and Crick); specific amino acid motifs can adopt different types of (secondary) structures (alpha-helix, beta-sheet and beta-turn) and foldings (tertiary structure) to underlie specific cell functions in adhesion, cycle, development, division, growth, shape, catabolism, metabolism, transport, regulation, signalling and immunological responses; to fulfill these tasks in multiple systems, proteins are often subjected to post-translational modifications (see phosphorylation) and it is said that the protein can even be subjected to specific (Cys, Gly or Pro) insertion mutation or inversion to acquire multi-function

Protein structure model (homology-modelling) An inference of protein's tertiary (3D) structure (prediction of alpha-helices and variations) from its amino acid sequence based on the known 3D crystal structure of a homologous protein used as reference or template

Protein variant (protein isoform) A representation of changes (mutations) in the amino acid sequence encoded by a specific DNA sequence (gene) in the genome; A new protein sequence in the repertoire of highly similar proteins that originate from the same gene but differ by one or a few amino acid replacements, the simplest variant (isoform or mutant) being the protein in which only one amino acid was subtly replaced by another to induce a new protein function

Protocerebrum The region of the insect brain innervating the compound eyes; it includes important higher centers like the mushroom bodies and the central body

Protozoan A rather informal term to refer to unicellular eukaryotic organism (or protist); a main class of parasites that cause infectious disease (Malaria) in human

Pyrethroid An organic insecticide compound similar to the natural pyrethrin molecule from pyrethrum flowers (*Chrysanthemum cinerariaefolium*)

Receptor potential A change of electrical voltage indicating the excitation of a sensory neuron, the stimulus-induced change of neuronal membrane conductance; it may be recorded extracellularly using capillary electrodes, with the "indifferent" reference electrode in contact to the hemolymph or blood space, and the "recording" electrode positioned near to the apical portion of a sensory neuron. The polarity of the receptor potential is negative or positive if the neuronal membrane conductance is increased or decreased upon stimulation

Receptor potential/current, elementary (ERP/ERC) An elementary small transient voltage/current wave ("bump" or group of "bumps") elicited by a single odorant molecule or (infrequently) spontaneously

Repellent An odorant chemical molecule that can elicit an aversive or repulsive behaviour specifically in some insect pests or predators

Reproduction The biological process by which a new individual organism (descendant or offspring) is produced from a « mother » and a « father » parent; one of the most important concepts in biology in which an organism is born and tends to make a copy or a likeness of itself to sustain and give a chance for a species, a genus, a family or an order to survive and/or have a continued existence during the process of evolution

- Retrotransposon** (transposon via RNA intermediate) A genetic element that can copy and paste itself at many different locations in a genome eventually inducing mutations by inserting near or within a particular gene sequence
- Rhizosphere** The region of soil where interactions between plant roots and associated bacterial microorganisms take place
- Rickettsia** A genus of bacteria of the tribe Rickettsiae; A small, nonmotile, non-spore forming, highly pleomorphic (occurring in many various distinct forms) rod-shaped to coccoid bacterial organism that lives in the body of lice or ticks and is responsible for Mediterranean spotted fever in humans
- Riptortus pedestris** An alydid hemipteran insect species (bean bug) extremely polyphagous; one of the major pests on leguminous crops (soybean), whose diapause is tightly regulated by circadian cycle and endogenous clock genes
- RNA** (ribonucleic acid) A polymeric single-stranded molecule that conveys the information from DNA to protein and therefore represents one essential core for gene expression and cell function; the origin of life: the components (chains of nucleotides, ribose and phosphate) built on crust in space and assembled on Earth
- RNA-DNA difference (RDD)** (mismatch or mutation) A site of base replacement or switch between DNA and RNA sequences during transcription (= copy of DNA to RNA) or following specific RNA editing by ADAR enzymes
- RNA editing** The guided post-transcriptional (= after copy of DNA to RNA) subtle modification of RNA sequence from the genomic DNA sequence that can lead to high number of protein variants and thereby multifunction from a single gene
- RNA interference (RNAi)** A mediated knockdown process in which specific RNA molecules inhibit the expression or translation of a specific gene resulting in the absence of a target protein in a given cell, tissue or organism
- Scavenger** An insect (fly or wasp) or a protein that feeds on or interacts with the residual matter, keeping a dust-free environment (or fluid) by specific nature recycling processes
- Schistocerca americana** (American bird grasshopper) The main pest for (palm) trees and lemon crops in Florida, also known for a specific family of fatty acids (caeliferins) from the grasshopper regurgitant that induces the plant to release allelochemicals
- Schistocerca gregaria** (gregarious desert locust) One of the most dangerous and threatening insect species for humans; it can build a swarm of 50–100 billion individuals and can eat up one-tenth of human agricultural production and food supply in three main parts of the world (Africa, Middle-East and Asia)
- Second messenger** A molecule inside the cell that transmits a specific signal from a transmembrane receptor to an intracellular target (the first messenger being the hormone or the odor chemical that conveys the signal to the cell)
- Selectivity** The quality of the insect olfactory system of discriminating, selecting and carefully choosing an odor as the most suitable
- Seminal fluid** (semen) A fluid that is produced by the male reproductive tract secretory tissues (accessory glands, seminal vesicles, ejaculatory duct and testis) and that contains sperm cells (= spermatozoa) and proteins that are transferred

to females with sperm during mating, resulting in specific changes in female behavior and physiology (pheromone inhibition, rejection of male, facilitation of feeding, ovulation and ovogenesis/egg production)

Sensillum (plural: sensilla) A small epithelial sensory unit including a cuticular structure (hair, plate) supplied with (often three) auxiliary cells, and innervated by one or several receptor neurons; in hairlike sensilla (hair length 10–500 μm) the apical neuronal processes (dendrites) may extend throughout the hair shaft, the axons of the receptor neurons conduct the nerve impulses to the central nervous system in the insect brain

Sensillum lymph The aqueous fluid that bathes the dendrites of olfactory neurons with pheromone solubilization/emulsification by binding to proteins, pheromone transport and degradation (see perireceptor events)

Sensillum type, gustatory and mechanoreceptive *S. chaeticum* (bristle, innervated by several taste neurons and often one mechanoreceptor neuron ending at the sensillum base)

Sensillum types, olfactory *S. trichodeum* (very long hair), *s. basiconicum* (short hair), *s. coeloconicum* (very short hair, sitting in a pit), *s. placodeum* (pore plate, in bees and beetles), *s. ampullaceum* (deeply hidden hair, found in ants for CO_2 detection)

Sensory adaptation A reduction in the responsiveness due to preceding stimulation, observed in responses of sensory receptor neurons and in behavioral responses

Sensory transduction The sum of processes in which a signal chemical (odorant, tastant) induces a receptor potential and impulse firing of a receptor neuron; this may happen via direct gating of ion channels or include a cascade (a series of) molecular events such as protein phosphorylation, second messenger formation, and release of intracellular Ca^{2+}

Serotonin (5-hydroxytryptamine or *5HT*) A monoamine neurotransmitter that acts also as a systemic hormone in insects where it regulates circadian rhythms, gut motility, tissue secretion, development, growth, locomotion, flight, learning and memory

Serotype A group of intimately related microorganisms distinguished by a common set of antigens or the set of antigens characteristic of this group

Sex pheromone A long-range highly volatile natural odorant pheromone chemical usually released by the female from a peculiar organ such as the sex pheromone gland of female moths to attract a conspecific male on a precise location, cocoon or plant site prelude to mating and reproduction

Sex pheromone gland A layer of glandular epithelial cells sandwiched between ovipositor and sclerotized cuticle at the tip of the female abdomen; A very active site for lipid and pheromone droplets, specifically devaginated (in nocturnal species of moths) during calling behavior at crucial moment of the night for release of sexual odor volatiles

Species similarity and difference A fundamental resemblance or common point, an homology (a shared ancestry) and/or an analogy (an apparent resemblance of

structures that clearly have different origins but similar function) and dissimilarity (or dissemblance) between different species

Specificity, neuronal The pattern of stimulatory chemicals producing excitatory and inhibitory responses of a receptor neuron; pheromone receptor neurons may have an extremely high specificity in responding >100-fold less sensitive if the pheromone structure is minimally changed, other neurons may respond to a number of chemicals in various proportions

Sphingolipid A lipid with sphingosine (a molecular structure shape as enigmatic as a Sphinx) that accumulates in tissues as diverse as the liver and the brain to regulate diverse cell functions in response to cellular stress (mainly oxidative stress)

Sphinx ligustri (privet hawk moth) The sphinx of the Palearctic zone (Europe and Asia)

Spodoptera frugiperda (*frugiperda* = “lost fruit”) The fall armyworm, a severe case study of cannibalism and herbivory in noctuid moths

Spodoptera littoralis (African or Egyptian cotton leafworm) The Mediterranean brocade labeled as quarantine pest (40 different plants and at least 87 different plant species) that feed on young leaves, young shoots, stem, pod, bud and fruit throughout the whole world

Stem cell An adult or embryonic cell that can differentiate into another type of cell and function to produce even more of these new cells and functions

Streptomyces The largest genus of *Actinobacteria* (about 500 Mya); the most adapted organism to the utilization of plant and soil residuum in all various environments

Structure activity relationship The relationship between a chemical (or drug ligand) and/or a 3D structure of a protein molecule and their biological activity

Suboesophageal ganglion (SOG) A part of the ventral nerve cord below the oesophagus inside the head in insects (and arthropods) connected to the brain and to the first thoracic ganglion that controls the mouthparts and salivary glands but also produces neuropeptides (e.g. PBAN) that will stimulate the pheromone gland at the abdominal tip

Sugar taste inhibition The loss of sweet taste perception as a result of the alteration in the activation of sweet taste receptors and/or a neurobiological disturbance in the insect brain or ventral nerve cord

Surface tension The attractive force exerted upon the surface molecules of a liquid by the molecules beneath; it tends to draw the surface molecules into the distinct mass of the liquid and makes the liquid such as water assume a shape with the least surface area (e.g. water or lymphatic surface in contact with air)

Surfactant A solute or substance which tends to reduce the surface tension of a liquid in which it is dissolved

Swarming A collective behavior displayed by insects of the same species (locusts, butterflies, moths, beetles, flies, mosquitoes, aphids, whiteflies, wasps, termites, flying ants and most other winged insects) to aggregate together, move in large numbers and migrate towards specific geographical locations to reproduce or continue development

- Synapse** (from Greek synopsis = “conjunction”) A structure or intercellular space where a neuron (or nerve cell) connects another neuron or a target cell and propagates a specific chemo-electrical signal
- Taste** (gustation) The primary sense used by human, animals and insects to distinguish one potential food source from another
- Taste sensillum** A bristle-like sensillum (chaeticum) on the insect maxillary palp (mouthpart) or insect antenna responsible for sweet sugar detection
- Temperature compensation** A phenomenon in which the output of the endogenous clock system remains nearly constant with fluctuations in external temperature
- TEP protein** (thioester-containing protein) An antimicrobial protein from the insect immune system that uses a specific thioester motif to damage the cell membrane at the surface of the invading infectious pathogen
- Termite** Eusocial insect that evolved from an ancestor of cockroaches (about 300 Mya) and entirely tuned to digestion of cellulose that the wood is made of
- Tip recording** The recording capillary electrode is slipped over the tip of a hair-like sensillum in order to record receptor potentials and nerve impulses from the sensillar neurons; in olfactory sensilla the hair tip may be opened for improving the electrical contact to the neuronal dendrites inside the hair shaft, taste sensilla (sensilla chaetica) have a terminal opening that receives tastants and also allows electrical contact to gustatory neurons and to a mechanoreceptive neuron
- Toll receptor** An immune receptor in the membrane of sentinel cells (macrophages) from the insect adaptive immune system that can recognize molecules that are broadly shared by pathogenic microbes (sense internal danger signals) and trigger many various responses of the insect defence system, including antimicrobial peptides, proinflammatory cytokines and chemokines
- Transcript (mRNA)** A single-stranded mRNA product synthesized by transcription of a genomic DNA sequence, eventually subjected to editing and processed for translation (protein synthesis); multiple transcripts or mRNA sequences do not mean necessarily multiple genes, a gene can lead to multiple transcripts and therefore to multiple proteins
- Transcription** The process in which the genetic information from DNA is transcribed into RNA by a specific enzyme called RNA polymerase
- Transepithelial recording** A tip recording implemented if the indifferent electrode is located basally from the epithelium; in cases of high electrical resistance across the epithelium (e.g. 200 MΩ), loose patch clamp conditions exist where the neuronal dendrites represent the patch of cell membrane
- Translation** The process in which the genetic information from RNA is translated into specific amino acid chain, protein or polypeptide before further editing and/or folding for the final protein product to perform specific function within the cell, tissue or organism
- Truncation** A mutation which induces premature stop codon thereby producing a shortened protein with a truncated (aborted) tail
- Type I pheromone** A major group of moth sex pheromones composed of a 12–18 carbons-long fatty acid chain (with one, two or three double bonds and trans (*E*))

or cis (*Z*) isomers) connected to an oxygenated functional group (acetate, alcohol or aldehyde) as the only polar and therefore hydrophilic (water loving) portion of the molecule

UDP-Glycosyltransferase An enzyme that catalyzes the addition of a glycosyl group from a uracyl-diphosphate (UDP) sugar molecule to a small hydrophobic (water hating) fatty acid chain

Varroa destructor An external parasitic mite that can only lives attached to the body of honey bees, spreading varroosis disease and deformed wing virus in the colony or hive

Vector An agent or organism (invertebrate arthropod such as insect) that carries and transmits an infectious pathogen responsible for epidemic disease into another living organism such as human

Visual pigment (rhodopsin) A G-protein coupled receptor molecule consisting of a protein (opsin) and a vitamin A-derived chromophore (11-cis retinal) that plays a key role in image formation in visual receptor neurons in both *Drosophila* and human eyes

Volatile organic compound (VOC) An organic chemical that has a high vapor pressure and low boiling point at normal temperature, which causes the chemical molecule to easily change to gas from the liquid or solid site of production and evaporate into the surrounding air (volatility); it probably includes most naturally-occurring odorants, most scents, odors or perfumes that play a key role in communication between plants and between plants and other organisms (including insects); for instance, specific subset of VOCs or green leaf volatiles that are released by damaged plants upon herbivore attacks in order to attract the herbivore natural enemy (predator) while alerting the other plants about the herbivore attacks

Voltage clamp An electrophysiological method for measuring the current across a cell membrane at a fixed voltage across the membrane

Wolbachia The most common inherited parasitic endosymbiotic bacterial species naturally present in more than 60% of insect species (including wasps and mosquitoes); the *Wolbachia*-mediated infection can result in cytoplasmic incompatibility and embryonic mortality in specific insect pest species

Xenobiotic A drug chemical substance that is foreign (exterior) to a biological system

Xenobiotic metabolizing enzyme A family of enzymes that modulate cellular interaction with environmental xenobiotic chemicals (insecticides or toxic pollutants) by degradation or modification (recycling) of the xenobiotic chemical structure

Zeitgeber An external environmental factor (e.g. length of daylight or temperature) that helps setting (or re-setting) the rythm of a biological clock