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Insect Sex Pheromone Research and Beyond

From Molecules to Robots

Springer

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Aims and Scope of This Book

Background

Female moths were suggested more than 100 years ago to release a kind of scent, which humans cannot detect, to attract conspecific males from a long distance (Fabre 1913); however, chemical identification of the "scent" remained impracticable for a long time because of the extremely small quantity of the compound produced by the females. The first identification of the attractive compound, bombykol, from the silk moth *Bombyx mori* had to wait for the breakthrough made by Butenandt et al. (1959). In view of potent attractancy, high species specificity, relatively simple structure, and nonhazardous nature of the new class of biologically active compounds, "sex pheromones" (Karlson and Lüscher 1959), researchers soon considered the use of synthetic sex pheromones as a measure to control agricultural pest moths. Accordingly, efforts have been made to identify sex pheromones of many pest moth species. Currently, sex pheromones of approximately 700 moth species have been identified (Ando and Yamamoto 2019), and their use is an indispensable measure in integrated pest management of moths, as exemplified by their large-scale use in the control of codling moth *Cydia pomonella* and gypsy moth *Lymantria dispar* (Witzgall et al. 2010). The increase in knowledge on the sex pheromones of moth species aroused interest in the sex pheromones of non-lepidopteran insects such as flies, cockroaches, longhorn beetles, seed beetles, aphids, and mealybugs.

In addition to their application in pest control, sex pheromones attracted the interest of researchers in many fields of basic biology such as reproductive isolation, speciation, signal transduction, biosynthesis, hormonal control of production, and neural mechanisms that enable efficient finding of female moths from a long distance. *B. mori* has also been frequently used in these lines of research because of their ease of culture, availability of many strains and mutants, genome data, and molecular biological techniques that cannot be applied to other moth species. It is of note that several epoch-making findings, such as the identification of pheromone biosynthesis-activating neuropeptide (PBAN)(Kitamura et al. 1989; Nagasawa et al. 1988), fatty-acyl-CoA reductase, a key enzyme involved in sex pheromone biosynthesis (Moto et al. 2003), and sex pheromone receptor (Sakurai et al. 2004), were all from *B. mori*.

Aims and Scope

This book aims to give an overview of the recent progress in insect sex pheromone research, which spans from their identification, biosynthesis, and reception to the control of odor-source searching behavior and from molecules to robots. To achieve this aim, this book summarizes the progress of studies conducted using *B. mori* and a few groups of moths on the one hand and reviews sex pheromones of some non-lepidopteran insect groups of agricultural importance on the other. It should be noted that although application of sex pheromones in the control of agricultural pests is an important outcome of insect sex pheromone research, I did not intend to make this book comprehensive in terms of this aspect because excellent reviews and books are amply available (e.g., Baker et al. 2016; Kydonieus 2019; Mitchell 2012; Saha and Chandran 2017; Suckling 2015; Tabata 2018; Witzgall et al. 2010).

Organization of This Book

This book consists of four parts: "Chemistry of Sex Pheromones" (Part I), "Biosynthesis of Sex Pheromones" (Part II), "Reception of Sex Pheromones" (Part III), and "Mechanisms Controlling Behavior and Its Application to Robotics" (Part IV).

Part I overviews mainly the chemical aspects of lepidopteran and non-lepidopteran sex pheromones. In Chap. 1, classification of lepidopteran sex pheromones (Type 0, Type I, Type II, and Type III), which has become both possible and necessary due to the increase in knowledge of their chemical structures (Ando and Yamamoto 2019; Allison and Cardé 2016), is discussed with reference to their possible evolutionary history. Chapter 2 deals with the evolution of sex pheromone communication systems in hawk moths, a large group of moths with both nocturnal and diurnal species, varying life cycles, and unique flight behavior (hovering at flowers). In the following Chaps. 3, 4, and 5, sex pheromones of mealybugs, seed beetles, and longhorn beetles, non-lepidopteran insects for which knowledge of their sex pheromones has rapidly expanded, are described in detail. The readers can learn the similarities and dissimilarities of chemicals used as sex pheromones in these groups of insects and those used in lepidopteran species.

Part II summarizes our current knowledge on hormonal control of pheromone production and enzymes involved in the biosynthesis of sex pheromone components in moths. In Chap. 6, the progress in understanding the control of pheromone biosynthesis in *B. mori* is described in detail from the identification of PBAN to the elucidation of the signal transduction cascade that leads to the production of sex pheromone. Chapter 7 describes our current knowledge of sex pheromone biosynthetic pathways in a group of closely related moths, *Ostrinia* spp., which underlie the production of species-specific sex pheromones in terms of the combination of components and/or their blend ratios. In the last chapter of this part (Chap. 8), recent identification of an epoxidase, which functions in the last step of so-called Type II sex pheromone biosynthesis, is reported.

Part III deals with the molecular mechanisms of sex pheromone reception in moths, which underlie the ultrasensitive and highly specific detection of conspecific sex pheromone molecules (Chap. 9), evolutionary history of lepidopteran genes associated with sex pheromone recognition (Chap. 10), and the application of sex pheromone detection systems in sensing technologies (Chap. 11).

Part IV comprises three chapters, which deal with mechanisms controlling behavior and its application to robotics. The neuronal mechanisms that generate locomotor command for pheromone-source localization, which underlie sophisticated olfactory navigation tactics in *B. mori*, are discussed in Chap. 12. In Chap. 13, progress in comparative and evolutionary studies on sex pheromone preference coding in male moths is overviewed. The last chapter of this book (Chap. 14) reviews the searching strategy of *B. mori* in terms of the integration of visual and olfactory information and also introduces studies using a silk moth-driven hybrid robot, which revealed how silk moths adaptively behave under challenging circumstances.

The chapters of this book are arranged as indicated above with a clear intention; however, the readers may start reading from any chapter depending on their interest because each chapter is independent and provides the necessary background to understand the content. In order for the readers to feel the exciting and rapid progress in insect pheromone research, I invited authors who are on the cutting edge of their respective research fields. I hope this book gives the readers an overview of the forefront of insect sex pheromone research.

Tokyo, Japan Yukio Ishikawa
November 2019

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