Insect Midgut as a Site for Insecticide Detoxification and Resistance

GUY SMAGGHE and LUC TIRRY

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1 Introduction

Pesticide resistance is a severe and important problem in situations where mainly chemicals are used to kill pests. However, apart from the economic, social and environmental costs associated with this problem, resistant insects and mites are a physiological marvel. Some strains have become so resistant to a given insecticide that they can survive exposure to virtually any dose. So there are numerous reasons for studying the underlying mechanisms by which insects become resistant to insecticides. Such studies are important for both the applied and basic aspects of insecticide resistance, as well as providing valuable information for workers in allied fields. For instance, if the biochemical basis of the resistance can be determined, then it may be possible to design a highly sensitive monitoring technique, which is one of the key factors in developing successful resistance management programs.

In order to exert activity, insecticide molecules have to enter the body and cross several barriers before arriving at their target site(s) of action. In the insect body, they can reversibly be absorbed by all kinds of tissue components, detoxified, and finally excreted via the feces, either unchanged or after metabolic conversion. The toxic effect exerted by a certain quantity of a chemical depends then on its intrinsic reactivity with the target site(s) of action, and on the time-course of its concentration at the target site.

For the purpose of this chapter, we focus on the insect midgut since it plays a major role in the buildup of toxicity for insecticides, it can serve as a target tissue for novel insecticidal modes of action, and modified midgut activities may imply resistance development.

The midgut epithelium is the first physical barrier after oral intake and it is a tissue that contains an armory of digestive enzymes that is needed for food conversion in nutrients but that also detoxifies insecticides. After a brief introduction on the midgut structure and its enzymatic capacity, we will discuss in more detail the significance of metabolic enzyme systems in the insect gut that
lead to resistance, particularly for different groups of insect growth regulators (IGRs).

Then, we survey and discuss the penetration process through the gut epithelium for several insecticides of various groups, followed by their translocation in the insect body and then the impact of excretion via the feces on their toxicity. Subsequently, we attempt to describe these processes as far as possible in quantitative terms for developing a theoretical model of the digestive-absorption architecture of the insect midgut.

Finally, we present some current and potential contributions of physiological and biochemical techniques using insect midgut to test and screen new insecticide activities and resistance. Interference by insecticide components in the midgut morphology or activities can be the basis of new insecticide actions, leading to inhibition of feeding, thus reducing crop damage, or to lethality. Good examples in this field are *Bacillus thuringiensis* insecticidal crystal proteins and digestive enzyme inhibitors. Together, these assays offer valuable tools for research in many areas: basic biochemical and physiological processes in the insect midgut, mode of action of insecticides, evolution, metabolism, pharmacokinetics and molecular genetics of insecticide resistance.

2 The Insect Gut: a Natural Digestive-Absorption Architecture

Structurally, the insect gut or the alimentary food canal is composed of three separate elements: the stomodaeum, or foregut, and proctodaeum, or hindgut, arise as invaginations of the embryonic ectoderm; the midgut (mesenteron) is endodermal in origin (Fig. 1). However, it should be noted that a great diversity of form and function among insects and developmental stages exists (Grasse 1949, 1951; Chapman 1985b; Lehane and Billingsley 1996). These three elements join together to form a continuous tube late in the embryonic development in nearly all insects. The epithelium which forms the alimentary canal consists of a single layer of cells irrespective of its embryonic origin. For fore- and hindgut, these ectodermal epithelial cells produce a cuticular lining that is shed and renewed at each molt. Midgut cells are specialized in the production and secretion of digestive enzymes and in the absorption of nutrients. In the hindgut resorption of water and salts, amino acids and sugars is performed before excretion of the feces. The foregut is concerned with ingestion of food and passing it back to the midgut. The different elements are connected with each other with sphincter-like structures. The Malpighian tubules open at or near the junction of the mid- and hindgut.

Typically, the midgut cells do not produce a cuticle but a delicate peritrophic membrane which acts as a lining of the midgut and which compartmentalizes the midgut into an endoperitrophic and ectoperitrophic region (Terra and Ferreira 1994; Chapman 1985b). Production of this chitin-protein matrix is