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Food Uptake and Utilization

1. Introduction

Insects feed on a wide range of organic materials. About 75% of all species are phytophagous, and these form an important link in the transfer of energy from primary producers to second-order consumers. Others are carnivorous, omnivorous, or parasitic on other animals. In accord with the diversity of feeding habits, the means by which insects locate their food, the structure and physiology of their digestive system, and their metabolism are highly varied.

The feeding habits of insects take on special significance for humans, on the one hand, because of the enormous damage that feeding insects do to our food, clothing, and health, and, on the other, because of the massive benefits that insects provide as plant pollinators during their search for food (see also Chapter 24). In addition, because many species are easily and cheaply mass-cultured in the laboratory, they have been used widely in research on digestion and absorption, as well as in the elucidation of basic biochemical pathways, the role of specific nutrients, and other aspects of animal metabolism.

2. Food Selection and Feeding

Distinct visual, chemical, and mechanical cues act at each step of the food location and ingestion process. These steps include attraction to food, arrest of movement, tasting, biting, further tasting as ingestion begins, continued ingestion, and termination of feeding. The sensitivity of the insect to these cues varies with its physiological state. For example, a starved insect may become highly sensitive to odors or tastes associated with its normal food, and in extreme cases may become quite indiscriminate in terms of what it ingests. On the other hand, a female whose abdomen is full of eggs is normally "uninterested" in feeding.

In some plant-feeding (phytophagous) species, visual stimuli such as particular patterns (especially stripes) or colors may serve to initially attract an insect to a potential food source. Usually, however, the initial orientation, where this occurs, is dependent on olfactory stimuli. In many larval forms there appear to be no specific orienting stimuli because, under normal circumstances, larvae remain on the food plant selected by the mother prior

to oviposition. In the migratory locust, on which much work has been done, olfaction is of primary importance in food location. Once the insect makes contact with the vegetation, tarsal chemosensilla initiate a reflex that results in the stoppage of movement. Sensilla on the labial and maxillary palps then taste the surface waxes of the plant, after which the locust takes a small bite. Whether feeding continues is sometimes determined by mechanosensillar responses to physical stimuli such as the hardness, toughness, shape, and hairiness of the food. More commonly, it is substances in the released sap that, by stimulating chemosensilla in the cibarial cavity, regulate the continuation or arrest of feeding (Chapman, 2003). These substances are called "phagostimulants" or "deterrents," respectively. The substances may have nutritional value to the insect or may be nutritionally unimportant ("token stimuli"). Nutritional factors are almost always stimulating in effect. Sugars, especially sucrose, are important phagostimulants for most phytophagous insects. Amino acids, in contrast, are generally by themselves weakly stimulating or non-stimulating, though may act synergistically with certain sugars or token stimuli. For example, Heron (1965) showed in the spruce budworm (*Choristoneura fumiferana*) that, whereas sucrose and L-proline in low concentration were individually only weak phagostimulants, a mixture of the two substances was highly stimulating. In addition to sugars and amino acids, other specific nutrients may stimulate feeding in a given species. Such nutrients include vitamins, phospholipids, and steroids. Token stimuli may either stimulate or inhibit feeding. Thus, derivatives of mustard oil, produced by cruciferous plants, including cabbage and its relatives, are important phagostimulants for a variety of insects that normally feed on these plants, for example, larvae of the diamondback moth (*Plutella xylostella*), the cabbage aphid (*Brevicoryne brassicae*), and the mustard beetle (*Phaedon cochleariae*). Indeed, *Plutella* will feed naturally only on plants that contain mustard oil compounds. Many secondary plant metabolites, including alkaloids, terpenoids, phenolics, and glycosides, are feeding deterrents for phytophagous insects. In a given food source there will probably be a mixture of phagostimulants and deterrents, and the balance of this sensory input, integrated through the central nervous system, determines the overall palatability of the food.

Species whose choice of food is limited are said to be oligophagous. In extreme cases, an insect may be restricted to feeding on a single plant species and is described as monophagous. Species that may feed on a wide variety of plants are polyphagous, though it must be noted that even these exhibit selectivity when given a choice. Not surprisingly, monophagous and oligophagous species are especially sensitive to the presence of deterrents in non-host plants.

In many predaceous insects, especially those that actively pursue prey, vision is of primary importance in locating and capturing food. As noted in Chapter 12 (Section 7.1.2), some predaceous insects have binocular vision that enables them to determine when prey is within catching distance. Carnivorous species, especially larval forms, whose visual sense is less well developed, depend on chemical or tactile stimuli to find prey. For example, many beetle larvae that live on or in the ground locate prey by their scent. Species parasitic on other animals usually locate a host by its scent, though tsetse flies may initially orient by visual means to a potential host. For many species that feed on the blood of birds and mammals, temperature and/or humidity gradients are important in determining the precise location at which an insect alights on a host and begins to feed.

The extent of food specificity for carnivorous insects is varied. Many insects are quite non-specific and will attempt to capture and eat any organism that falls within a given size range (even to the extent of being cannibalistic). Others are more selective; for example, spider wasps (Pompilidae), as their name indicates, capture only spiders for provisioning