Lec. 3/ Advanced insect physiology

3/15/2024

Digestive system: Alimentary canal and modification

One of the major reasons for the biological success of insects is their ability to eat, digest, and utilize an enormous diversity of foods. This ability allows the extreme diversity observed in the modification and specializations of the alimentary system of insects. The structural and biochemical modifications of the alimentary system of a particular species depends upon the type of food eaten. There are structural and functional differences in the way foods are obtained, stored, processed, and absorbed between the sexes, e.g., caterpillars chew up plant material, whereas adults suck up only floral nectar and female mosquitoes suck up a vertebrate blood, whereas males suck up plant sap.

Alimentary canal

The insect's digestive system is a closed system, with one long enclosed coiled tube called the alimentary canal which runs lengthwise through the body. The alimentary canal only allows food to enter the mouth, and then gets processed as it travels toward the anus. The insects alimentary canal has specific sections for grinding and food storage,enzyme production and nutrient absorption. Sphincters control the food and fluid movement between three regions. The three regions include the foregut (stomodeum), the midgut (mesenteron), and the hindgut (proctodeum).

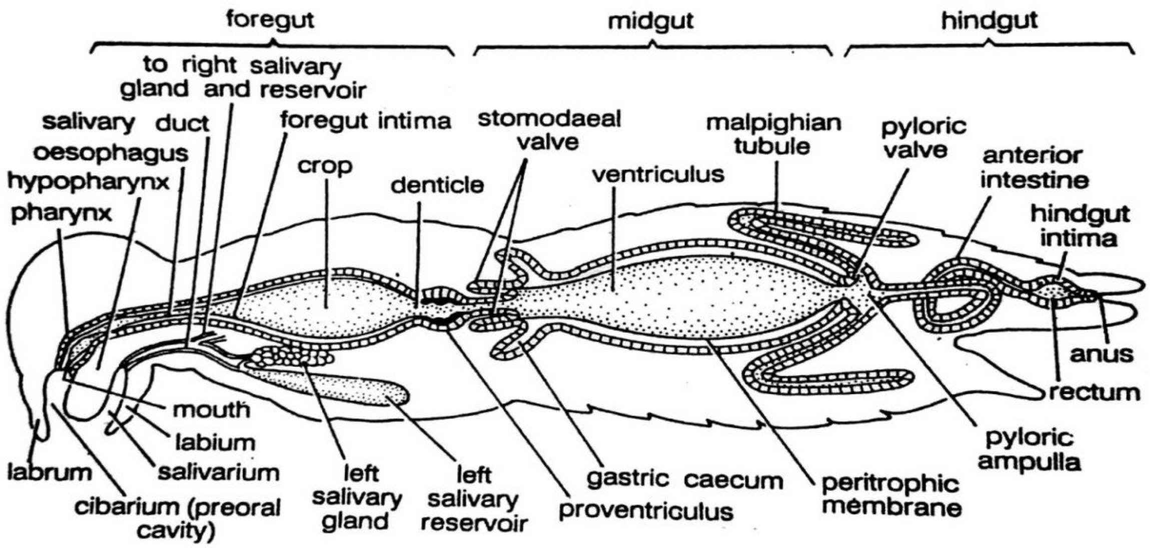

Fig.1 Alimentary canal of a generalized insect

In addition to the alimentary canal, insects also have paired salivary glands and salivary reservoirs. These structures usually reside in the thorax (adjacent to the fore gut). The salivary glands produce saliva, the salivary ducts lead from the glands to the reservoirs and then forward through the head to an opening called the salivarium behind the hypopharynx, which movements of the mouthparts help mix saliva with food in the buccal cavity. Saliva mixes with food which travels through salivary tubes into the mouth, beginning the process of breaking it down.

The stomodaeum and proctodeum are invaginations of the ectoderm and are lined with chitinous intima, which is continuous with the cuticle of the integument and therefore at the moult both foregut and hindgut and their contents are shed. The mesenteron is derived from endoderm and not lined with cuticle but with rapidly dividing and therefore constantly replaced, epithelial cells. The cuticle sheds with every moult along with the exoskeleton. Food is moved down the gut by muscular contractions called peristalsis.

Foregut or stomodeum

An insect's mouth, located centrally at the base of the mouthparts, is a muscular valve (sphincter) that marks the "front" of the foregut. Food in the buccal cavity is sucked through the mouth opening and into the pharynx by contractile action of cibarial muscles. These muscles, located between the head capsule and the anterior wall of the pharynx, create suction by enlarging the volume of the pharynx (like opening a bellows). This "suction pump" mechanism is called the cibarial pump. It is especially well developed in insects with piercing/sucking mouthparts. From the pharynx, food passes into the oesophagus by means of peristalsis(rhythmic muscular contractions of the gut wall).

The oesophagus is just a simple tube that connects the pharynx to the crop. Food remains in the crop until it can be processed through the remaining sections of the alimentary canal. While in the crop, some digestion may occur because of salivary enzymes that were added in the buccal cavity and/or other enzymes regurgitated from the midgut.

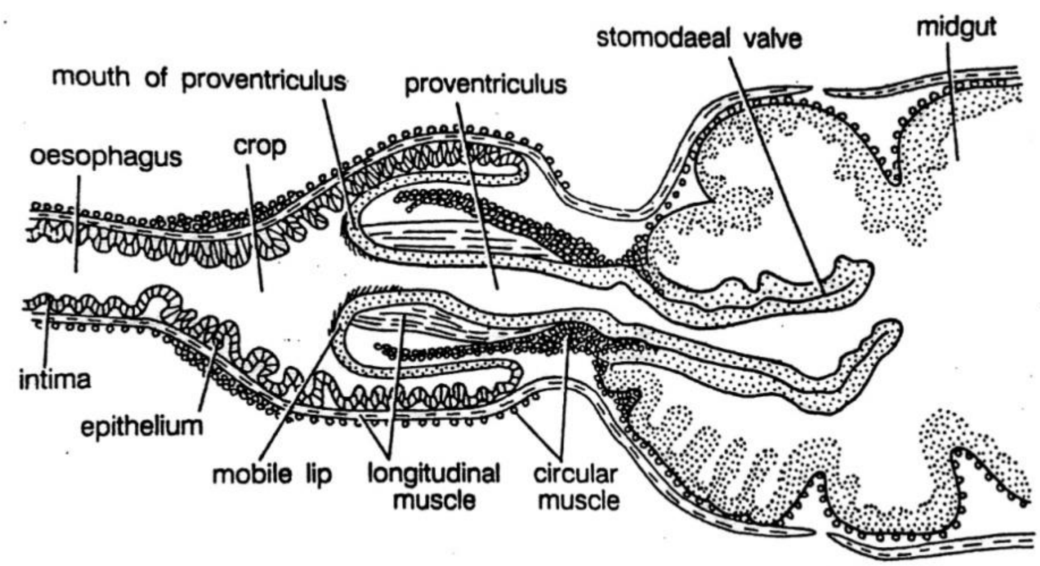

Fig.2 Longitudinal section of the proventriculus of honeybee

In some insects, the crop opens posteriorly into a muscular proventriculus or gizzard. It is absent in fluid feeder but is well developed in orthoperiod insects (e.g., cockroach). This organ contains tooth like denticles that grind and pulverize food particles. The proventriculus, regulates the flow of food from the stomodeum to the mesenteron. The hard denticles inside the proventriculus are made from the intima.

Midgut or mesentron or ventriculus

The midgut begins just past the stomodeal valve. Near its anterior end, fingerlike projections (usually from 2 to 10) diverge from the walls of the midgut. These structures, the gastric caecae, provide extra surface area for secretion of enzymes or absorption of water (and other substances) from the alimentary canal. The rest of the midgut is called the ventriculus -- it is the primary site for enzymatic digestion of food and absorption of nutrients. Digestive cells lining the walls of the ventriculus have microscopic projections (microvilli) that increase surface area for nutrient absorption.

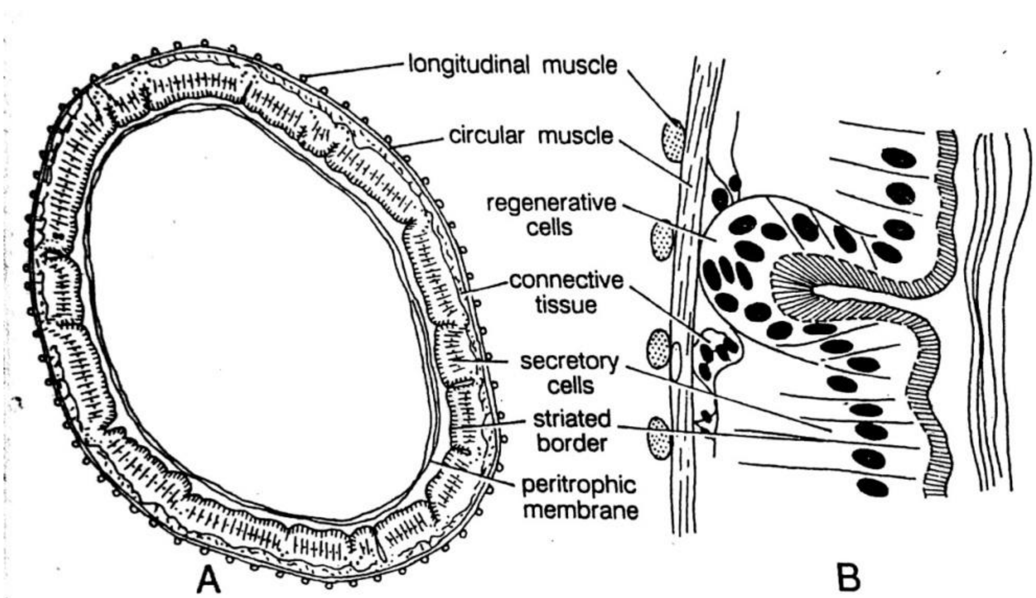

Fig.3 (A) Transverse section of midgut. (B) A section of midgut highly magnified

The midgut epithelium of most insects is composed of three basic cell types:

1- columnar digestive cells with microvilli forming a striated border regenerative cells and endocrine cells.

2- The basal plasma membrane of digestive cells is characteristically infolded, and mitochondria are associated with these folds. These cells are involved in the synthesis of digestive enzymes and absorption of digestive food

3- Epithelial cells are small, at the bases of the midgut regenerative cells or replacement cells. These cells replace the actively functioning gut cells that die

The midgut is derived from embryonic endoderm, so it is not protected by an intima. Instead, the midgut is lined with a semippermeable membrane secreted by a cluster of cells (the cardial epithelium) that lie just behind the stomodeal valve. This peritrophic membrane consists of chitin fibrils embedded in a protein carbohydrate matrix. It protects the delicate digestive cells without inhibiting absorption of nutrient molecules. The bugs, which are fluid feeders lack a peritrophic membrane.

The posterior end of the midgut is marked by another sphincter muscle, the puloric valve. It regulates the flow of material from the mesenteron to the proctodeum.

The plant bugs in order to obtain adequate quantity of nutrients ingest large amount of sap. In them, the gut is modified to provide the rapid elimination of the excess of water taken in to avoid excessive dilution of the haemolymph and to concentrate the food to facilitate enzyme activity. In leaf hoppers and aphids, the rapid removal of water to the rectum is achieved by the anterior midgut forming a large thin-walled bladder which is closely bound to anterior hindgut and malphighian tubules by its own basement membrane. The chamber formed within this fold is called the filter chamber.

Hindgut or proctodeum

The hindgut is composed of cuboidal epithelial cells and is lined by a layer of cuticle which is thinner and more permeable than that of the foregut. The pyloric valve serves as a point of origin for dozens to hundreds of malpighian tubules, these long, spaghetti like structures extend throughout most of the abdominal cavity where they serve as excretory organs, removing nitrogenous wastes (principally ammonium ions, NH_4^+) from the haemolymph. The toxic NH_4^+ is quickly converted to urea and then to uric acid by a series of chemical reactions within the malpighian tubules. The uric acid, a semi solid accumulates inside each tubule and is eventually emptied into the hindgut for elimination as part of the faecal pellet.

The hindgut is divided into three sections; the anterior is the ileum, the middle portion, the colon, and the wider, posterior section is the rectum. This extends from the pyloric valve which is located between the mid and the hindgut to the anus. The rectum usually contains a number of pads or papillae (usually six) that project into the lumen. These structures receive an extensive supply of tracheae and are metabolically very active. They play an especially important role in the excretory system.

Functions of the hindgut include the following:

i. Water absorption from urine and faeces,

ii. Ion absorption from urine and faeces,

iii. Cryptonephridial system for water conservation.

iv. Modifications in structure for housing symbiotic microorganisms (e.g., termites).

Salivary glands

Although there may be glands associated with the mandibles (e.g.silver fishes, queen honeybee), maxillae (e.g. proturans, spring tails), and hypopharynx (e.g.

worker honeybee), salivary glands are typically associated with the labial segment. The salivary glands or labial glands are paired structure lie ventral to the foregut in the head and thorax and occasionally extend posteriorly into the abdomen. Depending on the type of food eaten and the insect species involved salivary glands vary in size, shape and the type of secretion produced.

Two basic types of salivary glands exist:

a) Acinar (The acinar gland of insects with the acini structures resemble the appearance of a bunch of grapes, e.g., Orthoptera and Dictyoptera)

b) Tubular (e.g., Diptera, Lepidoptera and Hymenoptera)

In the acinar type of each acinus bears a tiny duct that communicates with other similar ducts, eventually forming a lateral salivary duct. Lateral salivary ducts run anteriorly and merge as the common salivary duct, which empties between the base of the hypopharynx and the base of the labium. This region is called the salivarium and in some sucking insects forms a salivary syringe that injects saliva into whatever is being pierced. The lateral salivary ducts may communicate with salivary reservoirs, as in the cockroaches

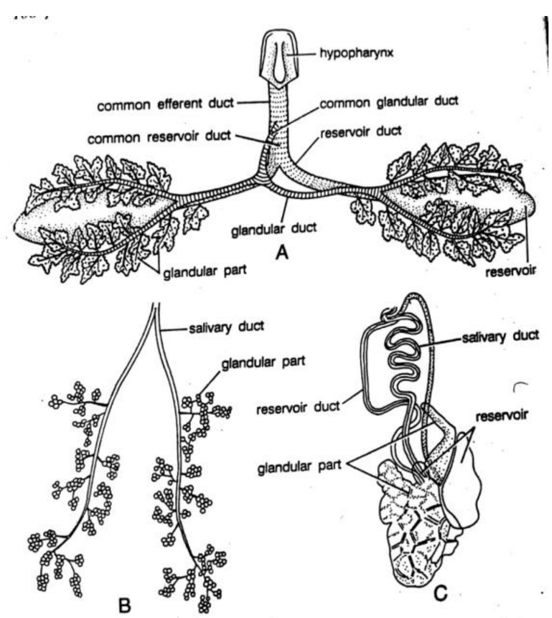

Fig.4 (A) Salivary glands of cockroach, (B) grasshopper and (C) red cotton bug

Functions of salivary gland:

The secretory products of the salivary glands are generally clear fluids that serve a variety of functions in different insect

1. They moisten the mouthparts and serve as a lubricant
2. They act as a food solvent
3. They serve as a medium for digestive enzymes and various anticoagulins and agglutinins.
4. They secrete silk in larval Lepidoptera (caterpillars) and Hymenoptera (bees, wasps and relatives)
5. They are used to flue puparial cases to the substrate in certain flies
6. They serve for the production of toxins.
7. They secret antimicrobial factors (e.g. in certain blow fly larvae).

Amylase and invertase are the most common enzymes found in saliva of insects however the saliva may also contain lipase and protease. Aphids secrete a pectinase that aids their mouthparts in the penetration of plant tissues.

The Production and secretion of saliva in the dragonflies, grasshoppers and cockroaches are regulated by nervous innervations from both the stomatogastric nervous system and the subesophageal ganglion whereas in the Diptera (e.g. the adult blow fly) these glands are controlled by an unidentified neurohormone.

Salivation has been shown to be controlled by phagostimulation of external chemoreceptors on the mouthparts. This same stimulus probably also activates the salivary pump.

Physiology of digestion, including special foods

In fluid feeders, digestion may begin before the food is ingested through the injection or regurgitation of enzymes on to the food, or in foregut but in general most digestion occurs in the midgut where most of the enzymes are produced. In insects having biting and chewing type of mouthparts, food is masticated not only in the buccal cavity but also in the proventriculus. This not only facilitates passage through the alimentary canal but increases the surface area for enzymatic action. Digestion takes place by a series of progressive enzymatically catalysed steps, each producing a simpler substance until molecules of absorbable size or nature are produced.

Extra intestinal digestion

Digestion of the food taking place outside the alimentary canal before the food is ingested is known as extra intestinal digestion. It happens with fluid feeders where salivary enzymes are injected onto the food (e.g., house fly) or into the host in predatory or parasitic insects for example, assassin bugs inject saliva into the prey which histolyses the contents before ingestion.

Intestinal digestion

In general, most of the digestion occurs in the midgut where enzymes are secreted however, some digestion also takes place in foregut, particularly in crop, where midgut enzymes are regurgitated into it. In locust, the major proportions of digestion take place in crop.

The enzymes synthesized in the midgut depend upon the diet. For example, insects feeding protein diet proteases are important, whereas a nectar feeding butterflies they are absent. Aphids feeding on phloem sap having no polysaccharides or proteins lack enzymes and proteinase but have invertase.

Digestion of carbohydrates

Carbohydrates are generally absorbed as monosaccharides so that, before they are absorbed, disaccharides and polysaccharides must be hydrolyzed to their component monosaccharides.

Polysaccharides: Starch, glycogen, chitin, and cellulose are the major polysaccharide food to be digested by different insects. Starch (amylose) is hydrolyzed to maltose, and glycogen to glucose by the action of amylase, which specifically catalyses the hydrolysis of 1,4-α-glucosidic linkage in polysaccharides. The major portion of the food of phytophagous and xylophagous insects contains cellulose, only few insects (Ctenolepisma, Schistocerca and some psocids) are able to secrete cellulase.

The insects unable to secrete cellulose, either cellulose is excreted as such or they harbour microorganisms(Bacteria, flagellates) to secrete cellulase.

Other polysaccharides, viz., chitin, lignocelluloses and hemicelluloses are digested by chitinase, lignocellulase and hemicellulase, respectively.

Disaccharides: The common disaccharides in the food are maltose, trehalose, sucrose, cellobiose, melibiose and lactose that contain a glucose residue which is linked to a second sugar residue by either α-linkage and β-linkage. In the hydrolysis water molecule is the typical acceptor for the sugar residues as follows :

Maltose +H2O maltase Glucose + Glucose

Trehalose + H2O trehalose Glucose + Glucose

Sucrose + H2O sucrase Glucose + Fructose

Cellobiose + H2O cellobiase Glucose + Glucose

Melibiose + H2O melobiase Galactose + Glucose

Lactose + H2O lactase Glactose + Glucose

Digestion of proteins: Insects possess a series of proteases. A trypsin like proteinase is secreted in the midgut which hydrolyses protein to peptones and polypeptides. The products are then broken down by peptidases.

It indicates that most of the polypeptides are absorbed before being further digested to amino acids. Certain insects can digest ordinarily stable proteins. For example, chewing lice and a few other insects can break down keratin a protein that occurs in hair and feathers.

Digestion of lipids: Many insects secrete lipases which hydrolyse fats to fatty acids and glycerol. Wax moth (*Galleria*) can digest beeswax (a mixture of esters, fatty acids and hydrocarbons). The insect is known to produce not only the lipase, but also lecithinase and cholinesterase with the help of bacteria. Midgut pH (typically pH 6-8) buffering capacity, oxidation reduction potential and temperature are important factors in the digestive process. These factors vary from species to species and may also vary from one region of the another within the same insect.

Absorption of the digested food

The midgut is the major site of absorption. In hindgut only reabsorption of urine components occur while in foregut no absorption takes place. All the substances are absorbed in solution and no phagocytosis of food particles occurs. There are three major factors that affect the absorption of digested food materials:

I. The presence of microvilli, which increase the surface area for absorption,

II. The functional differences in membrane permeability of various regions of the digestive tract.

III. The presence of a counter current.

Absorption may be active or passive. Passive absorption takes place from the higher concentration inside the lumen of the gut to lower one (inside the gut epithelium). Active absorption depends on some metabolic process for movement of a substance against a concentration or electrical gradient.

Carbohydrate: Carbohydrates are mainly absorbed as monosaccharides that diffuse concentration gradients between the midgut lumen and haemolymph. The diffusion of simple sugars like glucose and fructose is enhanced by the rapid conversion of these sugars to trehalose in the fat body a process called facilitated diffusion that maintains a concentration gradient across the gut epithelium. Some insects can absorb disaccharides as such.

Proteins: Proteins are absorbed as amino acids after hydrolysis mainly in the midgut and caeca. Some amino acids in urine are also reabsorbed in hindgut. Insects are unique in that they maintain rather high levels of free amino acids stores in the haemolumph, thus many amino acids have to be actively absorbed against a concentration gradient. Some insects can absorb peptide fragments or even the protein as such e.g., midgut cells of a haemolymph bug *Rhodnius* absorb haemoglobin as such. Active absorption of amino acids varies among insect species and depends on the composition of the diet and the haemolymph.

Lipids: Like some disaccharides and proteins, lipids are also sometimes absorbed unchanged. The products of wax are absorbed in a phosphorylated form while cholesterol is esterised before absorption. The midgut caeca appear to be particularly active in lipid absorption, but in few insects like adult Hymenoptera, lipid is absorbed in hindgut.

Water: Water is absorbed mainly in midgut and also in hindgut either by diffusion or active transport depending upon the need of the insect as insects regulate the salt water balance very precisely. As the amount of food is very poor in the contents of phloem and xylem, insects feeding on them, e.g., plant bugs, in order to obtain sufficient amount of amino acids and other nutrients, they possess various mechanisms for concentrating the necessary nutrients from a dilute food source by eliminating water. The filter chamber, present in the Cicadoidea and Cercopidae (order Homoptera) is a modification of the anterior midgut, which in combination with the malpighian tubules facilitates water removal and concentration of the desired nutrients prior to absorption.

Inorganic ions: Inorganic ions are absorbed in the midgut and reabsorbed in the fluid in the rectum. Even in the midgut there are specified cells that absorb particular ions, e.g., Fe^{+2} and Cu^{+2}. All the three ions Na^{+}, K^{+} and Cl^{-} are absorbed actively as their concentrations is very high in haemolymph than the gut lumen. The active transport of Na^+ may play a key role in the diffusion of other molecules. When Na^+ molecules are pumped from the midgut cells into the haemocoel, they are replaced by Na^+ diffusing into the midgut cells from the lumen. The movement of Na^+ across the cells tends to produce a water gradient between the lumen and the cells concentrating water in the lumen. Hence, water would diffuse into the cells which, in turn, tend to concentrate other molecules that would then diffuse down gradients into the cells. It implies that the work necessary to produce the gradients for diffusion (a passive process) of water and other absorbable molecules would be the active transport of Na^+.

Regulation of the alimentary system/ metabolism

Regulation of the alimentary system in insects involves control of food movement, control of enzyme secretion, and control of absorption. The alimentary canal is regulated in part through the action of the stomatogastric nervous system. Food is ingested by the actions of the mouthparts, cibarium and pharynx and is typically stored in the crop. It is then released gradually, via the stomodeal valve, into the midgut where digestion and absorption occur. In most insects that have been studied stretch receptors associated with the crop provide information to the brain (via the frontal ganglion) regarding crop distension and help prevent overfilling of this organ. In some insects, stretch receptors in the abdominal wall have a similar role.

Control of passage of food from the crop to the midgut (rate of crop emptying) has been studied mainly in the cockroach, Periplaneta americana. Passage of food from the cockroach crop is inversely related to the osmotic pressure of the food, i.e., the higher the concentration of food, slower the passage. Osmotic receptors have been identified in the wall of the cockroach pharynx.

Two mechanisms for the control of enzymes secretion in the insect gut have been suggested: Secretogogue (a substance in the ingested material may stimulate enzyme secretion) and hormonal. The secretogogue control is an immediate response to food, whereas hormonal control is more related to developmental and environmental effects. Nervous control is highly unlikely because the midgut is sparsely innervated or not at all.

Absorption appears to be controlled by the availability of absorbable molecules, release of food material from the crop being so regulated that digestion and subsequent absorption occurs at an optimal rate for a given circumstance. Many insects ingest foods with a very high water content. Some of these insects (e.g., butterflies and many true flies) store the dilute food in the impermeable crop and pass it gradually to the midgut. In others (e.g., many blood feeding insects) food may go to the midgut where excess water is rapidly absorbed in the haemolymph and then excreted via the malpighian tubules. Both mechanisms probably prevent extensive dilution of the haemolymph and removal of water concentrates solid food increasing the efficiency of digestion. Movements of the alimentary canal (mainly foregut and hindgut) that complement the action of the digestive enzymes and help absorption are under neural or neurosecretory control in some insects. In others, having no neural connections, gut movements are assumed to be myogenic. Hormonal stimuli may also have a great deal to do with the rate of gut movement.

Insect nutrition

Like other animals, insects also require a balance diet having appropriate amount of proteins, amino acids, carbohydrates, lipids, vitamins, minerals etc. The dietary requirement of the insect is species specific. For the proper development and growth, the insects derived most of the nutrients either by taking food or from the stores inside the body (e.g. fat bodies), or as a result of synthesis (by the insect itself or through associated micro-organisms). Certain moths do not feed as adult, and the food accumulated during larval stages is used for their metabolic processes. All insects are able to synthesise nucleic acids, however only some insects are able to synthesise vitamins, non essential amino acids.

Amino acids: Amino acids are the building blocks of protein making the tissues and enzymes. Different insects have different requirements, depending upon which amino acids they are capable of synthesizing. Although some 20 amino acids are needed for protein production only ten are essential in the diet, the others can be synthesised from these ten. The ten essential amino acids are arginine, lysine, leucine, isoleucine, tryptophan, histidine, phenylalanine, methionine, valine and threonine. In addition to essential amino acids, few insects need glycine (e.g., flies) or alanine (e.g., Blatella) or proline (e.g., Phorima), however in these cases methionine is not essential.

In general the absence of any one of these essential acids prevents growth. Although other amino acids are not essential, they are necessary for optimal growth to occur because their synthesis from the essential acids is energy consuming and necessitates the disposal of surplus fragments (Dadd,1973). Consequently glutamic acid and aspartic acid are necessary in addition to the essential amino acids for good growth of Bombyx larvae and further improvement is obtained if alanine, glycine or serine are also present. Good growth of Mysus persicae depends on the presence of cysteine with glutamic acid, alanine or serine.

Carbohydrate: Carbohydrate are not considered to be essential nutritive substance for most insects, but they are probably the most common source of chemical energy utilised by insects. However, many insects (e.g., many moths) do, in fact, need them if growth and development are to occur normally.

Schistocerca for instance needs at least 20% sugar in an artificial diet for good growth. Tenebrio fails to develop unless carbohydrate constitutes at least 40% of the diet and growth is optimal with 70% carbohydrate. The carbohydrate may be converted to fats for storage or to amino acids. In the diet of Galleria carbohydrate can be entirely replaced by wax and this is also true in many Diptera, such as Musca. Larval Phorima which normally live in necrotic tissues containing little carbohydrate are adversely affected by any carbohydrate in the diet.

There may be differences in the ability of larvae and adults to utilise carbohydrates. For instance, the larva of Aedes can use starch and glycogen while the adult cannot.

Lipids: Lipids or fats, like carbohydrates are good sources of chemical energy and are also important in the formation of membranes and synthesis of steroid hormones. Most insects are able to synthesise lipids from carbohydrates and protein sources. However, some insect species do require certain fatty acids and other lipids in their diets. For example, certain Lepisoptera require linoleic acid for normal larval development. All insects need a dietary source of sterol (cholesterol, phytosterols or ergosterol) for growth and development. Carotenoids are necessary in the diets of all insects as the visual pigment retinene is derived from the food.

Vitamins: Vitamins are unrelated organic substances that are needed in very small amounts in the diet for the normal functioning of insects as they cannot be synthesised. They provide structural components of coenzymes. Vitamin A (fat soluble) is required for the normal functioning of the compound eye of the mosquito. Insects principally require water soluble vitamins (e.g., B complex vitamins and ascorbic acid). In the absence of ascorbic acid (vitamin C) locusts undergo abortive moults and dies.

Minerals: Like vitamins several minerals are required in traces by insects for normal growth and development, e.g., potassium, phosphorous, magnesium, sodium, calcium, manganese, copper, iron, chlorine, iodine, cobalt, nickel and zinc. The aquatic larvae of mosquitoes are able to absorb mineral ions from the water through the thin cuticle.

The nucleic acids: Nucleic acids (DNA and RNA) constitute the genetic material. Like other animals, insects are also able to synthesise them. However, dietary nucleic acids (e.g., RNA) have been shown to have an influence on growth of certain fly larvae.

Water: Like all animals, insects require water. Insects fulfil their water requirements from body, by drinking, from absorption through the cuticle (in aquatic forms) or from a by product of metabolism. Insects vary greatly with respect to amounts of water needed. Some, like the rice weevil *(Sitophilus oryzae)* can survive and reproduce on essentially dry food. Others, for example honeybees and house flies, require large amounts of water for survival. The excrement of the rice weevil is hard and dry with almost all the water absorbed by the insect, while the excrement of bees and house flies contains large amounts of water.

Types of micro-organism

The most commonly occurring micro-organisms in insects are bacteria or bacterium like forms which are found in Blattoidea, Isoptera, Homoptera, Heteroptera, Anoplura, Coleoptera, Hymenoptera and Diptera. In addition flagellates are found in wood eating cockroaches and termites, yeasts in Homoptera and Coleoptera and an actinomycete in Rhodnius. In many cases the precise nature of the micro-organisms is not known.

Location in the insect body

In some insects the symbionts are free in the gut lumen. This is the case with the flagellates which live in the hindguts of wood eating cockroaches and termites and with the bacteria living in the caeca of the last segment of the midgut in plant sucking Heteroptera. In Rhodnius, Actinomyces lives in crypts between the cells of the anterior midgut.

Most micro organisms are intracellular in various parts of the body. The cells housing the symbionts are known as mycetocytes and these may be aggregated together to form organs known as mycetomes.

Mycetocytes are large, polyploid cells occurring in many different tissues. Normally the micro organisms are incorporated into them when the cells are first differentiated in the embryo, but sometimes the cells develop for a time before they are invaded. Most commonly the mycetocytes are scattered through the fat body, as they are in cockroaches and coccids, but in *Haematopinus* (Siphunculata) they are scattered cells in the midgut epithelium and in other insects they may be in the ovarioles or free in the haemolymph.

The presence of microbes in the gonads ensures the infection of any egg produced thus transferring the microbes in next generation.

The wood eating cockroaches have two sets of symbionts : intestinal flagellates and intracellular bacteroids in the fat body. This situation also occurs in the termites *Mastotermes darwiniensis* but the remainder of the wood eating termites only retain the intestinal fauna.

The association of microbes with the insects may either be casual or constant. The microbes are almost present in food and are ingested by the insects during feeding, e.g., locusts. Such casual association with microbes are important in the nutrition of dung beetles that have fermentation chamber in the hindgut in which decaying food with its content of microbes is retained. The insects may have constant association with the microbes, e.g., insects feeding on wood, dry cereal, feather and hair.

The roles of microorganisms in the insect

It is known that the intestinal flagellates of cockroaches and termites are concerned with the digestion of wood and that they release products which can be utilised by the insect. The yeast of Stegobium (Coleoptera) provides vitamins and sterols, which may be secreted into the gut or released by the digestion of the micro organisms. There is some evidence that the micro organisms particularly those in Homoptera and Heteroptera are concerned with nitrogen metabolism (Toth, 1952).

In the coccid *Stictococcus sjoestedti* the bacterium like micro organism may be concerned with sex determination. In the mature insect mycetocytes invade the ovary but only infect those oocytes to which they are adjacent. Consequently two types of eggs are developed : those with and those without micro organisms. The eggs develop parthenogenetically and the uninfected eggs develop into males, while the infected ones give rise to females (Richards and Brooks, 1958).

Summary

The unit of the muscle between two Z lines is called a sarcomere.

- Digestive system composed of alimentary canal and various glands related with it either directly (salivary glands, gastric caeca) or indirectly (malpighian tubules).
- The salivary glands or labial glands are paired structure lie ventral to the foregut in the head and thorax and occasionally extend posteriorly into the abdomen.
- The most commonly occurring micro-organisms in insects are bacteria or bacterium like forms which are found in Blattodea, Isoptera, Homoptera, Heteroptera, Anoplura, Coleoptera,

Hymenoptera and Diptera. In addition flagellates are found in wood eating cockroaches and termites, yeasts in Homoptera and Coleoptera and an actinomycete in Rhodnius.

References

- **Elements of Entomology by Rajendra singh**
- http://bugs.bio.usyd.edu.au/learning/resources/Entomology/importance/importance.html
- http://www.shivrai.co.in/elearning/lesson_1.html