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MZOE-005: Insect Physiology and Toxicology
Guess Paper-1

Q1. What do you understand by cuticular modifications? Describe it with suitable examples.

Ans. Cuticular Appendages: These structures comprise all cuticle outgrowths that are connected to it by a membranous joint. They originate from modified epidermal cells. These are categorized into setae and spurs.

a) Setae, also known as hairs, are hollow structures which arise from cupshaped pits, or alveolus-like cup. They are produced, as extensions of exocuticle, by a single expanded hypodermal trichogen cell. The tormogen cell, as discussed in the previous section, typically produce articular membrane which attaches the seta at its base. Setae have a crucial taxonomic role and differ in various insect species (Fig.).

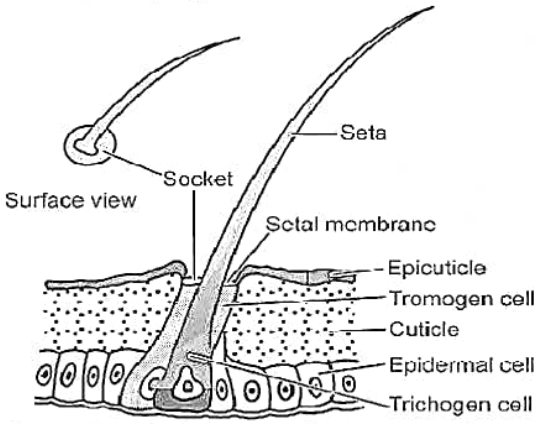

Fig.: A seta and its socket showing trichogen and tormogen cells

Various types of setae found in insects are given below.

- **Clothing hairs:** These cover the body's exterior or its appendages and usually display varying levels of specialisation. They are referred to as plumose hairs when they have branches that resemble threads, as in the Apoidea.
- **Bristles:** These are extremely robust and stiff setae, which are prominently displayed in certain families, like Tachinidae.
- **Scales:** Scales are essentially highly modified clothing hairs. These are a distinctive feature of Lepidoptera, Collembola, Coleoptera, Diptera, and Hymenoptera. Often transitional forms exist between the clothing hairs and the scales.
- **Glandular setae:** These are the setae that serve as the secretory exit of epidermal glands. They are regarded as glandular bristles if they are very stiff and robust, similar to the itchy hairs seen on some lepidopterous larvae.
- **Sensory Setae:** Often, the setae of specific body parts—especially the appendages—are modified in unique ways to acquire a sensory function. Sensory setae are associated with the neurological system.

b) Spur: Many insects have spurs on their legs, which are different from setae in being

Cuticular Processes: The exterior of the cuticle is not only sculptured in different ways, but it also has a wide range of outgrowths that are essential to its structure. They can easily be differentiated from cuticular appendages because they are firmly attached to the cuticle and lack a membranous articulation. The following are the main categories of cuticular processes.

- **Microtrichia:** Also known as fixed hairs or aculei, microtrichia are tiny structures that resemble hairs and are present on the wings of some Diptera. They lack the basal articulation, which gives them the appearance of extremely tiny covering hairs.
- **Spines:** They are cuticlular outgrowths that resemble thorns in some way. The production of spines from undifferentiated epidermal cells and their multicellular origins, typically if not always, set them apart from spine-like setae.

Q2. Write about the importance of integument in insects.

Ans. The integument of an insect is highly significant and plays an important role in their successful living on the Earth. It performs the following functions in an insect.

1. The integument provides protection and preservation of the interior organs.
2. It gives the insect a shape and limits the extents of an exoskeleton.
3. It provides a base for muscle insertions and, helps in mobility and flight.

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4. It is an important element in the defense of insects against various external factors, such as mechanical stresses, dry, wet, cold or hot environments. It also prevents the entry of extraneous substances like insecticides.
5. The waxy layer of the cuticle checks the loss of water and prevents desiccation.
6. Various cuticular structures provide sensory input, such as eyes, mechanoreceptors and chemoreceptors.
7. Other cuticular protuberances may help in oxygen retention, food grinding, body cleaning, etc.
8. It takes part in the transport of epidermal secretions, and acts as a chemical reservoir for the storage of metabolic wastes.
9. The coloration pattern and chemical components of the cuticle are important for thermoregulation and sometimes communication.

Q3. Define moulting. How and why does it occur in insects?

Ans. The body wall of insects has minimal tensibility due to the non-elastic structure of cuticle. Since the cuticle cannot grow and cannot even be stretched in more stiff portions like the head capsule or appendages, it needs to be shed periodically as the insect matures, making room for a new and larger cuticle. Moulting is the process of shedding the old cuticle which involves a sequence of events. These events can be categorized into three sub-processes.

a) Apolysis: Separation of old cuticle from the underlying epidermis.

b) Ecdysis: Shedding off the old cuticle.

c) Sclerotization: Chemical modification of the newly formed, soft and milky white cuticle to the dark and rigid cuticle.

However, the process of moulting includes a sequence of events which are discussed here and depicted in Figure 1.5.

Process of Moulting: During moulting, the intima, or lining, of the majority of the tracheal system, the fore and hind gut, the ectodermal glands, and the efferent reproductive ducts are shed together with the overall cuticle that covers the body and its appendages externally during each moult. All of them are replenished by the underlying epidermal cells, along with hairs, scales, and cuticular sensillae.

(a) Changes in the epidermis: When an insect is ready to shed its skin, it becomes less active. The epidermal cells start dividing mitotically resulting in the net increase in the total number of cells. The increase in cell density is accompanied by the changes in the cell shape. The epidermal cells usually become columnar and microvilli degenerate resulting in the increased size of cuticle.

(b) Apolysis: The changes in the shape of epidermal cells generate tension at the cell surface which causes its separation from the cuticle probably by withdrawing the cytoplasmic filaments from the pore canals. The space created between the epidermis and cuticle is called the exuvial or subcuticular space.

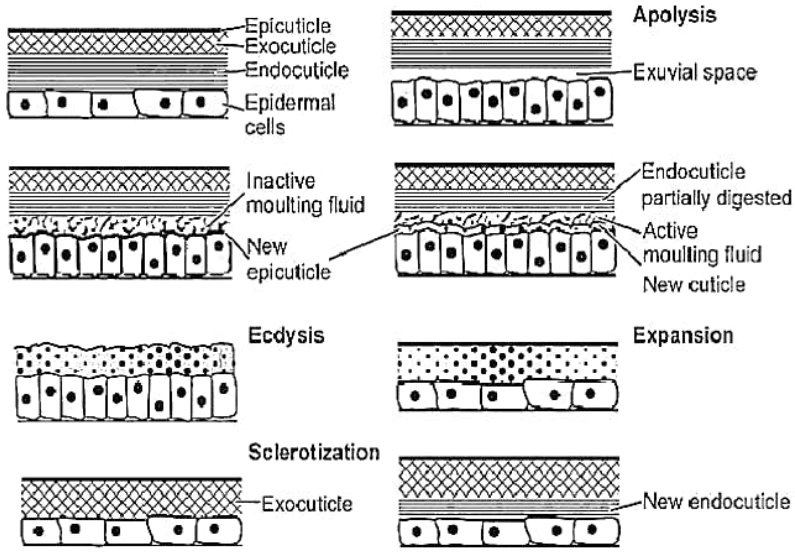

Fig.: Process of moulting in insects

(c) Secretion of moulting fluid: Before the cuticle is shed, the endocuticle is digested by enzymes secreted by the epidermal cells. This involves a mixture of enzymes including chitinases and peptidases. These enzymes are released in an inactive form and cannot digest the endocuticle. The fluid produced is called moulting fluid. The enzymes remain inactive until the new epicuticle is formed.

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(d) Formation of the new epicuticle: The outer epicuticle (cuticulin) is secreted first as the sporadic patches at the tips of microvilli of the epidermal cells. The patches grow and amalgamate to form a continuous layer over the epidermis. Thereafter, the ecdysial membrane is produced from the inner layers of the old endocuticle and becomes sclerotized probably due to the presence of polyphenols and phenoloxidases.

Once the outer epicuticle is complete, the inner epicuticle is secreted and the apical surfaces of the epidermal cells withdraw slightly. Shortly before ecdysis, wax is secreted onto the cuticular surface. Lipids are secreted by epidermal cells, most probably oenocytes, are released in the intercellular spaces.

(e) Digestion of old endocuticle: The enzymes become active and digest the unsclerotized cuticle except the ecdysial membrane, which is made of the procuticle's innermost layer. These enzymes do not affect the exocuticle, muscles and nerves connected to the old cuticle which help the insect to move and receive stimuli from the environment. The products of cuticular digestion are absorbed and the cuticle becomes very thin and weak along the ecdysial lines. In other words, these lines do not have the hardened exocuticle. Most insects have an inverted Yshape ecdysial lines along the head and prothorax.

(f) Ecdysis: After resorption of the moulting fluid and the products of digestion, the old cuticle consists of epicuticle and exocuticle which are separated from the new cuticle. The loosened old cuticle now breaks by the internal pressure exerted against it probably caused by increase in blood volume. It has been observed that insect swallows air or water leading to rise in the haemolymph pressure. The pumping of blood usually into the thorax exerts pressure on the old cuticle, because of which it splits along its ecdysial lines.

(g) Production of procuticle: New undifferentiated cuticle, sometimes called procuticle, is produced at this stage. Chitin microfibrils are produced on the epidermal cells while protein is released in the spaces between the fibrils. The zone of deposition of new cuticle is called Schmidt's layer.

(h) Splitting of old cuticle: Insect comes out as soon as the old cuticle splits, with head and thorax first, followed by the abdomen and appendages. During this process, insect sheds all the cuticular parts which apart from the integument, includes the lining of foregut, hindgut and major tracheae. The old cuticle shed by the insect is called an exuviae.

Q4. What is metamorphosis? Discuss its types with suitable examples

Ans. One of the most defining characteristics of insects is the fact that they hatch in a state that differs from the adult's morphological state. Metamorphosis (Gr. Meta- "changes" + morphe- "form") is a biological process in which insects change from one form to another and finally become adults. These changes are typically most noticeable near the conclusion of postembryonic development and are accompanied by physiological and biochemical changes.

Certain insects hatch from their eggs differently from the imago, primarily due to their immature reproductive organs and external genitalia, as well as minor morphological differences in shape, chaetotaxy (arrangement and nomenclature of bristles on the exoskeleton, important for insect taxonomy), and antennal and cerci segmentation. Apterygotes and secondary apterous exopterygotes, such as Mallophaga, Siphunculata, and female Embioptera, are examples of these insects. Although they are frequently thought to have no metamorphosis, the alterations listed above are typically enough to represent a minor metamorphosis. However, the majority of insects undergo a more significant metamorphosis, and these organisms are divided into two groups called as the hemimetabola and the holometabola.

The majority of exopterygotes are hemimetabolous insects, which undergo a straightforward metamorphosis that is frequently referred to as direct or incomplete.

The primary way in which the juvenile stages are different from the adult is that the wings and genitalia are only partially grown. Typically, wing rudiments are not evident during the first instar but later show up as exterior wing-pads that get bigger with each new moult. Compound eyes are virtually always present, the mouthparts have the same overall shape as in adults, and the habits of the young and adults are frequently similar. There is no pupal instar, although the juvenile stages are often called nymphs. The degree of metamorphosis which prevails in hemimetabolous insects varies among the different orders.

The Endopterygotes are holometabolous insects that undergo a complete or indirect metamorphosis. The life cycle includes a series of larval instars, with subsequent larvae typically having a close resemblance to one another but deviating significantly from the adult. Their eyes hardly ever consist of more than a few simple ocelli. Their mouthparts and feeding habits are typically different from those of an adult, and their wings are minimally represented by internal rudiments that may be submerged in epidermal sacs beneath the general body surface. Following the final larval instar is a more or less quiescent pupal instar, during which the majority of the internal and outward changes necessary for adulthood take place within the cuticle.

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Hypermorphosis is the term used to describe the development of an insect that goes through two or more distinctly different larval instars. Usually, this event is accompanied by a noticeable shift in behaviour. When hypermetamorphosis occurs, the first larval instar is a campodeiform. It searches for its future food throughout this stage, and once found, it goes through a series of morphological changes to adjust to its new way of life. This phenomenon can be observed in Sterpsiptera, some endoparasitic dipterans and hymenopterans, Mantispidae (Neuroptera), etc. Table 1.1 depicts various types of metamorphosis in insects.

Table: Types of metamorphosis in insects with examples.

Type of metamorphosis	Characteristic features	Examples
Ametamorphosis	No visible metamorphosis, minor changes in form during growth, immature resembles the adult ones	Springtails, Silverfish
Gradual metamorphosis/ Hemimetamorphosis	Immatures are called as nymphs, change is gradual, different from the adult in having no wings and undeveloped genitalia, nymphs and adults reside in the same habitat	Grasshopper, Cockroaches
Complete/ Holometamorphosis	Immatures are called as larvae and pupae. Larvae are adapted for feeding only whereas adults are involved in feeding, reproduction and dispersal. Larvae and adults may or may not share the same habitat	Butterfly, Wasp
Hypermetamorphosis	When insect undergoes through two or more distinctly different larval instars. Shift in behavior	Mantispidae (Neuroptera)

Q5. Where is the peritrophic membrane located? How it helps in insect digestion?

Ans. The midgut in majority of insects is lined by a peritrophic membrane secreted by the columnar epithelial cells. It is composed of chitin, sugars, and proteins. In locusts, the peritrophic membrane is multilaminar, while it is absent in some hemipterans, adult lepidopterans, ants, and fluid feeders.

The peritrophic membrane can be categorized into two types based on its production. Type I membrane is produced by all the cells of the midgut and is thus present through the length, for example in Coleoptera, Odonata, Orthoptera, and Hymenoptera. Type II membrane is secreted by the certain specialized anterior midgut cells, called cardia, as in Isoptera and Dermaptera.

The peritrophic membrane acts as a physical barrier between the gut contents and the midgut epithelium, and protects the delicate digestive cells from the luminal content which might contain abrasive particles, toxins, pathogens, etc. In some phytophagous insects that feed on plants, the membrane acts as a barrier against allelochemicals such as tannins, which are a major component of plants. In addition, the peritrophic membrane separates the midgut lumen into two regions; ecto-peritrophic space in the gut lumen and endoperitrophic space, the region between the peritrophic membrane and the midgut cells (Fig. 2.3). The digestive enzymes are secreted into the ectoperitrophic space from the midgut epithelial cells, which then diffuse into the endo-peritrophic space to carry out the process of digestion. Similarly, the digested food diffuses back to the ecto-peritrophic space to be absorbed by the midgut epithelial cells.

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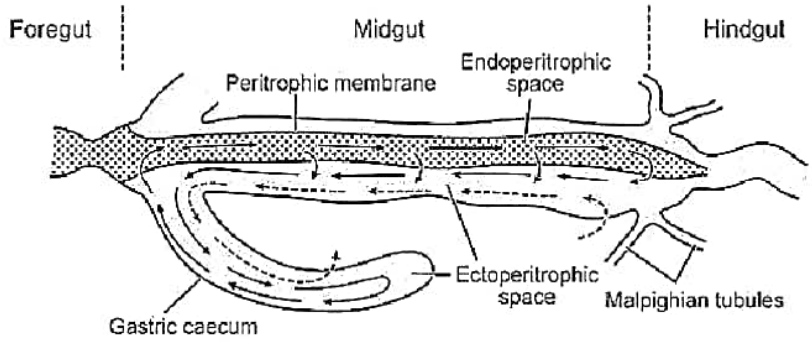

Fig.: Generalized scheme of endo-ectotrophic circulation of digestive enzymes in the midgut

Q6. What is the excretory system in insects?

Ans. Excretion is a significant process of removal of potentially toxic materials from the body. This process takes place in two steps;

a) Indiscriminate removal of substances from the hemolymph, forming the primary urine, and

b) The reabsorption of useful compounds from the urine or excretion of excess and unwanted compounds in the body. The excretion takes place with the help of certain organs comprising the Malpighian tubules, ileum and rectum; the primary organ is Malpighian tubules. We will discuss about different excretory organs in the following subsections:

Malpighian Tubules: The Malpighian tubules were discovered by Marcello Malpighi. These tubules are long, thin, blindly ending and freely lying tubes that arise at the junction of the midgut and hindgut and lie in the haemocoel. The tubules are derived from the hindgut ectoderm but are not lined with cuticle. These are found in almost all insects except in collembola and aphids while are rudimentary in strepsipterans.

The number of Malpighian tubules varies in insects from 2 in coccids to about 250 in desert locusts. The length varies from 2 mm to 100 mm, and the diameter ranges from 30 μm to 100 μm. The wall of the tubules is one cell thick with microvilli on the inner side. The proximal part is absorptive with a brush border while the distal part is a secretory with a honeycomb border (Fig. 2.6). Since tubules are blindly ended, the accumulation of fluid builds up hydrostatic pressure resulting in the flow of fluid into the gut.

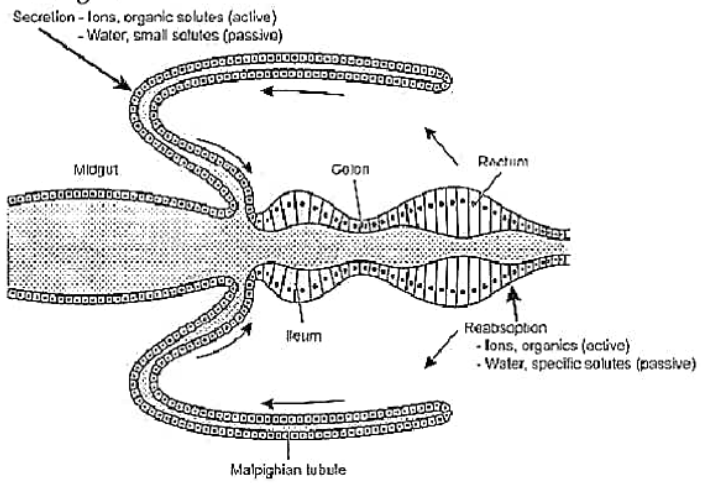

Fig.: Malpighian Tubules

Usually Malpighian tubules are made up of single type of cells, however, in some they may have different cell types or multiple kinds of regions performing different functions.

Nephrocytes: Nephrocytes are specialized cells for excretion present in the haemocoel. The cells were first described by Hollande (1922) and were known as pericardial cells due to their location along the dorsal heart. These take up compounds of high molecular weight, such as colloids and dyes, which cannot be excreted by Malpighian tubules. These are also referred to as storage kidneys.

Nephrocytes are large and binucleated with a deep network of infoldings of the plasma membrane. The external surface of the folds is held together by a desmosome-like structure; the cells are surrounded and held together by a basal lamina. In Drosophila,nephrocytes regulate hemolymph composition. These are of two types, the garland cells surrounding the

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