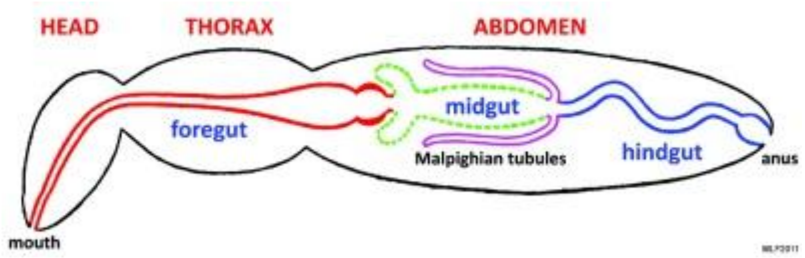
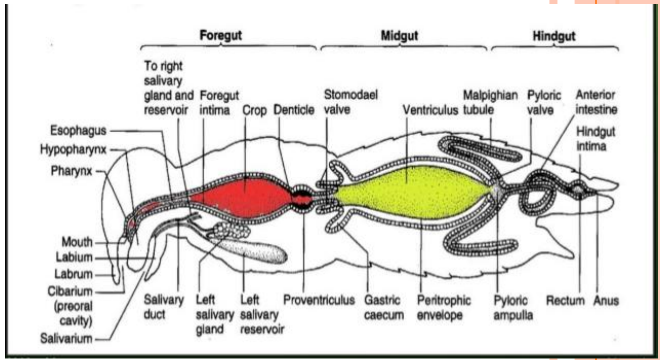
Insect digestion



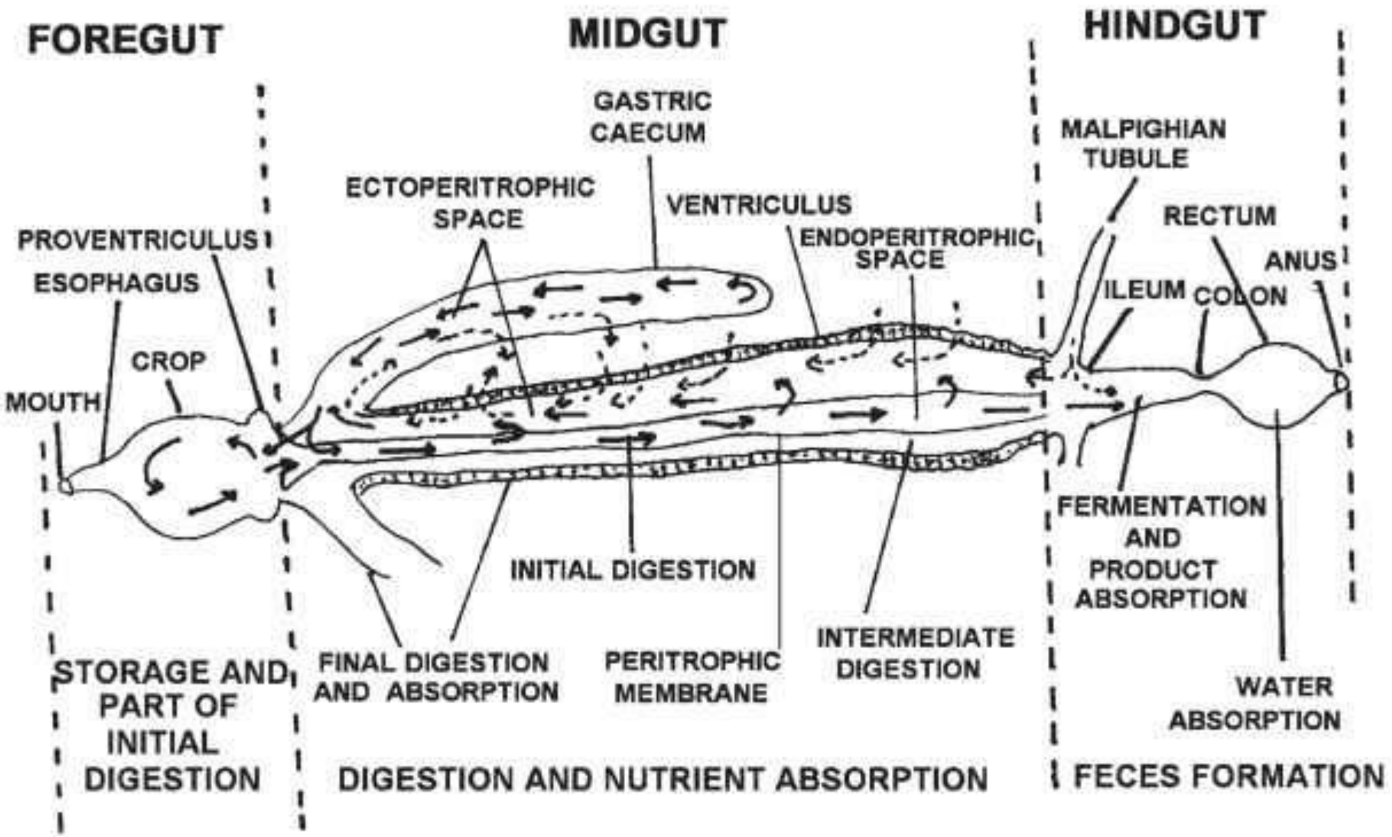
Zoo 514

Dr. Reem Alajmi

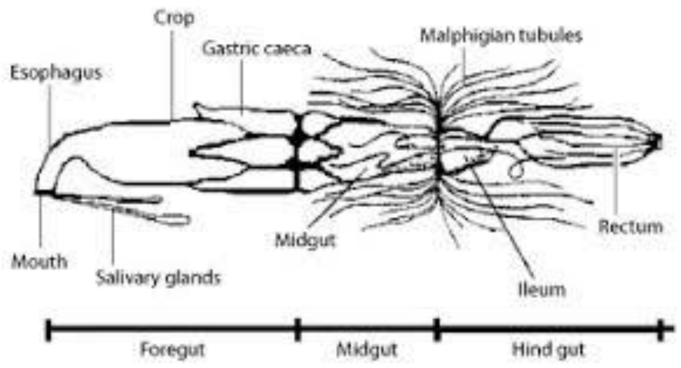
Insect digestive system



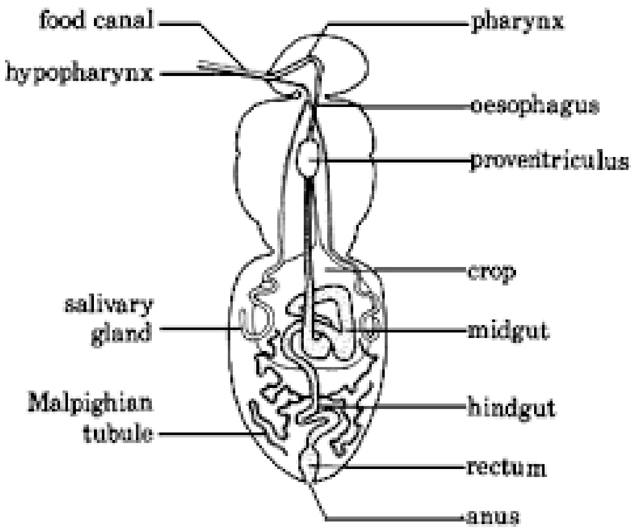
- The alimentary canal is concerned with digestion and absorption of food stuffs. Different parts of the gut are concerned with different aspects of these functions.
- In fluid feeding insects digestion begin before the food is ingested through the injection or regurgitation of enzymes on to the food .
- In general it occurs in the mid gut (most of the enzymes are produced).
- The enzymes break down the complex substances in the food into simple substances which can be absorbed and assimilated.
- Enzymes function optimally only within limited range of pH and temperature.
- Absorption is passive process in some cases , but in others active transport occurs.
- Absorption of water is important in terrestrial insects , rectum remove water from faeces.


FOREGUT
MIDGUT
HINDGUT
GASTRIC CAECUM
ECTOPERITROPHIC SPACE
VENTRICULUS
ENDOPERITROPHIC SPACE
MALPIGHIAN TUBULE
RECTUM
ANUS
ILEUM
COLON
PROVENTRICULUS
ESOPHAGUS
CROP
MOUTH
INITIAL DIGESTION
FERMENTATION AND PRODUCT ABSORPTION
INTERMEDIATE DIGESTION
FINAL DIGESTION AND ABSORPTION
PERITROPHIC MEMBRANE
WATER ABSORPTION
STORAGE AND PART OF INITIAL DIGESTION
DIGESTION AND NUTRIENT ABSORPTION
FECES FORMATION

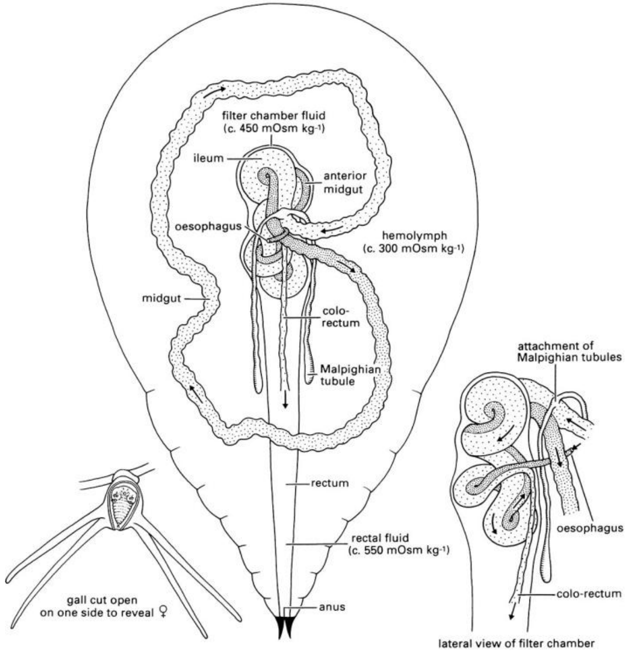
- Insects of different groups consume astonishing variety of foods, including watery xylem sap, vertebrate blood, dry wood, bacteria and algae and the internal tissues of other insects.
- Types of mouth parts correlates with the diets of insect. Also gut structure and function affected by nutrient composition of the food eaten by insect.
- Insects that take solid food typically have a wide, straight, short gut with strong musculature and obvious protection from abrasion (especially in the midgut, which has no cuticular lining).
- These features are most obvious in solid-feeders with rapid throughput of food, as in many insects and plant-feeding caterpillars



- In contrast, insects feeding on blood, sap or nectar usually have long, narrow, convoluted guts to allow maximal contact with the liquid food; here, protection from abrasion is unnecessary.
- The most obvious gut specialization of liquid-feeders is a mechanism for removing excess water to concentrate nutrient substances prior to digestion, as seen in hemipterans.



The filter chamber of Hemiptera



Most Hemiptera have an unusual arrangement of the midgut which is related to their habit of feeding on plant fluids. An anterior and a posterior part of the gut (typically involving the midgut) are in intimate contact to allow concentration of the liquid food. This filter chamber allows excess water and relatively small molecules, such as simple sugars, to be passed quickly and directly from the anterior gut to the hindgut, thereby short-circuiting the main absorptive portion of the midgut. Thus, the digestive region is not diluted by water nor congested by superabundant food molecules

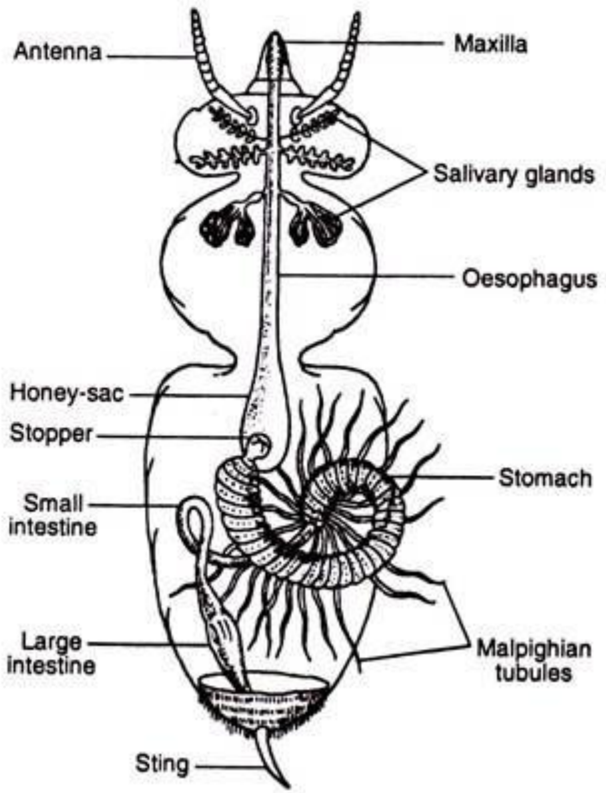
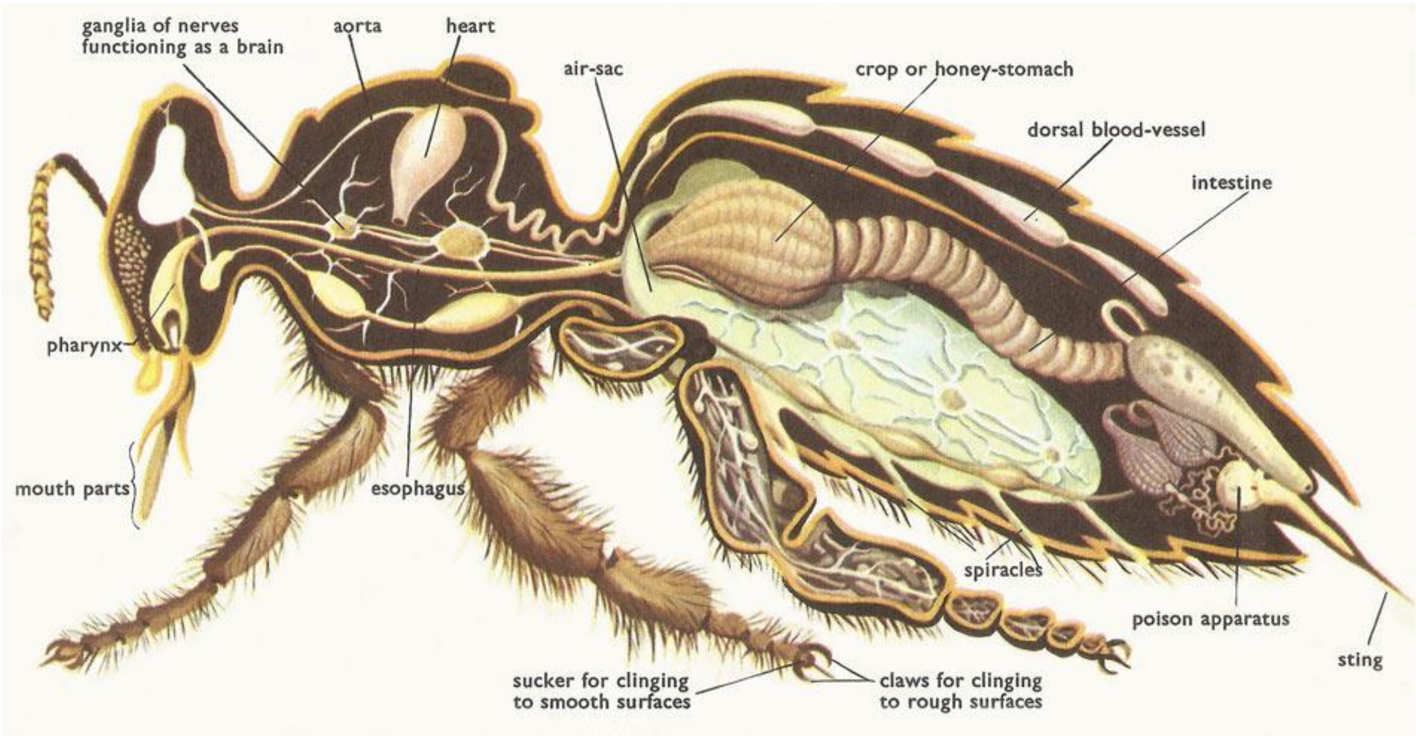
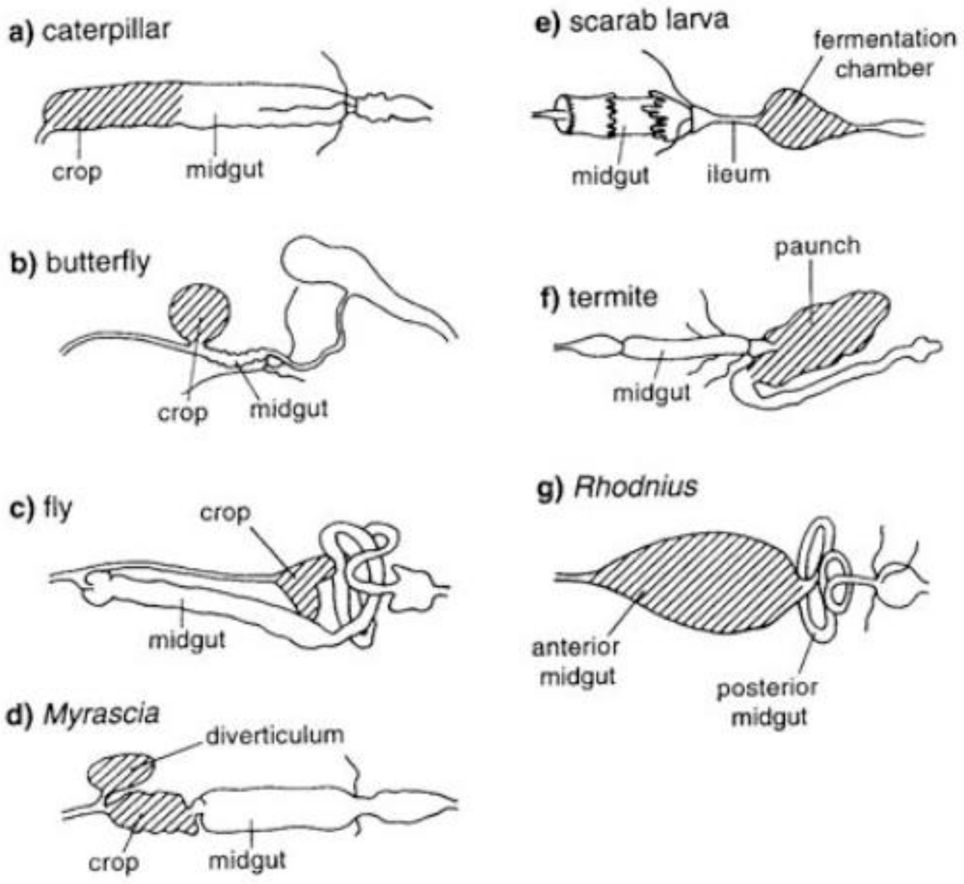


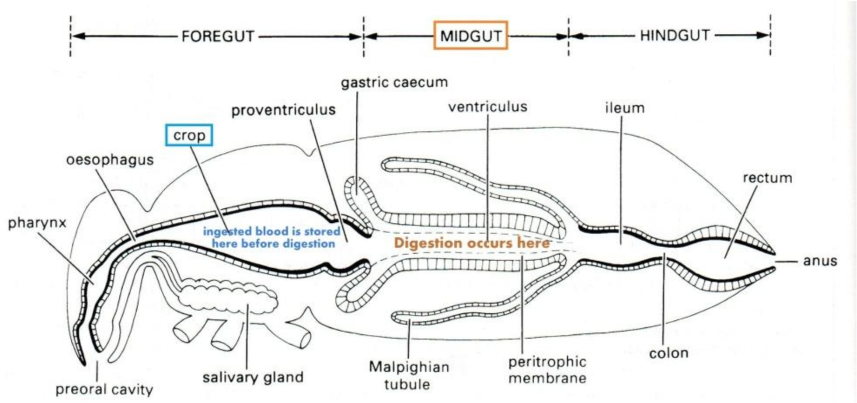
Fig. 18.79: Alimentary system of honey-bee (after Thomson).



Variation in insect guts



- The alimentary canal is divided into three main regions:
  - Foregut (stomodeum)
  - Midgut (mesenteron)
  - Hindgut (proctodeum)



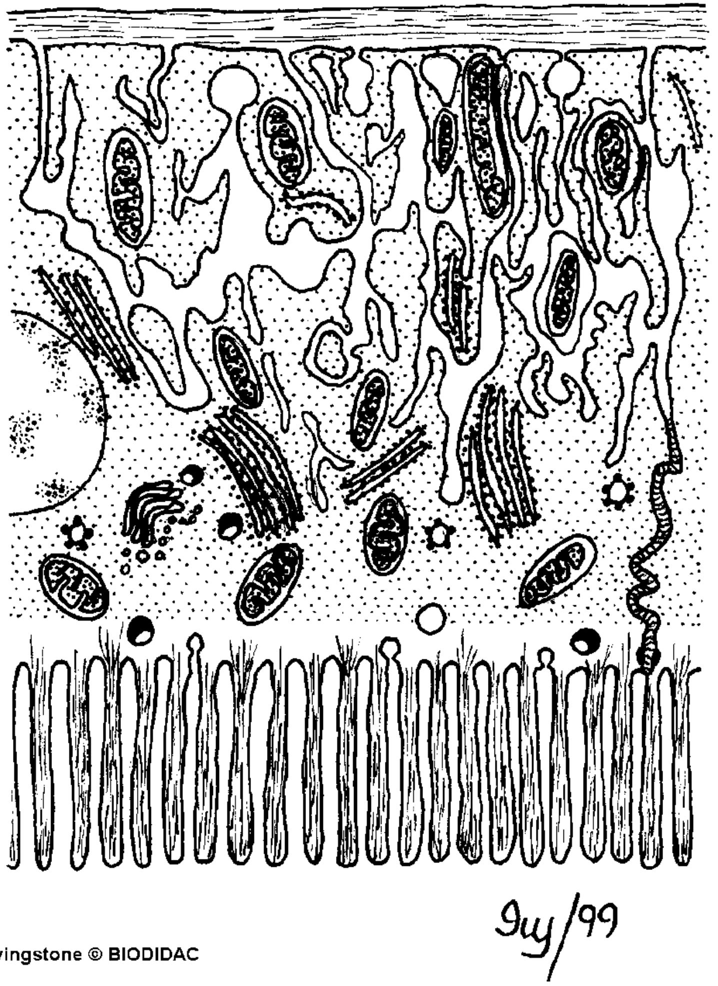
- The epithelium of all parts of the gut consists of a single layer of cells.

Foregut

- The cells of the foregut are usually flattened and undifferentiated since they are not involved in secretion or absorption, but the cuticular lining often varies in different regions.
- Spines or teeth may present in different part of the foregut. They are commonly pointed backward to facilitate movement of food backwards.
- Typically, the foregut is subdivided into a **pharynx**, an **esophagus** and a **crop** (food storage area), and in insects that ingest solid food there is often a grinding organ, the **proventriculus** (or gizzard).

Midgut

- The cells of midgut are actively involved in enzyme production and secretion, as well as absorption of nutrients.
- The majority of cells, called principal cells, are tall and columnar and the membrane on the luminal side forms microvilli (fig)
- The microvilli greatly increase the area of the cell membrane through which absorption occurs.
- The outer surface of the microvilli is covered by the glycocalyx (in most insect, is a layer of filamentous glycoproteins)



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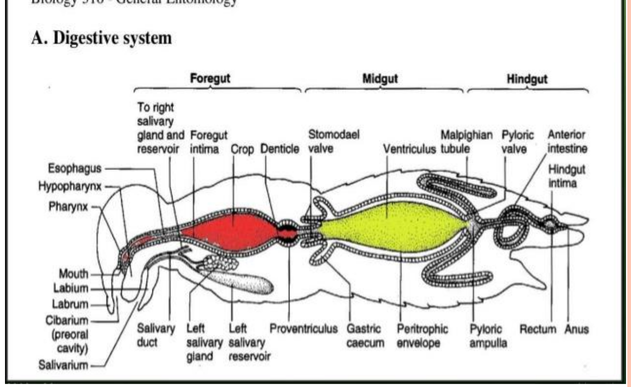
- When they are synthesizing enzymes, the principle cells are characterized by the presence of stocks of rough endoplasmic reticulum and Golgi bodies.
- In most insects, synthesis appears to occur at the time of secretion into the gut lumen. In few cases enzymes are stored as inactive precursors (zymogens) in membrane-bound vesicles in the distal parts of the cells.
- The principal cells of midgut have a limited life and, in most insects, they are continually replaced from regenerative cells at the base of the midgut epithelium.

- Endocrine cells are probably present in the midgut epithelium of all insects. They are probably involved in the regulation of enzyme production.
- Scattered amongst the principle cells of the midgut of caterpillars are goblet cells. These cells create a high concentration of potassium in the gut lumen.
- In many insects the midgut has diventricula known as ceca.
- The tubular part of the midgut is known as the ventriculus.

PERITROPHIC ENVELOPE



- It form a delicate lining layer to the midgut, separating the food from the midgut epithelium (fig..)
- The envelope is usually made up of a number of separate laminae.
- It has different functions:

 - Encloses the food bolus within the gut .

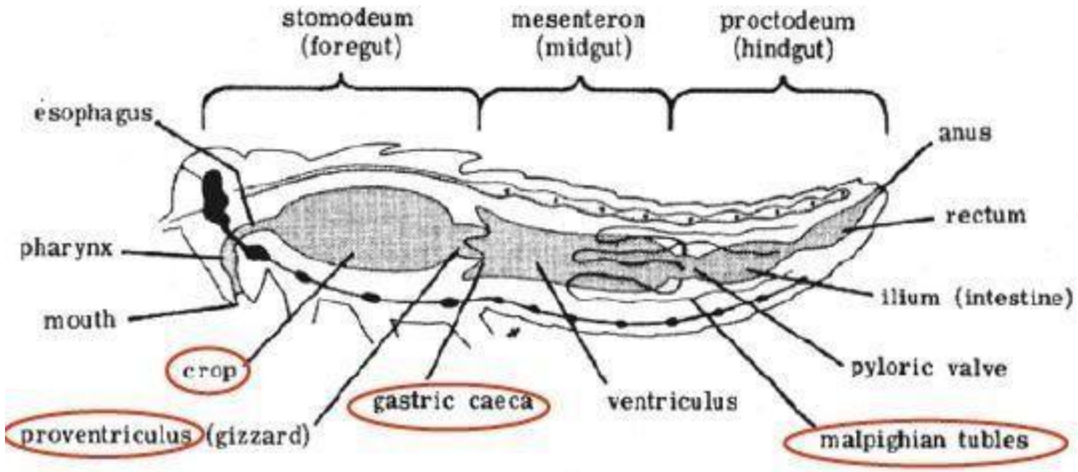
 - Increasing the efficiency of absorption.

 - Preventing solid food particles from coming into contact with microvilli (avoiding cell damage)

 - It confers some degree of protection against potentially harmful chemicals in the food of phytophagous insects and against some pathogenic organisms (the pore sizes are too small to permit the passage of most bacteria).

HINDGUT

- It is usually differentiated into the pylorus, ileum and rectum (fig..)



The "generalized" digestive system of insects.

- The pylorus sometimes forms a valve between the midgut and hindgut.
- Sometimes the posterior part of the ileum is recognizably different and is called the colon.
- In many insects, only a single cell type is present in the ileum. The cells have extensive folding of the apical plasma membrane (fig..).
- Amongst insects that have symbionts in their hindgut the ileum is expanded to house them (such as paunch in termites).
- The rectum is usually an enlarged sac with a thin epithelium except for certain regions, the rectal pads, in which epithelial cells are columnar.

- There are usually six rectal pads arranged radially round the rectum (fig..). The cuticle of the rectal pads is thin compared with that lining the rest of the rectum.
- The intima of the hindgut is usually differs from that of the foregut in being highly permeable.
- Insects living in freshwater possess specialized cells, called chloride cells, able to take up inorganic ions, not only chloride, from dilute solutions.
- These cells remove salts from water as it is pumped in and out of the rectum during respiration.

Digestion

- Food ingested by insects is macromolecular (polysaccharides, proteins , lipids (phospholipids, glycerides, glycolipids)) .
- Small molecules can only pass into tissues
- Large molecules must be broken down into a component of suitable size before absorption occurs.
- Enzymes concerned with digestion in saliva and in midgut secretions .
- Also microorganisms in the gut may facilitate digestion.

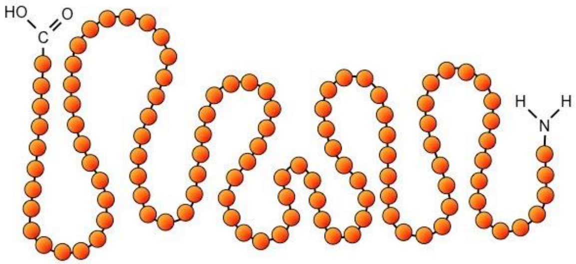
EXTRA- INTESTINAL DIGESTION

- Saliva contain enzymes that are injected into the host.
- Such extra-intestinal (or extra- oral) digestion may constitute a major part of the total digestion.
- In many phytophagous a pectinases injected in the saliva.
- This enzyme (pectinase) causes disruption of the plant cell wall that aids penetration of the tissues of the host – plant.
- An amylase is also present .
- In Orthoptera, the salivary enzymes contribute to the early stages of digestion within the gut.

- The paralysis of a prey is achieved through the rapid action of the enzymes which are injected into the prey.
- Proteolytic enzymes persist in the excreta of larval blowflies and the meat in which they live is liquefied before it is ingested.
- Enzymes are not present in the saliva of most haematophagus insects.

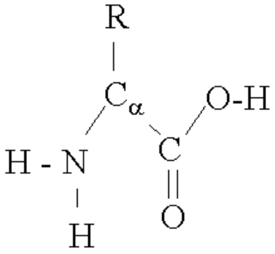
Internal digestion (in the gut lumen)

- Most digestion occurs in the mid gut in which the enzymes are secreted.
- It also takes place in the crop because of the regurgitation of the midgut juices. Little digestion occurs in the hindgut .
- Carnivorous, herbivorous, parasitic or saprophagous insects possess a range of enzymes in the midgut .
- Regardless the feeding habits, most insects must digest carbohydrates, proteins , and lipids so they have a similar array of enzymes in the midgut.
- Nevertheless, the enzymes produced do reflect the type of food eaten by each stage and species.
- For example, fly that feed on blood which has many proteins, the array of proteolytic enzymes reflect the protein rich diet. While in Lepidoptera that feed only on nectar, proteolytic enzymes are absent.
- Even if similar enzymes are present in different species, their activities may reflect the nature of their diet.



Digestion of proteins

- It involves endopeptidases, which attack peptide bonds within the protein molecule, and exopeptidases, which remove the terminal amino acids from the molecules.
- The principal endopeptidases in the majority of insects are the serine proteases, trypsin and chymotrypsin, which have serine at the active site.
- In many Coleoptera and in blood-sucking Hemiptera, the main endopeptidases have cysteine or aspartic acid at their active centers.
- Exopeptidases fall into two categories: carboxypeptidases that attach peptides from the carboxyl group end –COOH, and aminopeptidases that attack the chain from the –NH2 end.



- Different insect species regardless of their feeding habits, possess a range of enzymes in the midgut .But where the diet is specialized , the enzymes present are commonly adapted to it .
- Ex : larvae of blowfly , feeds primarily on protein diet , proteases are important.
- ex. : In adult (nectar – feeding Lepidoptera) they are absent.

- Dipeptidase hydrolyses all dipeptides.
- Some insects are able to digest the animal protein Keratin and collagen .
- Keratin is the protein found in wool, hair and feather. Mallophaga of birds and some dermestid larvae digest it.
- Tineola (Lepidoptera) has a keratinase , capable of digesting keratin under anaerobic conditions .
- The larvae of Hypoderma (Diptera) and of some blowflies produce collagenase that acting on the collagen of animal tissues.
- Hypoderma lays its eggs on hairs of the host and its larvae bore through the skin into the host tissues.

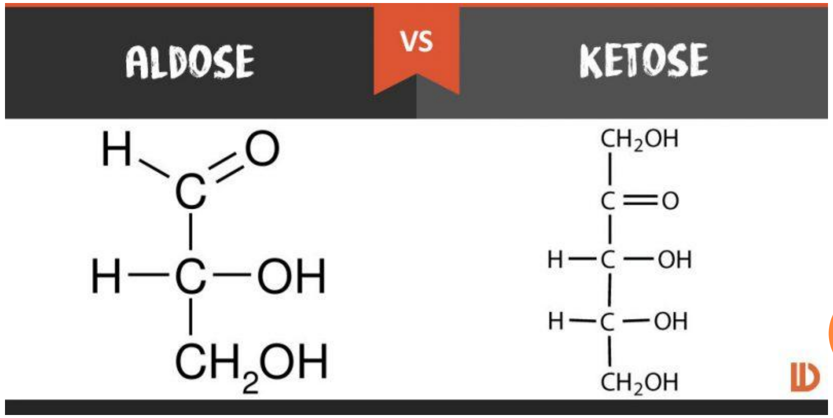
Digestion of carbohydrates

- Carbohydrates are the most abundant class of organic compounds found in living organisms. They originate as products of **photosynthesis**, an endothermic reductive condensation of carbon dioxide requiring light energy and the pigment chlorophyll.
- $n\ CO_2 + n\ H_2O + \text{energy} \longrightarrow C_nH_{2n}O_n + n\ O_2$

- As noted here, the formulas of many carbohydrates can be written as carbon hydrates, $C_n(H_2O)_n$, hence their name.
- Carbohydrates are called **saccharides** or, if they are relatively small, sugars. Several classifications of carbohydrates have proven useful, and are outlined as the following:

Complexity : Simple Carbohydrates monosaccharides **Complex Carbohydrates** disaccharides,oligosaccharides & polysaccharides

- **Size : Tetrose** C_4 sugars **Pentose** C_5 sugars **Hexose** C_6 sugars **Heptose** C_7 sugars
- **C=O Function : Aldose** sugars having an aldehyde function or **Ketose** sugars having a ketone function.
- Carbohydrates are generally absorbed as monosaccharides .
- Disaccharides and polysaccharides must be broken down to their components monosaccharides.
- This complex reaction takes place in the gut wall.



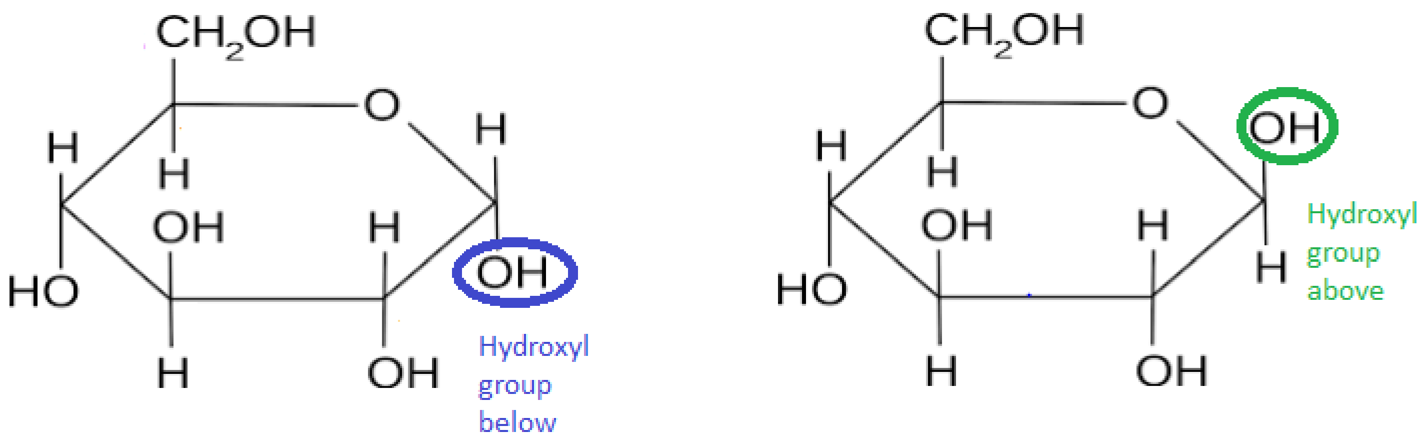
- The polysaccharide cellulose can be digested by phytophagous insects by the micro-organisms present in their gut.
- Starch and glycogen, the main storage polysaccharides of plants insects respectively, are digested by amylases.

Glucose

- Carbohydrates have been given non-systematic names, although the suffix **ose** is generally used.
- The most common carbohydrate is **glucose** ($C_6H_{12}O_6$). Applying the terms defined above, glucose is a monosaccharide, an aldohexose and a reducing sugar.

α – glucosidic link of glucose residue

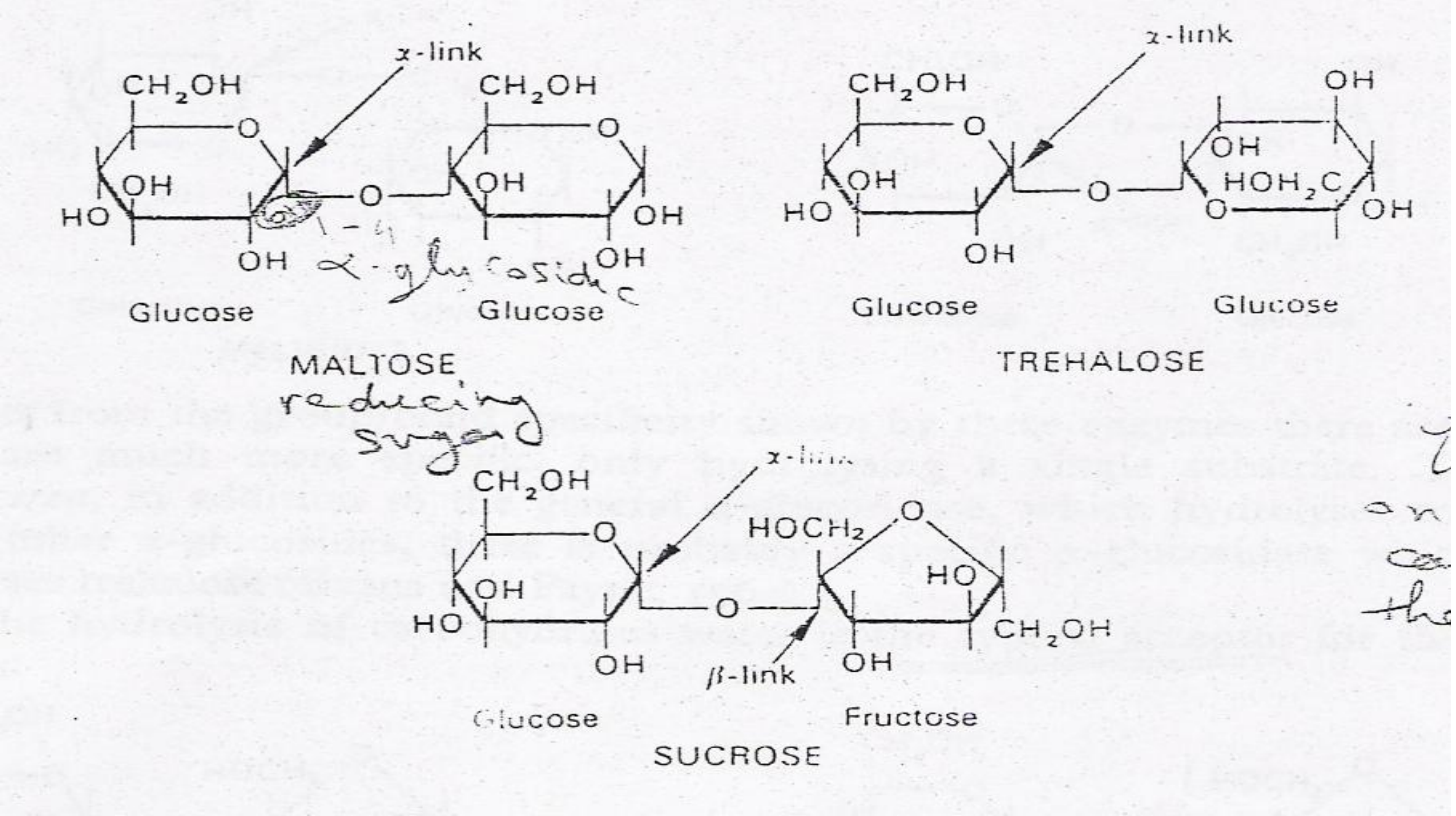
- If the hydroxyl gp of the anomeric carbon is below the plane of the ring : alpha – position, if it is above the plane it is ß- position.



Alpha glucose

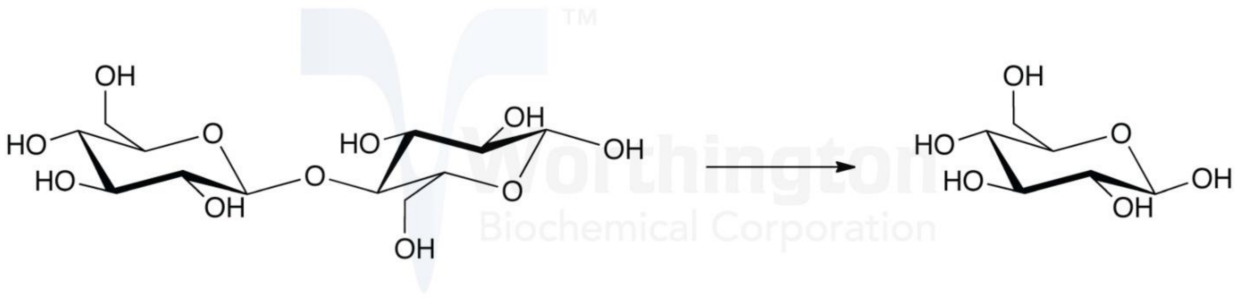
Beta glucose

- Disaccharides as maltose , trehalose and sucrose (reducing sugars) all contain glucose residue which is linked to a second sugar residue by an alpha – linkage.
- All these are hydrolyzed by alpha- glucosidase(an enzyme attacking the alpha – link of a glucose residue).



- **B- glucosidase**
- an enzyme attacking the B- link of the glucose residue as cellobiose (a product of cellulose digestion).
- The highest B- glucosidae activity is found in phytophagous insects.

Cellobiase



Cellobiose β-D-Glucose

Transglucosylation

- In the hydrolysis of carbohydrates water is a typical acceptor for the sugar residue.
- Other sugars may act as acceptors that leads to the formation of oligosaccharides.
- Thus in the hydrolysis of sucrose, other sucrose molecules may act as acceptors to form the trisaccharides glucosucrose and melezitose.
- These may accept further glucose to form tetrasaccharides.
- Trehalose has no transglucosylation , because the relevant enzyme has a high specificity for water as an acceptor.

Polysaccharides

- Starch and glycogen, the main storage polysaccharides of plants and insects, are digested by amylases that hydrolyze 1-4 alpha glucosidic linkages.
- **Starch** is a polymer of glucose (storage polysaccharide), found in roots, rhizomes, seeds, stems, tubers and corms of plants, as microscopic granules having characteristic shapes and sizes. Most animals, including humans, depend on these plant starches for nourishment. The structure of starch is more complex than that of cellulose. The intact granules are insoluble in cold water.
- Starch is a mixture of amylose1-6 + amylopectin .
- Starch is broken down to maltose.
- glycogen is broken down to glucose .

- Polysaccharides are broken down by the action of an **amylase** that specifically catalyzes the hydrolysis of 1:4 – alpha – glucosidic linkages in polysaccharides.
- There are two types of amylase working in different ways .

  - **An exoamylase** splits off maltose from the ends of two starch molecules adding to a rapid increase in the concentration of maltose.

  - **An endoamylase :** attacks bonds within the starch molecule so there is a slow build –up of maltose to start with .
- The products are then further digested in normal way by alpha – glucosidase.
- Amylose is unbranched polymer of alpha- D – glucose.

- The polysaccharide **cellulose** is a major constituent of green plants, but although many insects are phytophagous, few of them are able to utilize cellulose.
- A minority of insects have an enzyme , **cellulase**, so the insect must either feed on cell contents without digesting the cell walls , or they must rely on micro- organisms to digest the cellulose for them.
- A cellulase has also been identified in Schistocerca and its activity is slight because the food passes through the alimentary canal too quickly .
- Cellulose is a linear polyglucose formed by Beta 1-4 glucosidic linkage.

- Cellulase acts by breaking cellulose into cellobiose which further hydrolysed by the B- glucosidase.
- Larvae of Scarabaeoidea have no cellulase as they feed on rotten wood , the wood is retained in a pouch in the hindgut by branched spines arising from the intima
- In the pouch the bacteria ingested with the wood continue to ferment it.
- The digested food are absorbed through the wall of the pouch as, between spines the intima is very thin.
- In termite soldier, larvae and worker that are feeding on wood there is a permanent gut flora or fauna concerned with cellulose digestion (such as termite that depend on flagellate protozoans or on fungi).

Lipid digestion

- Very little is known about lipid digestion in insects.
- Midgut cells produce several different esterases which probably have specificity for different substrate.
- Lipid is usually ingested mainly in the form of triglycerides .
- Digestion involves the production of smaller molecules of diglycerides , monoglycerides and free fatty acids.
- Lipases cleave insoluble glycerides of long-chain fatty acids .
- Estrases; Which act on glycerides of short-chain acids. A number of estases are present in insects.
- Phosphatases, probably contribute to the digestion of phospholipids,

Control of enzyme activity

- The level of enzyme activity in the gut varies in insects which feed at frequent intervals, like caterpillars and grasshoppers, enzyme activity fluctuates with the state of feeding .
- Protease activity persists at a lowered level in the gut lumen of *Melanoplus* during a period without food, but rises when food is ingested.
- Enzyme activity also changes with development and season.
- The changes in enzyme activity which occur indicate that synthesis is regulated physiologically .Three possible regulatory mechanisms are known .
- Enzyme secretion or production may be induced by the food or its products directly stimulating the midgut cells.

Table:1 The midgut enzymes secreted by insects with different diets

Insects	Diet	Protease	Lipase	Amylase	Invertase	Maltase
Cockroaches	omnivorous					
Lepidoptera larva	phytophagous					
adult	nectar	-	-	-	-	-
Lucilia larvae	meat					
Calliphora adults	sugars	weak	-			

Insect	Diet	Protease	Lipase	Amylase	Invertase	Maltase
Cockroach	omnivorous	√	√	√	√	√
Carausius	phytophagous	√	√	√	√	√
Lepidoptera larvae	phytophagous	√	√	√	√	√
adults	nectar				√	
adults	Non-feeding					
Lucilia	meat	√	√			
Glossina	blood	√				


ANY
QUESTIONS?
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