Food and Fuel

Chapter 4

Why Do Animals Need Food?

• Energy needed to maintain homeostasis
  – Energy to drive otherwise unfavorable chemical reactions
  – Need to maintain order and complexity in a universe that moves towards disorder

• Raw materials needed to assemble and maintain cellular structure and metabolic machinery
  – maintenance, growth, and reproduction

Sources of Energy

• Ultimate sources
  – Sun
  – Inorganic chemicals

• Energy must be in the form of high-energy organic molecules for animals to use it
  – producers
    • plants (capture light energy)
    • chemosynthetic bacteria (oxidize inorganic chemicals)
  – other consumers (animals, fungi, bacteria, protozoans)
  – detritus

Obtaining Food

• Feeding - acquisition and ingestion of food
• Digestion - breakdown of food into simple molecules and release of energy from those molecules
• Nutrition - need for particular types of molecules

Feeding

• Food absorption through body surfaces
• Endocytosis
• Suspension Feeding
• Fluid Feeding
• Seizing of Prey
• Grazing
• Symbiosis with Producer

Absorption Through Body Surfaces

• Protozoans, endoparasites, aquatic invertebrates
• e.g. Tapeworms
  – surrounded by high-nutrient media
  – lack digestive tracts and digestive enzymes
  – absorb nutrients through the integument
• e.g. soft-bodied aquatic invertebrates (polychaetes, echinoderms, bivalves, etc.)
  – absorb amino acids from sea water via active transport
Endocytosis

- Protozoa, radiolarians, alimentary canal cells
  - active engulfing of food particles by cells
  - formation of food vacuoles inside cells
  - merge with lysosomes to digest food.

Suspension Feeding

- Bivalves, sponges, small crustacea, fish, birds, mammals
  - Food items captured out of suspension
  - Often employ mucus to catch small particles
  - Enable “short” food chains

Fluid Feeding

- Piercing and Sucking
  - platyhelminths, nematodes, annelids, arthropods, humming birds
- Cutting and licking
  - biting flies, cyclostomes, vampire bats, vampire finches
- Nursing animals
  - mammals, some birds, some fish

Seizing of Prey

- Limbs
  - arthropods, birds, mammals
- Mouth
  - insect mandibles, fangs, beaks, tongues, pointed teeth
- Toxins (venom)
  - coelenterates, arachnids, insects, snakes

Grazing

- Scraping or cropping food (plants)
- e.g. Gastropods
  - radula
- e.g. Grazing vertebrates
  - bony plates, molars, or continuously growing teeth

Symbiotic Relationships

- Form symbiotic relationship with producer
  - obtain needed energy substrates from the producer
- e.g. photosynthetic bacteria or algae
  - sponges, coelenterates, platyhelminths, bivalves
  - produce sugars, glycerol, etc. for host
- e.g. chemosynthetic bacteria
  - tubeworms from hydrothermal vents
  - located in organs called trophosomes
  - produce ATP via oxidation of H₂S
Digestion

- Food typically consists of protein, carbohydrates and fats
  - very large molecules
  - need to be broken down into subunits
    - amino acids, monosaccharides, fatty acids
- Digestion – breakdown of large, complex molecules/structures into smaller, simpler ones

Digestion

- Mechanical digestion
  - breaking of large clumps of food into smaller ones
  - Teeth, gizzard, stomach
- Chemical digestion
  - Breakdown of complex molecules into simpler molecules

Digestive (Alimentary) Systems

- Internal cavity for intracellular digestion and absorption of nutrients
- Tube-like canal in more advanced organisms

Digestive System Types

- Batch
  - Single opening
  - Food processed in batches
    - enters, is digested, then is expelled
- Continuous flow, stirred-tank
  - Two openings
  - Food continuously enters and is mixed into a homogenous mass
    - Overflow continuously enters remainder of tract
- Plug-flow
  - Iloths of food progressively digested as it moves through tube-like reactor
    - Composition changes with position in the tube

Generalized Alimentary Canal

- Headgut
  - Receiving ingested material
    - Oral cavity, pharynx
- Foregut
  - Conduction, storage and digestion
    - Esophagus and stomach
- Midgut
  - Chemical digestion and nutrient absorption
    - Small intestine
- Hindgut
  - Water and ion absorption, waste storage, defecation
    - Large intestine

Headgut

- Mouth and Pharynx
  - tongue
    - chemosensory organs (taste buds)
    - mechanical digestion and swallowing
  - teeth
    - mechanical digestion (mastication)
  - salivary glands
    - secrete saliva
    - moistens and lubricates food
    - contains enzymes
Foregut

- **Esophagus**
  - conducts food from headgut to stomach
  - movement by peristalsis

- **Crop**
  - Sac-like expansion for storage of food
  - Common in animals that feed infrequently

Foregut

- **Gizzard**
  - Muscular organ for grinding

- **Stomach**
  - Primary site of mechanical and chemical digestion
    - Secretes digestive enzymes and hydrochloric acid
    - Muscular activity mixes food
    - Storage of food

Types of Stomachs

- **Gastric Ceca** (insects, crustaceans)
  - Tube-like outpouchings from foregut
  - Extracellular digestion and phagocytic uptake of nutrients

Types of Stomachs

- **Monogastric stomachs** (most vertebrates)
  - Single, muscular tube or pouch
  - Epithelium secretes gastric juices (enzymes and HCl)

Types of Stomachs

- **Digastric stomachs** (ruminant mammals)
  - Multi-chambered stomachs
    - **Rumen** – large chamber for fermentation of food by microorganisms
    - **Abomasum** – secretes digestive fluids

Midgut

- **Small Intestine**
  - Chemical digestion
  - Nutrient absorption
    - various membrane transport mechanisms
  - Long tube
  - Greatly enhanced surface area
    - Intestinal folds
    - Finger-like villi
    - Microvilli on cells
Hindgut

- **Large intestine and rectum**
  - Absorption of water and ions
  - Storage of waste materials until defecation
  - Hindgut fermentation
    - Microorganisms break down cellulose and other materials
    - Storage in ceca

Digestion of Proteins

- Proteins are polymers of *amino acids*
- Digestion of proteins involves *hydrolysis* of peptide bonds linking amino acids

Digestion of Proteins

- **Endopeptidases**
  - break up proteins from the middle of the chain
  - e.g. *pepsin* - stomach
    - activated by low pH (inert form = *pepsinogen*)
    - cleaves proteins at specific amino acids sequences
      - between acidic amino acid and an aromatic one
  - e.g. *trypsin* - small intestine
    - produced by pancreas (*trypsinogen*)
    - activated by *enterokinase* (small intestine)
    - cleaves proteins at basic amino acids

Digestion of Proteins

- **Exopeptidases**
  - break up proteins from ends of the proteins
  - e.g. *carboxypeptidase* (pancreas)
    - hydrolyzes peptide bonds from the carboxyl end
  - e.g. *aminopeptidase* (small intestine)
    - hydrolyzes peptide bonds from the amino end

Digestion of Fats

- Fats are combinations of alcohols and fatty acids
  - *triglycerides* - glycerol + three fatty acids
  - *waxes* - fatty alcohol + fatty acids
- Digestion involves hydrolysis of fatty acids from the alcohol

Digestion of Fats

- Fats are generally hydrophobic
  - tend to form large droplets in digestive tract
  - need to be emulsified
  - ↓ droplet size and ↑ surface area
- *Bile salts* (liver) - emulsify fats in small intestine
- *Lipase* (pancreas) - hydrolyzes triglyceride into fatty acids, glycerol and monoglycerides
Digestion of Carbohydrates

- Complex carbohydrates (polysaccharides)
  - polymers of simple carbohydrates (monosaccharides)
- Digestion = hydrolysis of glycosidic bonds

Nutrition

- Food needs to contain materials to meet two needs of the animals
  1. *Energy* for external activity and internal maintenance of homeostasis (Calories)
  2. *Raw building materials* for maintenance and growth of body structures

Energy

- Derived from carbohydrates, fats, and proteins via *cellular respiration*
  - *Aerobic respiration*
    - oxygen consuming process
  - *Anaerobic respiration*
    - non-oxygen consuming

Building Blocks

- *Amino acids*
  - Needed for assembly of structural proteins, enzymes, etc.
  - Proteins are constantly being broken down in the body
    - Some amino acids recycled
    - Some amino acids lost

Digestion of Carbohydrates

- Various enzymes (carboxylases) involved in carbohydrate digestion
  - e.g. salivary amylase - breakdown starch (amylose) into maltose
  - e.g. sucrase - breaks down sucrose into glucose and fructose
- Some organisms have *cellulases* to break down cellulose
  - often carried out by symbiotic organisms (e.g. termites, ruminants)

Building Blocks

- *Amino acids*
  - ~20 different amino acids commonly appear in proteins (standard amino acids)
  - Not stored as raw materials pool
  - Many synthesized by body cells
    - Non-essential amino acids
    - Some cannot be synthesized and must be in diet
      - Essential amino acids

Fig 4.4, Table 4.1
Building Blocks

- **Lipids**
  - Construction of cell membranes
  - Formation of hormones, etc.
  - Some essential fatty acids
    - e.g. omega 3 and omega 6 fatty acids
  - Other lipids may be essential
    - e.g. insects cannot synthesize cholesterol

Building Blocks

- **Carbohydrates**
  - Construction of cell membranes
  - Adhesives, lubricants
  - Formation of hormones
  - Structural (e.g., chitin in exoskeletons)
  - No essential carbohydrates (all used can be synthesized)

Building Blocks

- **Vitamins**
  - Coenzymes necessary for various metabolic processes
  - Intermediates for biologically important molecules, etc.
  - Some synthesized by the body, some essential, depending on organism
    - e.g. most organisms can synthesize ascorbic acid, but humans, primates and some bats cannot

Building Blocks

- **Minerals (inorganic ions)**
  - Sulfur – skeletal structure, protein (methionine, cysteine)
  - Phosphorus – nucleic acids, ATP and other phosphorylated compounds, skeleton
  - Sodium – membrane potentials, cotransport
  - Potassium – membrane potentials, cotransport
  - Chloride – membrane potentials,
  - Calcium – skeletal structure, nerve and muscle function
  - Magnesium – nerve and muscle function, dynein function, cofactor of phosphate-related enzymes

Building Blocks

- **Trace Minerals (< 0.01% of body composition)**
  - Iron – cytochromes, hemes, catalase
  - Cobalt (in vitamin B12) – blood formation
  - Copper – hemoglobin formation, hemocyanin, cytochrome oxidase and other enzymes
  - Zinc – enzyme cofactor (e.g. carbonic anhydrase)
  - Manganese – enzyme activating cofactor
  - Molybdenum – enzyme cofactor (xanthine oxidase)
  - Iodine – thyroid hormone constituent