ENERGY

Introduction

Energy is defined as the ability or capacity to do work. Energy may exist in different forms and do different kinds of work. Aquatic animals require food to supply the energy they need. The energy value of foods may come from carbohydrates, fats, and proteins and can be measured directly by means of a bomb calorimeter. Energy is required to do mechanical work (muscle activity), chemical work (chemical processes which take place in the body), electrical work (nerve activity), and osmotic work (maintaining the body fluids at equilibrium with each other and with the medium, whether fresh, brackish or sea water in which the animal lives). Free energy is that which is left available for biological activity and growth after the energy requirement is met.

The quantity and cost of energy which is available for the growth of the species being cultured is most important from the point of view of the aquaculturist. The energy requirements of the animal vary in quantity according to the species, feeding habits, size, environment and reproductive state. The energy supplied by food is one of the important considerations in determining its nutritional value. Energy is expressed in kilocalories (kcal) or kilojoule (kJ). A kilocalorie is the amount of heat necessary to raise the temperature of one kilogram of water 1°C. The Joule (J) is the unit of energy in the metric system and one kcal is equal to 4.186 kJ. For example, 70 kcal is equal to 293.02 kJ.

After studying this section, the reader should be able to differentiate the forms of energy and their measurement. understand dietary energy metabolism, the energy balance equation and factors that influence dietary energy requirement of fish; and understand the significance of optimal protein to non-protein energy in fish diets.

Utilization of Energy

The gross energy (GE) value of feed is the total energy contained in the feed. Not all of the GE is available to the animal. Digestible energy (DE) of a feed is the difference between the GE and the energy excreted in the feces. The energy available for growth is that which remains after the requirements for metabolism, reproduction, etc., have been supplied (Figure 2.8).

The use of digestible energy values is a more sensible and practical way of expressing the energy value of feedstuffs. Theoretically, metabolizable energy values are a more exact measure of the dietary energy used for metabolism by the tissues. However, direct measurement of metabolizable energy in fish is difficult and involves confining the fish in small volumes of water in metabolism chambers.

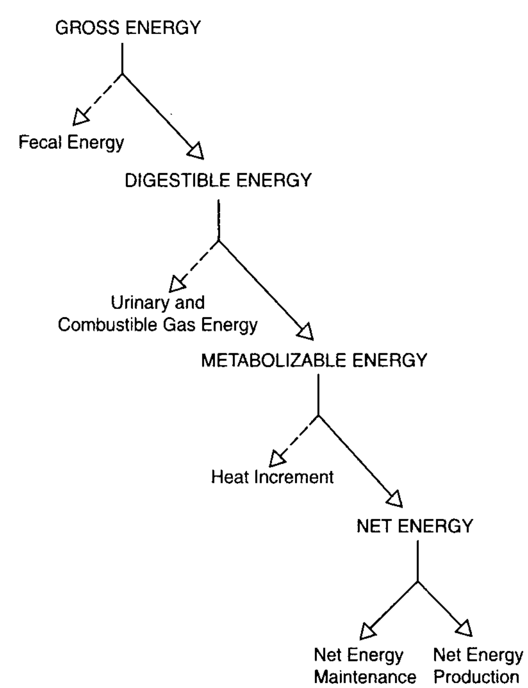

Figure 2.8
Utilization of energy. The energy available for growth is that which remains after the requirements for metabolism, reproduction, etc. have been supplied.

The metabolic rate or energy expenditure of small aquatic animals is greater than that of large animals. Small animals grow faster than large ones in terms of percentage increase in weight per day. Thus, the feed requirements of small animals are higher than those of large ones, when expressed as percentage of their weights.

Energy Metabolism

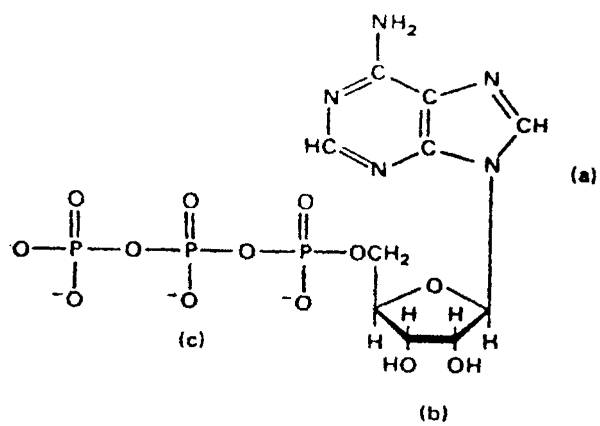

Figure 2.9
Chemical structure of ATP. Adenosine triphosphate contains adenine (a), ribose (b), and triphosphate unit (c) .

Energy is obtained after major nutrients carbohydrates, fats, and proteins undergo several chemical processes such as catabolism and oxidation within the animal body. The energy liberated is used for the maintenance of life processes such as cellular metabolism, growth, reproduction, and physical activity.

The free energy liberated from the catabolism and oxidation of major food nutrients is not utilized directly by the animal, but is trapped in the form of the energy-rich phosphorus bond of adenosine triphosphate or ATP (Figure 2.9). It is ATP which is the principal driving force in the energy requiring biochemical processes of life such as anabolism or synthesis, mechanical energy, electrical energy, osmotic work, and energy for transferring substances against concentration gradients. The role of ATP in cellular energetics is shown in Figure 2.10.

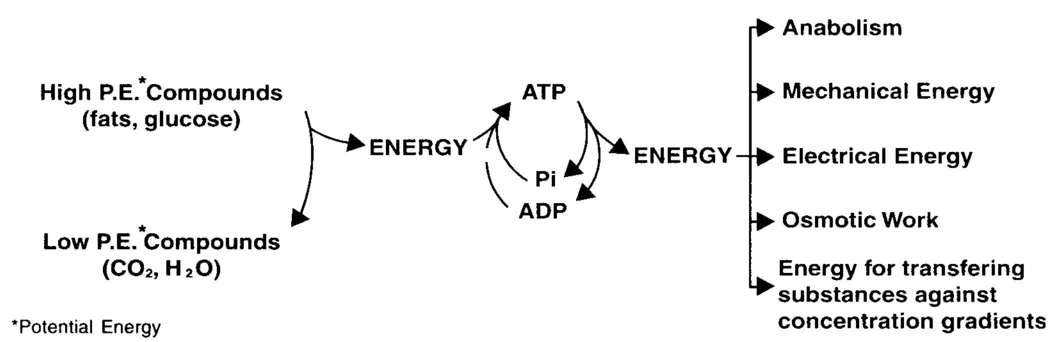

Figure 2.10
The role of ATP in cellular energetics. ATP is the principal driving force in the energy-requiring biochemical processes of life.

ATP is an energy-rich molecule because its triphosphate unit contains two phosphoanhydride bonds. A large amount of free energy is liberated when ATP is hydrolyzed to adenosine diphosphate (ADP) and orthophosphate (Pi) or when ATP is hydrolyzed to adenosine monophosphate (AMP) and pyrophosphate (PPi), as shown below:

$$ATP + H_2O \text{ —— } ADP + Pi + H^+$$
$$ATP + H_2O \text{ —— } AMP + PPi + H^+$$

Under typical cellular conditions the ΔG for these reactions is -12 kcal per mol. ATP, ADP, and AMP are interconvertible. The number of moles of ATP that is liberated in the complete oxidation of 1 mole of a carbohydrate like glucose and 1 mole of a fatty acid like palmitate to CO_2 and H_20 are 30 ATP and 106 ATP, respectively.

Energy Balance and Dietary Requirement

Since all biological systems obey the laws of thermodynamics, the energy balance equation can be represented as follows:

C = P + R + U + F

where:

C (consumption)	- the gross energy content of the food ingested
P (production)	- energy utilized in growth materials
R (respiration)	- net loss of energy as heat
U (urinary loss)	- energy lost in nitrogenous excretory product
F (fecal loss)	- energy lost in the feces

A generalized energy budget for young carnivorous and herbivorous fishes fed on natural food has been developed by Brett & Groves. An energy budget is the amount of energy in percent of ingested food that is utilized for each major process such as for growth and reproduction, digestion, respiration, urinary, and fecal production.

Carnivores : 100 C = 29P + 44R + 7U + 20F
Herbivores : 100 C = 20P + 37R + 2U + 41F

*Brett and Groves 1979

where the figures are expressed as percentage of ingested food energy or percentage of energy derived from eaten food. Metabolizable energy values for fish in kilocalories per gram of substance are: 4.5, 3.3, and 8.0 for protein, carbohydrate and fat, respectively. The energy needs for maintenance and voluntary swimming activity must first be satisfied before energy can be made available for growth.

Fish, like other animals, eat primarily to satisfy their energy requirements. When the feed has low energy density, fish are able to compensate by eating more of the feed but within certain limits. Therefore, it is essential that fish have easy access to feed or are given a palatable ration with sufficient energy to meet their energy needs.

Dietary Energy Requirement

Fish diets should have an optimal proportion of energy from dietary lipids, carbohydrates, and proteins. An excess or a deficiency of lipids and carbohydrates, which are nonprotein energy sources, may result in lower growth. If the diet is deficient in nonprotein energy, protein whose function is for growth and repair of tissues will be used as energy source rather than for growth. Similarly, if the diet contains an excess of lipids and carbohydrates, fish appetite is met even before enough protein (and possibly other nutrients) is eaten to meet the demand for maximum protein synthesis and growth. Many factors influence the energy requirements of fish:

1. water temperature - metabolic rate and consequently energy requirements for maintenance increase with temperature.
2. animal size - metabolic rate and consequently maintenance energy requirements, decrease with increasing animal size.
3. physiological status - energy requirements increase during production of gonads and reproduction activity such as migration during spawning.
4. water flow rate - energy requirements for maintaining a certain position in water increase with an increase in water flow rate.
5. light exposure - energy requirements for voluntary activity decrease during rest periods at night.
6. water quality and stress - pollutants, increased salinity, low dissolved oxygen, crowding or overstocking increase energy requirements for maintenance.

Guide Questions

1. What is a kilocalorie? Give the equivalent of kilocalorie in kilojoules.
2. What is the difference between gross energy in feed and energy excreted in the feces?
3. Give three examples of energy-requiring biological processes.
4. Differentiate between digestible energy and metabolizable energy. Why is metabolizable energy more difficult to measure?
5. What is ATP? What is its function?
6. Write and explain briefly the energy balance equation.
7. What are the factors that influence the energy requirements of aquatic animals?
8. Why is it important to provide an optimal proportion of protein to non protein energy in fish diets?