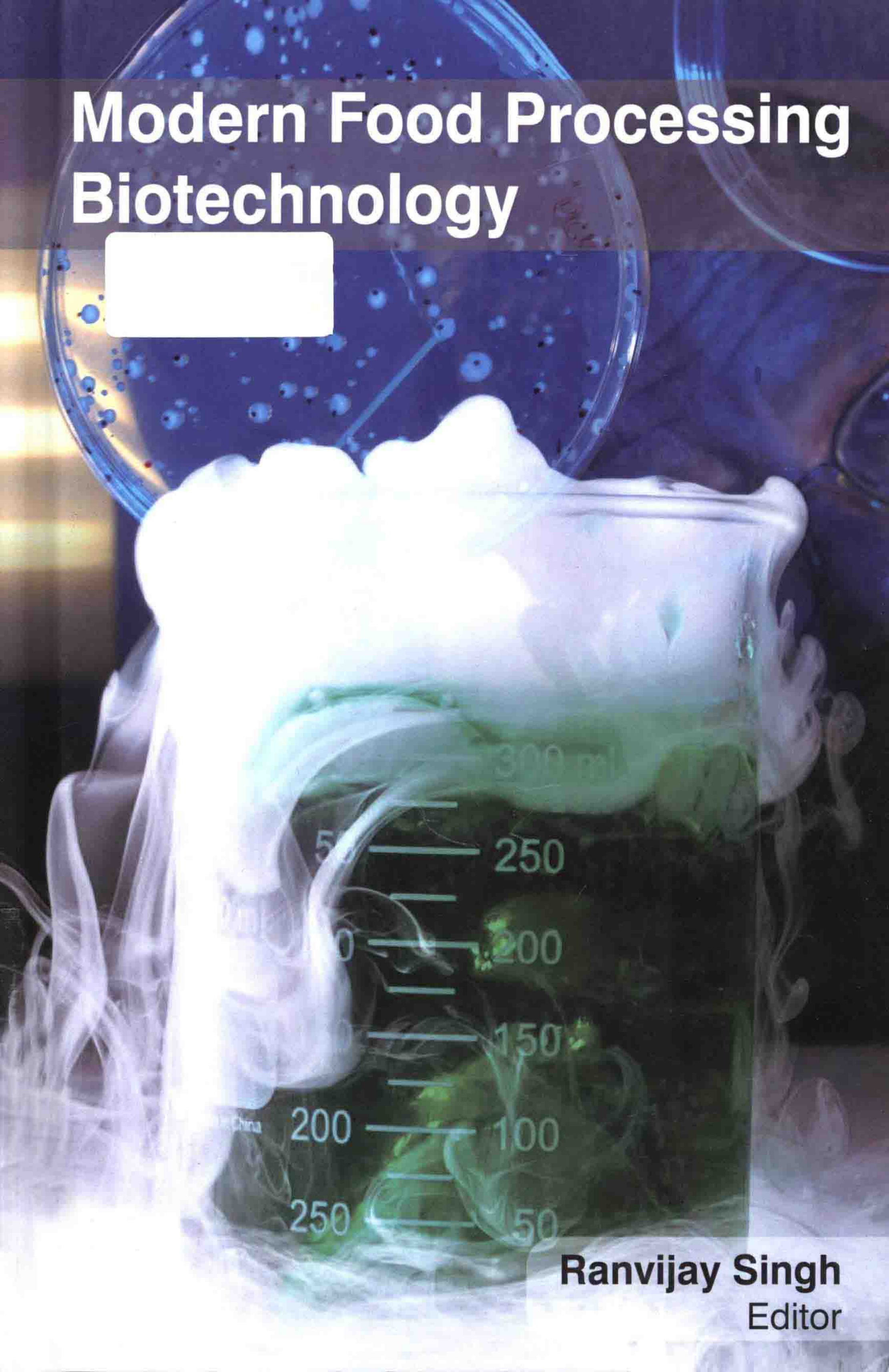
Modern Food Processing Biotechnology



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Preface

Survey research over the past decade shows that biotechnology is not likely to become an important issue for most American consumers. Consumers find biotechnology acceptable when they believe it offers benefits and it is safe. Surveys have consistently found that a majority of American consumers are willing to buy insect-protected food crops developed through biotechnology that use fewer chemical pesticides, as well as more nutritious foods. American consumers also appreciate the role that biotechnology can play in feeding the world. Research shows that European consumers are much less supportive of all biotechnology applications. Surveys since 1992 show that relatively few U.S. consumers have heard or read much about biotechnology. News about the cloned sheep pushed awareness to 50 percent in March 1997. Surveys in the first three months of 2000 show that awareness has fallen back to just over one-third in the United States. Such trends reflect the fact that most people get their information about biotechnology from the media. Unfortunately, many consumers also do not understand some fundamental principles of biology. European consumer awareness is somewhat higher, but knowledge is still low.

Media coverage in the United States has generally been balanced (which helps account for our relatively high levels of acceptance). This is in sharp contrast to the European media, which have played upon fear of the unknown. The European media have also tended to accept opponents' claims without question. Another issue is that many people no longer have a connection to agriculture. In fact, research has shown that many consumers are unaware that all foods are derived from plants or animals that already have been genetically modified through traditional (but imprecise) breeding methods. American consumers look to health professionals and scientific experts for credible information, but place relatively little trust in the activists who oppose biotechnology. Research shows that acceptance increases significantly when American consumers learn that organizations such as the National Academy of Sciences and the U.S. Food and Drug Administration have determined that biotech-derived foods are safe.

In contrast, European consumers express the most trust in those groups that oppose biotechnology. They have much less confidence in government, industry, or even scientists. American culture is more supportive and rewarding of new technology.

Europeans tend to view food differently from U.S. consumers. In fact, some Europeans reject all American food products. Europeans also want to protect their small farms to maintain open space and rural employment. Such forces underlie much of the European anxiety about agricultural biotech - especially since it is seen as an "American invention." Most of the industry leaders interviewed are quite enthusiastic about the benefits of biotechnology — especially in terms of increased food availability, enhanced nutrition, and environmental protection. Most feel that biotechnology has already provided benefits to consumers. Almost all recognize that foods developed through biotechnology have already been part of consumers' everyday diet. They clearly do not agree with most of the opponents' claims and tend to have almost no trust in such groups. Their main concerns involve lack of consumer acceptance — not the safety of the foods. They express high levels of confidence in the science and the regulatory process. In fact, almost none feel that biotechnology should not be used because of uncertain, potential risks. Most food industry leaders do not feel it is necessary to have special labels on biotech-derived foods. They express concerns that such labels would be perceived as a warning by consumers. They also worried that the need to segregate commodities would pose financial and logistical burdens on everyone in the system - including consumers. Food industry leaders recognize a major need to educate the public about biotechnology. They look to third parties, such as university and government scientists to provide such leadership.

The book has been written keeping in mind for the graduate and post graduate level bio-sciences and interdisciplinary courses.

—Ranvijay Singh

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Chapter 1

Food Processing

Food is any substance or materials that is consumed to provide nutritional support for the body or for pleasure. It is usually of plant or animal origin, and contains essential nutrients, such as carbohydrates, fats, proteins, vitamins, or minerals. It is ingested and assimilated by an organism to produce energy, stimulate growth, and maintain life.

Historically, people obtained food from hunting and gathering, farming, ranching, and fishing, known as agriculture. Today, most of the food energy consumed by the world population is supplied by the food industry operated by multinational corporations using intensive farming and industrial agriculture methods.

Food safety and food security are monitored by agencies such as the International Association for Food Protection, World Resources Institute, World Food Programme, Food and Agriculture Organization, and International Food Information Council. They address issues such as sustainability, biological diversity, climate change, nutritional economics, population growth, water supply, and access to food.

The right to food is a human right derived from the International Covenant on Economic, Social and Cultural Rights (ICESCR), recognizing the "right to an adequate standard of living, including adequate food", as well as the "fundamental right to be free from hunger".

Food Sources

Almost all foods are of plant or animal origin. Cereal grain is a staple food that provides more food energy worldwide than any other type of crop. Maize, wheat, and rice together account for 87% of all grain production worldwide.

Other foods not from animal or plant sources include various edible fungi, especially mushrooms. Fungi and ambient bacteria are used in the preparation of fermented and pickled foods such as leavened bread, alcoholic drinks, cheese, pickles, kombucha, and yogurt. Another example is blue-green algae such as Spirulina. Inorganic substances such as baking soda and cream of tartar are also used to chemically alter an ingredient.

Plants

Many plants or plant parts are eaten as food. There are around 2,000 plant species which are cultivated for food, and many have several distinct cultivars.

Seeds of plants are a good source of food for animals, including humans, because they contain the nutrients necessary for the plant's initial growth, including many healthy fats, such as Omega fats. In fact, the majority of food consumed by human beings are seed-based foods. Edible seeds include cereals (such as maize, wheat, and rice), legumes (such as beans, peas, and lentils), and nuts. Oilseeds are often pressed to produce rich oils, such as sunflower, flaxseed, rapeseed (including canola oil), and sesame. Seeds are typically high in unsaturated fats and, in moderation, are considered a health food, although not all seeds are edible. Large seeds, such as those from a lemon, pose a choking hazard, whereas seeds from apples and cherries contain the poison cyanide.

Fruits are the ripened ovaries of plants, including the seeds within. Many plants have evolved fruits that are attractive as a food source to animals, so that animals will eat the fruits and excrete the seeds some distance away. Fruits, therefore, make up a significant part of the diets of most cultures. Some botanical fruits, such as tomatoes, pumpkins, and eggplants, are eaten as vegetables.

Vegetables are a second type of plant matter that is commonly eaten as food. These include root vegetables (such as potatoes and carrots), leaf vegetables (such as spinach and lettuce), stem vegetables (such as bamboo shoots and asparagus), and inflorescence vegetables (such as globe artichokes and broccoli). Many herbs and spices are highly flavour some vegetables.

Animals

Animals are used as food either directly or indirectly by the products they produce. Meat is an example of a direct product taken from an animal, which comes from either muscle systems or from organs. Food products produced by animals include milk produced by mammary glands, which in many cultures is drunk or processed into dairy products such as cheese or butter. In addition, birds and other animals lay eggs, which are often eaten, and bees produce honey, a reduced nectar from flowers, which is a popular sweetener in many cultures. Some cultures consume blood, sometimes in the form of blood sausage, as a thickener for sauces, or in a cured, salted form for times of food scarcity, and others use blood in stews such as civet.

Some cultures and people do not consume meat or animal food products for cultural, dietary, health, ethical, or ideological reasons. Vegetarians do not consume meat. Vegans do not consume any foods that are or contain ingredients from an animal source.

Food Chain

Food chains and food webs are representations of the predator-prey relationships between species within an ecosystem or habitat.

Many chain and web models can be applicable depending on habitat or environmental factors. Every known food chain has a base made of autotrophs, organisms able to manufacture their own food (e.g. plants, chemotrophs).

Organisms Represented in Food Chains

In nearly all food chains, solar energy is input into the system as light and heat, utilized by autotrophs (i.e., producers) in a process called photosynthesis. Carbon dioxide is reduced (gains electrons) by being combined with water (a source of hydrogen atoms), producing glucose. Water splitting produces hydrogen, but is a nonspontaneous (endergonic) reaction requiring energy from the sun. Carbon dioxide and water, both stable, oxidized compounds, are low in energy, but glucose, a high-energy compound and good electron donor, is capable of storing the solar energy. This energy is expended for cellular processes, growth, and development. The plant sugars are polymerized for storage as long-chain carbohydrates, including other sugars, starch, and cellulose.

Glucose is also used to make fats and proteins. Proteins can be made using nitrates, sulfates, and phosphates in the soil. When autotrophs are eaten by heterotrophs, i.e., consumers such as animals, the carbohydrates, fats, and proteins contained in them become energy sources for the heterotrophs.

Chemoautotrophy

An important exception is lithotrophy, the utilization of inorganic compounds, especially minerals such as sulphur or iron, for energy. In some lithotrophs, minerals are used simply to power processes for making organic compounds from inorganic carbon sources. In a few food chains, e.g., near hydrothermal vents in the deep sea, autotrophs are able to produce organic compounds without sunlight, through a process similar to photosynthesis called chemosynthesis, using a carbon source such as carbon dioxide and a chemical energy sources such as hydrogen sulfide, H_2S, or molecular hydrogen, H_2.

Unlike water, the hydrogen compounds used in chemosynthesis are high in energy. Other lithotrophs are able to directly utilize inorganic substances, e.g., iron, hydrogen sulfide, elemental sulphur, or thiosulfate, for some or all of their energy needs.

Involvement in the Carbon Cycle

Carbon dioxide is recycled in the carbon cycle as carbohydrates, fats, and proteins are oxidized (burned) to produce carbon dioxide and water. Oxygen released by photosynthesis is utilized in respiration as an electron acceptor to release chemical energy stored in organic compounds. Dead organisms are consumed by detritivores, scavengers, and decomposers, including fungi and insects, thus returning nutrients to the soil.

Food Web

Food chains are overly simplistic as representatives of the relationships of living organisms in nature. Most consumers feed on multiple species and in turn, are fed upon by multiple other species.

For a snake, the prey might be a mouse, a lizard, or a frog, and the predator might be a bird of prey or a badger. The relations of detritivores and parasites are seldom adequately characterized in such chains as well.

A food web is a series of related food chains displaying the movement of energy and matter through an ecosystem. The food web is divided into two broad categories: the grazing web, beginning with autotrophs, and the detrital web, beginning with organic debris. There are many food chains contained in these food webs.

In a grazing web, energy and nutrients move from plants to the herbivores consuming them to the carnivores or omnivores preying upon the herbivores. In a detrital web, plant and animal matter is broken down by decomposers, e.g., bacteria and fungi, and moves to detritivores and then carnivores.

There are often relationships between the detrital web and the grazing web. Mushrooms produced by decomposers in the detrital web become a food source for deer, squirrels, and mice in the grazing web.

Earthworms eaten by robins are detritivores consuming decaying leaves.

Flow of Food Chains

Food energy flows from one organism to the next and to the next and so on, with some energy being lost at each level. Organisms in a food chain are grouped into trophic levels, based on how many links they are removed from the primary producers. In trophic levels there may be one species or a group of species with the same predators and prey.

Autotrophs such as plants or phytoplankton are in the first trophic level; they are at the base of the food chain. Herbivores (primary consumers) are in the second trophic level. Carnivores (secondary consumers) are in the third. Omnivores are found in the second and third levels. Predators preying upon other predators are tertiary consumers or secondary carnivores, and they are found in the fourth trophic level.

Food chain length is another way of describing food webs as a measure of the number of species encountered as energy or nutrients move from the plants to top predators. There are different ways of calculating food chain length depending on what parameters of the food web dynamic are being considered: connectance, energy, or interaction. In a simple predator-prey example, a deer is one step removed from the plants it eats (chain length = 1) and a wolf that eats the deer is two steps removed (chain length = 2). The relative amount or strength of influence that these parameters have on the food web address questions about:

- the identity or existence of a few dominant species (called strong interactors or keystone species)
- the total number of species and food-chain length (including many weak interactors) and
- how community structure, function and stability is determined.

Trophic Level

The trophic level of an organism is the position it occupies on the food web. The word trophic derives from the Greek τροφη (trophe) referring to food or feeding. A food chain represents a succession of organisms that eat another organism and are, in turn, eaten themselves. The number of steps an organism is from the start of the chain is a measure of its trophic level. Food chains start at trophic level 1 with primary producers such as plants, move to herbivores at level 2, predators at level 3 and typically finish with carnivores or apex predators at level 4 or 5. The path along the chain can form a one-way flow, or a food "web." Ecological communities with higher biodiversity form more complex trophic paths.

The plants in this image, and the algae and phytoplankton in the lake, are primary producers. They take nutrients from the soil or the water, and manufacture their own food by photosynthesis, using energy from the sun. The three basic ways organisms get food are as producers, consumers and decomposers.

- Producers (autotrophs) are typically plants or algae. Plants and algae do not usually eat other organisms, but pull nutrients from the soil or the ocean and manufacture their own food using photosynthesis. For this reason, they are called primary producers. In this way, it is energy from the sun that usually powers the base of the food chain. An exception occurs in deep-sea hydrothermal ecosystems, where there is no sunlight. Here primary producers manufacture food through a process called chemosynthesis.
- Consumers (heterotrophs) are animals which cannot manufacture their own food and need to consume other organisms. Animal that eat primary producers (like plants) are called herbivores. Animals that eat other animals are called carnivores, and animals that eat both plant and other animals are called omnivores.
- Decomposers (detritivores) break down dead plant and animal material and wastes and release it again as energy and nutrients into the ecosystem for recycling. Decomposers, such as bacteria and fungi (mushrooms), feed on waste and dead matter, converting it into inorganic chemicals that can be recycled as mineral nutrients for plants to use again.

Trophic levels can be represented by numbers, starting at level 1 with plants. Further trophic levels are numbered subsequently according to how far the organism is along the food chain.

- Level 1: Plants and algae make their own food and are called primary producers.
- Level 2: Herbivores eat plants and are called primary consumers.
- Level 3: Carnivores which eat herbivores are called secondary consumers.

- Level 4: Carnivores which eat other carnivores are called tertiary consumers.
- Level 5: Apex predators which have no predators are at the top of the food chain.

In real world ecosystems, there is more than one food chain for most organism, since most organisms eat more than one kind of food or are eaten by more than one type of predator. A diagram which sets out the intricate network of intersecting and overlapping food chains for an ecosystem is called its food web. Decomposers are often left off food webs, but if included, they mark the end of a food chain. Thus food chains start with primary producers and end with decay and decomposers. Since decomposers recycle nutrients, leaving them so they can be reused by primary producers, they are sometimes regarded as occupying their own trophic level.

Biomass Transfer Efficiency

Generally, each trophic level relates to the one below it by absorbing some of the energy it consumes, and in this way can be regarded as resting on, or supported by the next lower trophic level. Food chains can be diagrammed to illustrate the amount of energy that moves from one feeding level to the next in a food chain. This is called an energy pyramid. The energy transferred between levels can also be thought of as approximating to a transfer in biomass, so energy pyramids can also be viewed as biomass pyramids, picturing the amount of biomass that results at higher levels from biomass consumed at lower levels.

The efficiency with which energy or biomass is transferred from one trophic level to the next is called the ecological efficiency. Consumers at each level convert on average only about 10 percent of the chemical energy in their food to their own organic tissue. For this reason, food chains rarely extend for more than 5 or 6 levels. At the lowest trophic level (the bottom of the food chain), plants convert about one percent of the sunlight they receive into chemical energy. It follows from this that the total energy originally present in the incident sunlight that is finally embodied in a tertiary consumer is about 0.001 %

Fractional Trophic Levels

Food webs largely define ecosystems, and the trophic levels define the position of organisms within the webs. But these trophic levels are not always simple integers, because organisms often feed at more than one trophic level. For example, some carnivores also eat plants, and some plants are carnivores. A large carnivore may eat both smaller carnivores and herbivores; the bobcat eats rabbits, but the mountain lion eats both bobcats and rabbits. Animals can also eat each other; the bullfrog eats crayfish and crayfish eat young bullfrogs. The feeding habits of a juvenile animal, and consequently its trophic level, can change as it grows up. The fisheries scientist Daniel Pauly sets the values of trophic levels to one in plants and detritus, two in herbivores and detritivores (primary consumers), three in secondary consumers, and so on. The definition of the trophic level, TL, for any consumer species i is:

$$TL_i = 1 + \sum_j \left(TL_j . DC_{ij}\right)$$

where TL_i is the fractional trophic level of the prey j, and DC_{ij} represents the fraction of j in the diet of i. In the case of marine ecosystems, the trophic level of most fish and other marine consumers takes value between 2.0 and 5.0. The upper value, 5.0, is unusual, even for large fish, though it occurs in apex predators of marine mammals, such as polar bears and killer whales.

Mean trophic level

In fisheries, the mean trophic level for the fisheries catch across an entire area or ecosystem is calculated for year y as:

$$TL_y = \frac{\sum_i \left(TL_i . Y_{iy}\right)}{\sum_i Y_{iy}}$$

where Y_{iy} is the catch of the species or group i in year y, and TL_i is the fractional trophic level for species i as defined above.

It was once believed that fish at higher trophic levels usually have a higher economic value; resulting in overfishing at the higher trophic levels. Earlier reports found precipitous declines in mean trophic level of fisheries catch, in a process known as fishing down the food web. However, more recent work finds no relation between economic value and trophic level; and that mean trophic levels in catches, surveys and stock assessments have not in fact declined, suggesting that fishing down the food web is not a global phenomenon.

FiB Index

Since biomass transfer efficiencies are only about 10 percent, it follows that the rate of biological production is much greater at lower trophic levels than it is at higher levels. Fisheries catches, at least to begin with, will tend to increase as the trophic level declines. At this point the fisheries will target species lower in the food web. In 2000, this led Pauly and others to construct a "Fisheries in Balance" index, usually called the FiB index. The FiB index is defined, for any year y, by

$$FiBy = \log((Y_y/(TE)^{TLy})/(Y_0/(TE)^{TL0}))$$

where Y_y is the catch at year y, TL_y is the mean trophic level of the catch at year y, Y_0 is the catch and TL_0 the mean trophic level of the catch at the start of the series being analyzed, and TE is the transfer efficiency of biomass or energy between trophic levels.

The FiB index is stable (zero) over periods of time when changes in trophic levels are matched by appropriate changes in the catch in the opposite direction. The index increases if catches increase for any reason, e.g. higher fish biomass, or geographic expansion Such decreases explain the "backward-bending" plots of trophic level versus catch originally observed by Pauly and others in 1998.

Entropic Losses in the Chain

It is the case that the biomass of each trophic level decreases from the base of the chain to the top. This is because energy is lost to the environment with each transfer as entropy increases. About eighty to ninety percent of the energy is expended for the organism's life processes or is lost as heat or waste. Only about ten to twenty percent of the organism's energy is generally passed to the next organism. The amount can be less than one percent in animals consuming less digestible plants, and it can be as high as forty percent in zooplankton consuming phytoplankton. Graphic representations of the biomass or productivity at each tropic level are called ecological pyramids or trophic pyramids. The transfer of energy from primary producers to top consumers can also be characterized by energy flow diagrams.

Ecological Efficiency

Ecological efficiency describes the efficiency with which energy is transferred from one trophic level to the next. It is determined by a combination of efficiencies relating to organismic resource acquisition and assimilation in an ecosystem.

Energy Transfer

Primary production occurs in autotrophic organisms of an ecosystem. Photoautotrophs such as vascular plants and algae convert energy from the sun into energy stored as carbon compounds.