SPECIAL PROCESSES FOR PRODUCTS, FUEL AND ENERGY

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Summary

This topic embraces a diverse range of biotechnological processes, virtually all of which have as a common feature the sustainable production of biomass, either as a source of food, bioproducts (e.g. food additives, pharmaceuticals, dietary supplements), fuel or energy. Algal biomass, particularly in the form of macroalgae (seaweeds), has been consumed by humans and their livestock for centuries, and is the source of alginates, agars and carrageenans used as thickening agents in foods, cosmetics and pharmaceuticals. Algae are also rich in vitamins and carotenoids used in foods, vitamin supplements and health food products, and as feed additives for poultry, livestock, fish, and crustaceans. Furthermore, algae and algal products exhibit a manifold range of activities effective in the prevention and treatment of diseases associated with modern-day lifestyles. The past 20 years has also recorded a dramatic increase in worldwide mushroom production resulting from a wider appreciation of their nutritional,

organoleptic and medicinal attributes, combined with improvements in cultivation technology. Edible mushroom cultivation represents a prime example of an economically viable process for the direct conversion of certain types of low-grade organic wastes, consisting mainly of lignocellulose and generated for the most part by the agricultural, forestry and food processing industries, into a value-added commodity that is beneficial to humankind. Mushroom cultivation was initially directed at food production but, following the application of modern scientific methodology, earlier empirical observations relating to the health-promoting features of these fungi are now being explained in mechanistic terms. This has led to the rapid development of a new industry involving mushroom products (mushroom nutriceuticals/dietary supplements), the annual current market value of which is estimated to be in excess of US$14 billion. Inextricably linked to adequate supplies of food and bioproducts important for human health and wellbeing, and arguably the greatest challenge facing humankind, is the provision of sufficient energy supplies needed by the existing developed and the growing economies without adverse impacts on the environment. Solving all the problems related to the present high dependency of the world's economy on fossil fuels requires an integrated approach, a potential major contributor to which is "biomass energy", a term used to describe renewable fuels (e.g. biogas, biodiesel, bioethanol) made from plant material. However, whilst biofuels may have a promising future, current consumption of biofuels worldwide represents less than 0.5% of the world's annual oil consumption. Production costs are still relatively high, and feedstocks (raw materials) are often obtained through intensive agriculture raising concerns for biodiversity, world food availability, the environment and social stability. Some of these concerns can be addressed if the focus of the biomass industry shifts more to using waste raw materials, and on developing alternative (non-food) feedstock crops. For the foreseeable future, the success of biomass energy will depend on the political will to encourage its development by means of direct or indirect aid.

1. Introduction

This topic is concerned with a selection of special biotechnological processes, the underlying themes of which are sustainability and environmental protection. Most relate to the production of biomass as a source of food and other products, or biomass conversion to sources of fuel and energy. Biomass energy is the energy stored in non-fossil organic materials including wastes generated by the forest, agricultural and industrial sectors. Unlike fossil fuels that are formed only after long periods of time, usable forms of biomass energy can be generated in a continuous manner. Since all plant and plant-derived biomass is derived from energy originally captured by photosynthesis, its use for manufacturing biomass-derived fuel, energy and other products essentially generates no net greenhouse gas. However, it is necessary to include the energy required for growing, collecting and converting the biomass in the final economic and environmental equation. Along with hydroelectric, wind and direct solar power, biomass energy represents a key renewable energy resource.

2. Historical Background

2.1 Bioproducts

Biotechnology for the purpose of product formation has been exploited since humankind first practiced the art of fermentation, and biotechnological processes, many of which today employ genetically modified organisms, are currently used to generate a plethora of products [see also – *Fermented Foods and Their Processing*]. One notable example, the production of acetone by *Clostridium acetobutylicum*, is generally considered to have influenced the course of human history. Acetone was used in the manufacture of cordite explosive propellants critical to the Allies during World War I. In gratitude to Chaim Weitzman, who developed the process, Lloyd George, the British Prime Minister at the time, is thought to have instigated a chain of events that resulted in the Balfour Declaration of 1917 that ultimately led to the establishment of modern-day Israel. Non-fuel/energy articles included in this topic are focused on selected biotechnological processes used to produce food, food supplements, and pharmaceuticals of algal origin.

The acetic acid bacteria, consisting of two genera, *Acetobacter* and *Gluconobacter*, have long been applied in the manufacture and preservation of traditional fermented foods and food-related products worldwide [see – *Biotechnological Applications of Acetic Acid Bacteria for Food Production*]. These obligate aerobes oxidize ethanol, sugar alcohols, and sugars into their corresponding acids, of which the most prominent reaction is the conversion of ethanol to acetic acid. The best-known food-related product of *Acetobacter* is vinegar (from the French *vin aigre*, meaning "sour wine") and vinegar's use as a condiment and food ingredient spans thousands of years. Vinegar folklore also has it that Hannibal of Carthage (c. 200 BC), used vinegar to dissolve boulders that blocked his army's path. Hippocrates (c. 420 BC) used vinegar medicinally to clean ulcerations and treat sores, and prescribed oxymel, a popular ancient medicine composed of honey and vinegar, for persistent coughs. Sung Tse, the 10th century creator of forensic medicine, advocated hand washing with sulfur and vinegar to avoid infection during autopsies. Numerous ailments, including dropsy, poison ivy, croup, and stomach ache, were treated with vinegar, and, prior to the development of hypoglycemic agents, vinegar “teas” were commonly consumed for controlling diabetes.

Natural colorants represent another important group of food-related bioproducts. [see – *Natural Food Colorants*] From ancient times, the practice of adding coloring materials such as turmeric, paprika and saffron has been used as a means of enhancing the aesthetic value of foods and beverages. The wide spectrum of colorants adopted for this purpose were usually derived from natural sources—plant, animal, or mineral – although *Monascus*, a red pigment producing fungus, has traditionally been used to colour foodstuffs in the Orient for hundreds of years. More specifically, natural food colours come from variety of sources such as seeds, fruits, vegetables, herbs, spices, algae and insects. Individual colorants include carmine, betalains, monascus, gardenia yellow, paprika, annatto, lycopene, phycobilins, tumeric, chlorophylls, caramel and anthocyanins. The anthocyanins have a long history as part of the human diet, and these and other flavonoids are receiving renewed attention for their perceived health attributes. Nowadays, a colouring ingredient is selected because it contributes a unique flavour in addition to added colour alone, as in the case of the unique dual functions of turmeric and mustard in fermented pickle products.

The Aztecs of pre-Columbian Mexico recognized and exploited the nutritional benefits

of *Spirulina* (*Arthrospira*) and, even today, this aquatic, unicellular cyanobacterium is an important staple food in the diet of the Kanembous living near the small lakes and dunes that border Lake Chad. Normally found in warm, freshwater, alkaline, volcanic lakes in hot, sunny climates around the world, *Spirulina* is now cultivated in closed pond systems, often on marginal land unsuitable for most forms of conventional agriculture. Macroalgae also have a long history as a food source in many cultures. Nori (*Porphyra*) (used for rolling sushi), wakame (*Undaria pinnatifida)* (a component of miso soup) and kombu (*Laminaria* spp) (used a a soup stock) continue to form part of the staple part of the diet in countries like Japan and Korea. *Porphyra* is also used to prepare Welsh laver bread.

Algae as a source of medicinal compounds dates back even further and examples (*Sargassum*, *Ecklonia*) are recorded in the first official version of 'Ben Cao, the compendia of Chinese medicines, which was published during the Han Dynasty (100 BC). Europeans have historically used marine algae as food and medicines for themselves and their livestock and cough medicines made from *Chondrus crispus* (Irish moss) are still common. Gerard's 'On the History of Plants', first published in 1658, recommended algae for treating lung diseases, gangrene, venereal disease and cholera, and to settle the stomach. In the last few centuries, macroalgae-based treatments have been used as a dieting aid, and brown algae are still included in supplements designed to aid weight loss. Marine algae have also been used as food and medicines by ancient civilizations throughout the American continent [see also – *Pharmaceuticals from Algae*]. In 1995, *Sargassum*, *Gracilaria*, *Porphyra* and *Durvillea*, were found at the site at Monte Verde in Chile that dated back 12,000 years.

Mushrooms, the fruiting bodies of many basidiomycetes and a much smaller number of ascomycetes, have been highly regarded as a nutritious and healthy food, especially by the peoples of Asia **[**see also – *Nutriceuticals from Mushrooms*]. Prehistoric man almost certainly used mushrooms as food and there is ample evidence that the great early civilizations of the Greeks, Egyptians, Romans, Chinese and Mexicans prized mushrooms as a delicacy, for purported therapeutic value and, in some cases, for use in religious rites. Consequently, it is not surprising that the intentional cultivation of mushrooms had a very early beginning. We now know that this occurred in China around 600 AD with the cultivation of *Auricularia auricula* on wood logs. Other wood-rotting mushrooms such as *Flammulina* and *Lentinula* were cultivated later in a similar manner using relatively low-tech systems, but the greatest advance in mushroom cultivation occurred in France around 1600 AD when *Agaricus* ('champignon' or 'button mushroom') was grown on a composted substrate. In the years since World War II, there has been a consistent increase in mushroom production that greatly accelerated in the period from 1986 until the present day. In the Western world, *Agaricus* has remained the most extensively cultivated mushroom in quantitative terms although mushrooms long popular in Asia (*Lentinula, Pleurotus*) are now produced in similar quantities.

2.2 Biofuels

Biogas, a mixture of mainly methane (~65%) and carbon dioxide produced by anaerobic digestion of organic matter, is one of the earliest recorded biofuels [see also – *Biogas as*

Renewable Energy from Organic Waste]. Biogas was used to heat bath water in Assyria as early as the 10th century BC and, in 1895, sufficient quantities were recovered from the sewage system of Exeter in southwest England to light the town's street lamps. Jan Baptista van Helmont (1577-1644), the Flemish chemist, physiologist and physician, observed that decaying organic material generated flammable gases, and Count Alessandro Volta subsequently demonstrated in 1776 that the amount of gas produced was directly proportional to the amount of organic material present. In 1808, Sir Humphrey Davy determined that methane was present in the gases produced by cattle manure. In the 1930's, people began to recognize anaerobic digestion as a science, and subsequent research led to the discovery of anaerobic bacteria and the conditions required to grow methane bacteria.

Biodiesel is an alternative diesel fuel produced from renewable sources such as vegetable oils, recycled cooking oils, and animal fats [see also – *Biodiesel*]. Biodiesel can be used in neat form, or blended with petroleum diesel for use in diesel engines, and requires no engine modifications. Its physical and chemical properties as it relates to operation of diesel engines are similar to petroleum based diesel fuel. Rudolph Diesel used peanut oil when he first demonstrated his compression ignition engine at the World Exhibition in Paris in 1898. He was not alone in believing that biomass fuels would be the foundation of a future transportation industry. Henry Ford designed his 1908 Model T to use ethanol and built a plant to produce ethanol from hemp. Hemp seed oil also constituted a high-grade diesel fuel and could be used as a machine lubricant and engine oil. Vegetable oils were used in diesel engines until the 1920's when alteration were made to engines enabling them to take advantage of the much lower-priced low-grade fuels on offer by the petroleum industry.

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Bibliography

Bhat, M.K. (2000) Cellulase and related enzymes in biotechnology. *Biotechnology Advances* 18: 355-383. [An overview of the biotechnological state-of-the-art for cellulases and related enzymes].

Chang S. T. and Miles, P. G. (2004). *Mushrooms: Cultivation, Nutritional Value, Medicinal Effect, and Environmental Impact* (Second Edition), 451 pp. Boca Raton, Fl: CRC Press. [This book presents the latest cultivation and biotechnological advances that contribute to the modernization of mushroom farming and the mushroom industry].

Del Campo, J.A., García-González, M. and Guerrero, M.G. (2007). Outdoor cultivation of microalgae for carotenoid production: current state and perspectives. *Applied Microbiology and Biotechnology,* **74**: 1163-1174. [A mini-review that compares the current state of the technologies for cultivating microalgae based on either open-pond systems or closed photobioreactors]

Dixon, B. (1994) *Power Unseen: How microbes rule the world.* W.H. Freeman:Oxford. 237pp. [A collection of short essays about micro-organisms and their complex relations with humankind].

Ethanol fuel markets 2007: Alternative Fuel Solutions

http://www.the-infoshop.com/study/vt51739-ethanol-fuel.html [This study is a comprehensive review of the current and future global role of ethanol as a vehicular fuel and fuel additive through 2012].

Fitton, J.H. (2005). Marine algae and health: A review of the scientific and historical literature. *Glycoscience and Nutrition*, **6**: Issue 2. (www.glycoscience.org) [A comprehensive review of the bioactivities attributed to macroalgae]

Johnston, C.S. and Gass, C.A. (2006). Vinegar: Medicinal Uses and Antiglycemic Effect. *Medscape General Medicine*, **8:** 61-69. [This review documents the historical applications of vinegar, and assesses more recent scientific data relating to attributed medicinal properties]

Knowles, J., Lehtovaara, P. and Teeri, T. T. (1987). Cellulase families and their genes. *Trends in Biotechnology.* **5:** 255-261. [A detailed description of the biochemistry and molecular biology of cellulases]

Mapari, S. A. S., Nielsen, K. F., Larsen, T. O., Frisvad, J. C., Meyer, A. S. and Thrane, U. (2005) Exploring fungal biodiversity for the production of water-soluble pigments as potential natural food colorants. *Current Opinion in Biotechnology*, **16:** 231-238. [This article reviews the potential and advantages of fungi as a source on natural food colorants]

Pimentel, D. and Patzek, T.W. (2005) Ethanol production using corn, switchgrass, and wood; Biodiesel production using soybean and sunflower. *Natural Resources Research*, 14:65-76. [A research paper comparing the fossil fuel input required for ethanol production from different feedstocks]

Pulz O, Gross W. (2004) Valuable products from biotechnology of microalgae. *Applied Microbiology and Biotechnology*, **65**: 635-648. [This mini-review describes various biotechnological applications of micro-algae ranging from simple biomass production for food and feed to the generation of high-value products]

REN21. (2006). Renewables - global status report (2006 update). 35pp. Paris:REN21 Secretariat and Washington, DC: Worldwatch Institute. [A report by the Renewable Energy Policy Network for the 21st Century emphasizing the importance of renewable energy]

Tomme, P., Warren, R. A. J. and Gilkes, N. R. (1995). Cellulose hydrolysis by bacteria and fungi. *Advances in Microbial Physiology*. **37:** 2-81. [A comprehensive review of microbial cellulose degradation]

Zemke-White W.L. (1999). World seaweed utilisation: An end-of-century summary. *Journal of Applied Phycology*. **11**: 369-376. [A comprehensive assessment of world seaweed production and utilisation at the end of the last century]

Biographical Sketch

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