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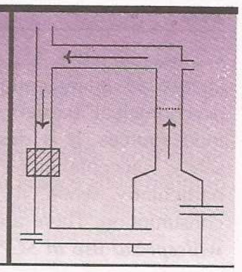
Single-Cell Protein, and Mushrooms



Single-cell protein (SCP) refers to the microbial cells or total protein extracted from pure microbial cell culture (monoculture) which can be used as protein supplement for humans or animals. The word SCP is considered to be appropriate, since most of the microorganisms grow as single or filamentious individuals. This is in contrast to complete multicellular plants and animals. If the SCP is suitable for human consumption, it is considered as ***food grade***. SCP is regarded as ***feed grade***, when it is used as animal feed supplement, but not suitable for human consumption.

Single-cell protein broadly refers to the ***microbial biomass*** or ***protein extract used as food or feed additive***. Besides high protein content (about 60–80% of dry cell weight), SCP also contains fats, carbohydrates, nucleic acids, vitamins and minerals. Another advantage with SCP is that it is rich in certain essential amino acids (lysine, methionine) which are usually limiting in most plant and animal foods. Thus, SCP is of high nutritional value for human or animal consumption.

It is estimated that about 25% of the world's population currently suffers from hunger and malnutrition. Most of these people live in developing countries. Therefore, SCP deserves a serious consideration for its use as food or feed supplement. In addition to its utility as a nutritional supplement, SCP can also be used for the isolation of several compounds e.g. carbohydrates, fats, vitamins, minerals.

Advantages of using microorganisms for SCP production

The protein-producing capabilities of a 250 kg cow and 250 g of microorganisms are often compared. The cow can produce about 200 g protein per day. On the other hand, microorganisms, theoretically, when grown under ideal conditions, could produce about 20–25 tonnes of protein. There are many advantages of using microorganisms for SCP production.

1. Microorganisms grow at a very rapid rate under optimal culture conditions. Some microbes double their mass in less than 30 minutes.

2. The ***quality and quantity of protein content in microorganisms is better compared to higher plants and animals.***

3. A ***wide range of raw materials***, which are otherwise wasted, ***can be fruitfully used*** for SCP production.

4. The culture conditions and the fermentation processes are very simple.

5. Microorganisms can be easily handled, and subjected to genetic manipulations.

Safety, acceptability and toxicology of SCP

There are many non-technological factors that influence the production of SCP. These include the geographical, social, political and psychological factors. In many countries, there are social and psychological barriers to use microorganisms as food sources. It is desirable to first consider the safety, acceptability and toxicology of SCP, particularly when it is considered for human consumption. There are several ***limitations for the widespread use of SCP***.

1. The ***nucleic acid content*** of microbial biomass is ***very high*** (4-6% in algae; 10–15% in bacteria; 5–10% in yeast). This is highly hazardous, since humans have a limited capacity to degrade nucleic acids.

2. The presence of ***carcinogenic and other toxic substances*** is often observed in association with SCP. These include the hydrocarbons, heavy metals, mycotoxins and some contaminants. The nature and production of these compounds depends on the raw materials, and the type of organism used.

3. There is a possibility of contamination of pathogenic microorganisms in the SCP.

4. The digestion of microbial cells is rather slow. This is frequently ***associated with indigestion and allergic reactions*** in individuals.

5. Food grade production of SCP is more expensive than some other sources of proteins e.g. soy meal. Of course, this mainly depends on the cost of raw materials. In general, SCP for human consumption is 10 times more expensive than SCP for animal feed.

For the above said reasons, many countries give low priority for the use of SCP for human consumption. In fact, mass production of SCP using costly raw materials has been discontinued in some countries e.g. Japan, Britain, Italy. However, these countries continue their efforts to produce SCP from cheap raw materials such as organic wastes.

MICROORGANISMS AND SUBSTRATES USED FOR PRODUCTION OF SCP

Several microorganisms that include bacteria, yeasts, fungi, algae and actiomycetes utilizing a wide range of substrates are used for the production of SCP. A selected list is given in ***Table 29.1***.

The selection of microorganisms for SCP production is based on several criteria. These include their nutritive value, non-pathogenic nature, production cost, raw materials used and growth pattern.

Substrates

The nature of the raw materials supplying substrates is very crucial for SCP production. The cost of raw material significantly influences the

TABLE 29.1 A selected list of microorganisms and substrates used for single-cell protein production

Microorganism	*Substrate(s)*
Bacteria	
Methylophilus methylotrophus	Methane, methanol
Methylomonas sp	Methanol
Pseudomonas sp	Alkanes
Brevibacterium sp	C_1–C_4 hydrocarbons
Yeasts	
Saccharomycopsis lipolytica (previous name—*Candida lipolytica*)	Alkanes
Candida utilis	Sulfite liquor
Kluyveromyces fragilis	Whey
Saccharomyces cerevisiae (baker's yeast)	Molasses
Lactobacillus bulgaricus	Whey
Tosulopsis sp	Methanol
Fungi	
Chaetomium cellulolyticum	Cellulosic wastes
Paecilomyces varioti	Sulfite liquor
Aspergillus niger	Molasses
Trichoderma viride	Straw, starch
Algae	
Spirulina maxima	Carbon dioxide
Chlorella pyrenoidosa	Carbon dioxide
Scenedesmus acutus	Carbon dioxide
Actinomycetes	
Nocardia sp	Alkanes
Thermomonospora fusca	Cellulose
Mushrooms (a type of fungi)	
Agaricus biosporus	Compost, rice straw
Morchella crassipes	Whey, sulfite liquor
Auricularia sp	Saw dust, rice bran
Lentinus edodes	Saw dust, rice bran
Volvariella volvaceae	Cotton, straw

final cost of SCP. The most commonly used raw materials may be grouped in the following categories.

1. **High-energy sources** e.g. alkanes, methane, methanol, ethanol, gas oil.

2. **Waste products** e.g. molasses, whey, sewage, animal manures, straw, begasse.

3. **Agricultural and foresty sources** e.g. cellulose, lignin.

4. **Carbon dioxide**, the simplest carbon source.

Some details on the production of SCP from most important raw materials are briefly described.

PRODUCTION OF SCP FROM HIGH ENERGY SOURCES

There are a large number of energy-rich carbon compounds or their derivatives which serve as raw materials for SCP production. These include ***alkanes, methane, methanol, ethanol and gas oil.*** Bacteria and yeasts are mostly employed for SCP production from high energy sources. Some scientists question the wisdom of using (rather misusing) high-energy compounds for the production of food, since they regard it as a wasteful exercise.

Production of SCP from alkanes

Alkanes can be degraded by many yeasts, certain bacteria and fungi. The major limitation of alkanes is that they are not easily soluble, hence they cannot enter the cells rapidly. It is believed that the cells produce emulsifying substances which convert insoluble alkanes into small droplets (0.01-0.5 μm) that can enter the cells by passive diffusion. It is observed that when cells are grown on a medium of alkanes enriched with lipids, the diffusion of alkanes into the cells is enhanced.

Certain yeasts have been successfully used for producing SCP from alkanes e.g. *Saccharomycopsis lipolytica, Candida tropicalis, Candida oleophila.*

Petroleum products for SCP production : Several oil companies have developed fermentation systems, employing petroleum products for large scale manufacture of SCP by yeasts. Two types of petroleum products are mainly used for this purpose.

1. ***Gas oil*** or ***diesel oil*** containing 10-25% of alkanes with carbon length C_{15}–C_{30} (i.e. long chain alkanes).

2. ***Short chain alkanes*** with carbon length in the range of C_{10}–C_{17}, isolated from gas oil by use of molecular sieves.

Airlift bioreactor system with continuous operation was once used (in France and Britain) to produce SCP from gas oil employing the organism *Saccharomycopsis lipolytica*. But this is now discontinued for political reasons.

Degradation of alkanes : Alkanes have to be first broken down to appropriate metabolites for their utilization to form SCP. The most important step in this direction is the introduction of oxygen into alkanes which can be brought out by two pathways-terminal oxidation and subterminal oxidation (***Fig. 29.1***).

In ***terminal oxidation***, the terminal carbon gets oxidized to the corresponding monocarboxylic acid. The latter then undergoes β-oxidation to form acetic acid. In some microorganisms, the oxidation may occur at both the terminal carbon atoms (by a process referred to as ω-oxidation) to form a dicarboxylic acid. This can be further broken down to acetate and succinate by β-oxidation. Terminal oxidation is the predominant pathway occurring in majority of yeasts and bacteria.

Subterminal oxidation involves the oxidation of interminal carbon atoms (any carbon other than terminal i.e. C_2, C_3, C_4, and so on). The corresponding ketone produced undergoes α-oxidation, decarboxylation, and finally β-oxidation to form acetate and propionate.

The individual enzymes responsible for terminal oxidation or subterminal oxidation have not been fully identified.

Limitations of SCP production from alkanes

The production of SCP from alkanes is a very complex biotechnological process and has been extensively studied. The major drawback of alkanes as substrates is the formation of carcinogens, along with SCP which are highly harmful. For this reason, many countries have discontinued alkane-based production of SCP.

Production of SCP from methane

Methane is the chief constituent of natural gas in many regions. Although methane can be isolated in pure gas form, it cannot be liquified. The handling