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REVIEW ARTICLE

Single Cell Protein - A Review

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ABSTRACT

The term 'single cell protein' was coined in 1968 at a meeting held at the Massachusetts Institute of Technology (MIT) to replace the less aesthetic 'microbial protein' and 'petroprotein' which were the terms originally used. Use of microbes as a food source may appear to be unacceptable to some people but the idea of consumption of microbes as food for man and animals is certainly innovative to solve the global food problem. Single cell protein (SCP) has many applications in food and feed industries The microorganisms which can be used as SCP include a variety of bacteria, marine microalgae, yeasts and molds Production of SCP using cheap materials as substrate provides an economically feasible source of protein for use in animal feed or the processing of products for human consumption, as it often meets dietary requirements for protein. Many microorganisms have been used to convert various substrates into biomass SCP production technologies arose as a promising way to solve the problem of worldwide protein shortage. They evolved as bioconversion processes which turned low-value by-products into products with added nutritional and market value and since SCP belongs to one of the cheapest protein products in the market, its production is profitable.

KEYWORDS

Single cell protein, Applications, Uses, Fermentation, Bacillus subtilis

INTRODUCTION

The term single cell protein refers to the dried microbial cell or total protein extracted from pure microbial cell culture (algae, bacteria, filamentous fungi, yeast) which can be used as food supplement to humans. (Food grade) or animals (Feed grade)[1]. Most of the developing countries of the world are facing a major problem for malnutrients. Due to rapid growth in the population deficiency of protein and nutrients are seen in human food and as well as animals feed single cell proteins have application in animal nutrient as fattening calves, poultry, pigs and fish breeding. In food it is used as aroma carriers, vitamin carriers, emulsifying aids and to improve the nutritive value of baked products in soups, in readymade-to serve meals, in recipes. In the technical field in paper processing, leather processing and as foam stabilizers.

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It has been estimated that if necessary measures are not taken, the mal nutrition conditions will lead to some major crisis in the developing countries. Therefore it is important increase protein production and also its availability to the population by utilizing all the available ways and also methods. The increased world demand for food and in particular feed protein sources to supplement the available proteins source. SCP production technologies arose as a promising way to solve the problem of worldwide protein shortage[2].

Interest in microbial protein for animal fodder largely depends on production costs in relation to the prevailing price of the main market competitors, particularly soya protein and fishmeal. The reason that more microbial protein is not currently produced for fodder is due to the present low price of these conventional protein sources. However, this may change, as there have been forecasts of future shortages of soya and fishmeal.

History of SCP[3]

Yeast has been used in bread and beverage production since 2500 BC. In 1781 methods are discovered to produce high concentration of yeast. The term single cell protein was coined by Carol L. Wilson during 1966. The "food from oil" idea became quite popular by the 1970s, with Champagnat being awarded the UNESCO Science Prize in 1976, and paraffin-fed yeast facilities being built in a number of countries. The primary use of the product was as poultry and cattle feed. The Soviets were particularly enthusiastic, opening large "BVK" (*belkovo-vitaminny kontsentrat*, i.e., "protein-vitamin concentrate" plants next to their oil refineries in Kstovo (1973) and Kirishi (1974). The Soviet Ministry of Microbiological Industry had eight plants of this kind by 1989, when, pressured by the environmentalist movements, the government decided to close them down, or convert to some other microbiological processes.

In olden days, the filamentous alga *Spirulina* was harvested in the lake Chad of Africa was consumed as food. During 1st world war Germans used *Candida utilis* in soups and sausages. It was extensively used during Second World War. It was produced in industrial scale in 1967. Protein derived from cultured bacteria, Yeast, fungi, and algae. Algae (seaweed) have long been used as food. Brewer's yeast, a by-product of the brewing industry, and Torula yeast are widely available food supplements. The potential of cultured microorganisms serving as an edible protein source is huge. A single-cell fermenters covering 0.8 sq km (one-third of a square mile) could theoretically supply 10 percent of the protein requirement of the world's population. By-products of the food, paper, and chemical industry can be fermented by many microorganisms as inexpensive energy sources. These include methane, alcohol, starch, molasses, cellulose, and animal waste products.

Even fewer requirements are needed for algae; photosynthetic organisms can be grown in illuminated ponds supplied with mineral nutrients. Problems associated with single-cell protein have limited its development as a major food source. Most single-cell protein is not palatable, unless processed to eliminate bitter or unpleasant tasting materials. Digestibility of single-cell protein varies with the sources. Cooking algae increases its digestibility, but the digestibility of yeast is little altered by processing. The high nucleic acid content of single-cell organisms leads to increased purine uptake. When purines are metabolized, uric acid output rises and increases the risk of Gout in susceptible people. Furthermore, toxic materials and pollutants can contaminate single-cell protein. Another consideration is the fact that single-cell protein is generally deficient in the dietary essential amino acid, lysine and methionine. Though the amino acid profile is more balanced than in cereal grain protein it remains inferior to animal protein. Genetically engineered microorganisms may overcome this deficiency.

Production of Single Cell Protein[4]

The production of Single Cell Protein can be done by using waste materials as the substrate, specifically agricultural wastes such as wood shavings, sawdust, corn cobs, and many others. Examples of other waste material substrates are food processing wastes, residues from alcohol production, hydrocarbons, or human and animal excreta.

The process of SCP production from any microorganism or substrate would have the following basic steps:

1. Provision of a carbon source; it may need physical and/or chemical pretreatments.
2. Addition, to the carbon source, of sources of nitrogen, phosphorus and other nutrients needed to support optimal growth of the selected microorganism.
3. Prevention of contamination by maintaining sterile or hygienic conditions. The medium components may be heated or sterilized by filtration and fermentation equipments may be sterilized.
4. The selected microorganism is inoculated in a pure state.
5. SCP processes are highly aerobic (except those using algae). Therefore, adequate aeration must be provided. In addition, cooling is necessary as considerable heat is generated.
6. The microbial biomass is recovered from the medium.
7. Processing of the biomass for enhancing its usefulness and/or storability.

Single Cell Protein - Yeast[5]

Yeast is another source of Single Cell Protein, and has been produced since a long time ago. In World War I, Torula yeast (*Candida utilis*) was produced in Germany and used in soups and sausages. Nowadays, the pet food industry is a major outlet of microbial biomass. The dog, cat, fish feed is supplemented with yeasts, it will make the product more palatable to the animals. Use of yeast as food seasoning is commonly found in vegetarian's diet, Torula yeast has been commercially used for this purpose, an example of this product is Hickory Smoked Dried Torula Yeast. Yeast has some advantages among other SCP sources, such as:

1. Easy to harvest because of their size (larger than bacteria)
2. High level of malic acid content
3. High lysine content
4. Can grow at acidic pH
5. Long history of traditional use

This nutritious microbe unfortunately has few disadvantages that have to be taken as consideration, such as:

1. Lower growth rates compared to bacteria
2. Lower protein content than bacteria (45-65%)
3. Lower methionine content than bacteria, solved by the addition of methionine in the final product.

Single Cell Protein - Algae[6, 7, 8]

Since a decade ago studies on Single Cell Protein (SCP) had drawn the attention of scientist to bridge the protein gap. The use of algae as food and feed is known since centuries as they form part of the diets is East Asian countries as well as the natives in Central Africa. Some of the algae like *Chloralla*, *Soenedesmus*, *Coelastrum* and *Spirulina* have been found to suitable for mass cultivation and utilization. The advantages in using algae include simple cultivation, effective utilization of solar energy, faster growth and high protein and nutrient content.

Cultivation of *Spirulina*

In tropical countries *Spirulina* cultured under authotrophic, heterotrphic and mixotrophic conditions.

- Mass cultivation easier than other algal cultivation because aeration of CO_2 is not necessary for this species since it can maximally utilizes the amounts of carbon

Single Cell Protein - Filamentous Fungi [9]

Background

In 1973, when Second International Conference was convened at MIT, some actinomycetes and filamentous fungi were reported to produce protein from various substrates. Since then many filamentous fungi have been reported to produce protein. Therefore, the term SCP is not logical, if an organism produces filaments. The term 'mycoprotein' has been introduced by Ranks Hovis McDougall (RHM) in the United Kingdom for protein produced on glucose or starch substrates. 3000 fungal isolates "from all over the world" were tested for efficiency of growth, and safety as food.

Production of Fungal Biomass, the Mycoprotein (other than Mushrooms)[10]

During the World War II, attempts were made to use the cultures of *Fusarium* and *Rhizopus* grown in fermentation as protein food. The inoculum of *Aspergillus oryzae* or *Rhizopus arrhizus* is chosen because of their non-toxic nature. Saprophytic fungi grow on complex organic compounds and render them into simple forms. As a result of growth, high amount of fungal biomass is produced. Mycelial yield vary widely depending upon organisms and substrates. Strains of some species of moulds, for example, *Aspergillus niger, A. fumigatus, Fusarium graminearum* are very hazardous to human, therefore, use of such fungi should be avoided or toxicological evaluations should be done before recommending to use as SCP. Substrates used for single cell protein production in filamentous fungus are given in Table 1.

Table 1: Microorganism and substrate used for single cell protein production

Microorganism	Substrate
Fungi	
Aspergillus fumigatus	Maltose, Glucose
Aspergillus niger, A. oryzae, Cephalosporium eichhorniae, Chaetomium cellulolyticum	Cellulose, Hemicellulose
Penicillium cyclopium	Glucose, Lactose, Galactose
Rhizopus chinensis	Glucose, Maltose
Scytalidium aciduphilium, Thricoderma viridae, Thricoderma alba	Cellulose, Pentose
Paecilomyces varioti	Sulphite waste liquor
Fusarium graminearum	Starch, Glucose

Single Cell Protein - Bacteria [9,10]

Many species of bacteria have been investigated for use in single cell protein production. *Methylophilus Methylotrophus* has a generation time of about 2 hours and is usually and mainly used in animal feed as bacteria, in general produce a more favorable protein composition than yeast or fungi. Therefore the large quantities of SCP animal feed can be produced using bacteria. Among the characteristics that make bacteria suitable for this application include:

- Their rapid growth
- Their short generation times; most can double their cell mass in 20 minutes to 2 hours.
- Capable of growing on a variety of raw materials, ranging from carbohydrates such as starch and sugars, to gaseous and liquid hydrocarbons such as methane and petroleum fractions, to petrochemicals such as methanol and ethanol.
- Suitable nitrogen sources for bacterial growth include ammonia, ammonium salts, urea, nitrates, and the organic nitrogen in wastes.
- A mineral nutrient supplement must be added to the bacterial culture medium to furnish nutrients that may not be present in natural waters in concentrations sufficient to support growth.

Comparisons of Single Cell Protein Sources[11,12]

The parameters used by them to evaluate the ranking of SCP showing that nucleic acid from algae is safer than fungi and bacteria. Nucleic acid from fungi is much better than bacteria due to their low nucleic acid contents. Therefore the ranking will be algae > fungi > bacteria.

Economics of the Single Cell Protein Production[13]

The term biomass indicates the organic cell substance of plant or animal organisms. It is used both for the total body substance of an organism and as a group term for a biological raw material produced from plants and animals. Correspondingly, by microbial biomass is understood the cell substance of microorganisms that arises during their mass cultivation.

Table 2: The comparison chart shows the composition of SCP from the respective organisms.

Component	Percentage composition of weight		
	Algae	Fungi	Bacteria
True Protein	40-60[a]	30-70[a]	50-83[a]
Total nitrogen (Protein + nucleic acids)	45-65[a]	35-50[a]	60-80[a]
Lysin	4.6-7.0[a]	6.5-7.8[a]	4.3-5.8[a]
Methionine	1.4-2.6[a]	1.5-1.8[a]	2.2-3.0[a]
Fats/Lipids	5-10[a]	5-13[a]	8-10[a]
Carbohydrate	9	NA	NA
Bile pigments and Chlorophyll	6	NA	NA
Nucleic acids	4-6[a]	9.70	15-16[a]
Mineral acids	7	6.6	8.6
Amino acids	NA	54	65
Ash	3	NA	NA
Moisture	6.0	4.5-6.0[a]	2.8
Fiber	3	NA	NA

[a]The yield varies with the type of substrate used, the specific organism used and the culture conditions maintained. NA - Not available

The production of microbial biomass is the technical manufacture of the cell mass of microorganisms from suitable organic raw material. In technical fermentation processes, in addition to the desired synthesis of a natural substance, the multiplication and growth of the culture of microorganisms itself also takes place. As early as the beginning of the twentieth century, it was recognized that this cell mass, or microbial biomass, forms a useful product, so that its production with the actual removal of accompanying processes was made the subject of a new development, the production of microbial biomass.

The main interest of the biomass is the protein component. Therefore, microbial biomass is also called single cell protein (SCP) or bioprotein. In view of the insufficient world food supply and the high protein content of microbial cells, the use of biomass produced in the fermenters would be an ideal supplement to conventional food supply. Process engineering uses for this purpose on the large technical scale the cheapest possible raw materials and sources of energy that are available in large amounts in simple and low energy processes.

As industrial products from agriculture, forestry, and fisheries, with these points the productions of biomass industrially in a technically controllable manner are independent of soil, climate, and weather. A main example of this is the discovery of fossil materials that can be used as a substrate for micro-organisms.

So the production of microbial biomass (SCP) has taken a firm and important place in research, development and technical production and has led to new groups of tasks for microbiology, process engineering and the development of new bioproducts. However with SCP production large-scale fermenters are required for this process. So with high biomass production this must involve. High oxygen transfer rate which promotes high respiration rates which in turn increase metabolic heat production and the need or an efficient cooling system and by doing this it is important to operate continuous fermentation processes. Therefor with such a continuous operation for SCP production the economics of this production must be strongly taken into account.

The Economics factors that should be taken into account during this fermentation period are: Investment, Energy, Operating costs, Waste, Safety and the Global market.

Fermentation Process[14,15]

The production of single cell protein takes place in a fermentation process. This is done by selected strains of microorganisms are multiplied on suitable raw materials in technical cultivation process directed to the growth of the culture, and the cell mass so obtained is isolated by separation processes. Process development begins with microbial screening, in which suitable production strains are obtained from samples of soil, water an air or from swabs of inorganic or biological materials and are subsequently optimized by selection, mutation, or other genetic methods. Then the technical conditions of cultivation for the optimized strains are worked out and any special metabolic pathways and cell structures are determined. In parallel to these biological investigations, process engineering and apparatus technology adapt the technical performance of the process and the apparatus in which the production of microbial biomass is to be carried out in order to make them ready for use on the large technical scale. Here is where the economic factors (energy, cost) come into play.

For the overall provability of biomass processes, the raw material, their production and preparation and the energy demands play the most important role. The various raw materials carriers must be investigated for their suitability from a technical economic, and biological point of view and be prepared for the special biological process. Safety demands and questions of environmental protection rise in the production o SCP in relation both to the process and to the product. Finally, safety and the protection of innovation throw up legal and controlled aspects, namely operating licenses, product authorizations for particular applications, and the legal protection of new process and strains of microorganisms.

A fermenter is the instrument, which is set up to carry out the process of fermentation mainly the mass culture of plant or animal cells. Fermenters can vary in size from laboratory experimental models of one or two liters capacity, to industrial models of several hundred liters capacity. A bioreactor is different from a fermenter as it used for the mass culture of microorganisms. The chemical compounds synthesized by these cultured cells such as therapeutic agents can be extracted easily from the cell biomass.

The design engineering and operational parameters of both fermenters and bioreactors are identical. Fermenters and bioreactors are also equipped with an aerator, which supplies oxygen to aerobic processes also a stirrer is used to keep the concentration of the medium the same. A thermostat is used to regulate temperature and a pH detector and some other control devices, which keep all the different parameters needed for growth constant. The fermentation process requires the following. A pure culture of the chosen organism, that is in the correct physiological state. Sterilization of the growth medium is undertaken which is used for the organism. A production fermenter, which is the equipment, used for drawing the culture medium in the steady state, cell separation, collection of cell free supernatant, product purification and effluent treatment [16].

Raw Materials[17,18,19]

The classical raw materials are substances containing mono- and disaccharides, since almost all micro organisms can digest glucose, related hexose and pentose sugars, and disaccharides. They arise as by-products of agriculture, the foodstuffs industry, and timber processing (Whey) or are manufactures by Agarian means (sugar cane juice). They are therefore renewable raw materials. These materials also find use in other branches of industry with a high price level, which puts the economic aspect of the production of microbial biomass in doubt.

Effect of Glucose as Carbon Source in the Production of Single Cell Protein[20,21]

In the production of protein by microorganism carbon source plays an important role. The lower cost of the glucose sources is the attractive features to use of glucose as carbon source. By growing the organism with glucose 8 % highest level of SCP production was obtained. The glucose concentration significantly affects the SCP.

Effect of Nitrogen Source in the Production of Single Cell Protein[22]

During the synthesis of protein, nitrogen source is one of the important factor due to structure properties of proteins. When tryptone and yeast extract were used, SCP production by Haloarcula Spp IRU1 was better. It can't able to produce SCP when it is grown on the medium contains NH_4Cl and peptone. When tryptone was supplemented at a concentration of 0.8 % w/v maximum yield of SCP was obtained.

Effects of Phosphorous Sources on Single-Cell Protein Production[23,24]

For SCP production K2HPO4 and NaH2PO4 were the best sources of phosphorous. The maximum SCP production was achieved by microorganisms growing in the medium supplemented with NaH_2PO_4 0.016% (w/v). Higher concentrations of phosphorous sources caused increasing of the SCP production in all experiments.

Economic Aspects [25]

Cost Distribution of SCP Production

The industrial manufacture of SCP is greatly affected from the economic point of view by the C-substrate used. While in the case of locally available highly diversified waste substrate no general consideration of profitability is possible, more accurate calculation can be made for the synthetic raw materials methane, methanol and ethanol.

Substrate Costs

The substrate costs are the largest single cost factor. Due to the variation in the costs means that the greatest possibility of affecting the total manufacturing costs. Simplifying the manufacture and purification of raw material can save costs. Moreover the manufacture of raw materials is more economical in larger plants for producing them.

Factors Involved in the Raw Materials Costs are

- Site
- Raw material production process
- Capacity of the plant
- Substrate yield
- Product concentration

Utilities

The energy for compressing air, cooling, sterilizing and drying forms the next most important cost factor. Sites with cheaply available thermal, electrical, fossil or process derived energy are to be preferred. If the main energy is natural gas, both the productions of compressed air and of electricity and also sterilization and drying can be provided through natural gas.

Capital Load

The capital dependent costs are determined, by the cost of the apparatus for the process, the capacity of a plant, and the capacity conditions. The main variable here is the size of the plant. Small plants can be profitable only if they include simplifications of processes and material to a considerable degree:

- Non-sterile working
- Cheap apparatus materials
- High fermenter productivity
- Renouncement of the drying of the product

The greater expenditure on apparatus in processes with cheap, simple and unpurified raw materials usually does not pay in comparison with more expensive pure substrates with simpler technology. High productivities in fermentation are compensated by the greater expenditure on energy to achieve these productivities, so that optimum can be determined.

Product-Specific Variables

The process costs arising are covered only by the product produced. The absolute value of the product is governed by the amount of product referred to the costs involved and by the quality of the product.

The quality of the product is poorer for a low-value unpurified product of a rational mini process with varying composition or one including numerous additional components than for upgraded products. The upgrading of the product may consist of purification and separation into the components of the microbial biomass.

Because of genetic variability, the possibilities of technical control in manufacture, and the simplicity of the process, microbial is more suitable for such special products than biomass from plants or animals.

Global Marketing of SCP[26]

BP (United Kingdom)

By far Britain's largest company, with around 1500 subsidiaries and a market capitalization of little than €10,000,000,000 (€9,482 million to be exact), BP also has the world's greatest secure oil reserves and is generally acknowledged to be the best company in the world at finding oil.

Shell

This firm has recently announced it was investing $500 million in renewable energy over five years, including plantations that would supply timber to burn as an electricity source. Shell says its long. Range planning scenarios envisage that, by the year 2050, the world energy consumption of biomass (microbial) for electricity generation will equal that of gas and oil today. It envisages that its biomass business will grow at a rate of 15% a year, reaching 250MW installed by 2015.

Beltra

Plant bio-refineries have the potential to create a new outlet for farm crops. Grass, potatoes, etc. and even by-products like straw and beet tops could be converted via this process into compounds that are considerably more valuable than the raw material. One such example is ethyl lactate where one tonne straw can generate about 350 liters of the substance, which is currently valued at about €850. A four nation development group consisting of Ireland, Iceland, Germany and France are seeking to build a pilot plant here in Ireland to test the theory. Beltra is the Irish company involved in the project. The pilot plant suggested would have a capacity to process about 5,000t of biomass and the initial investment is put at about six million Euro.

Acceptability and Toxicology of SCP

The name of the raw materials used in SCP processes represents the main safety hazard e.g. the possibility of carcinogenic hydrocarbon in the gas oil or n. paraffins, of heavy metals or other contamination in the minerals salts solvents after extraction. Toxicology testing of the final product must include short- term acute toxicity testing with several different laboratory animal species, followed by extensive and detailed long term studies. It represents a major scientific and financial investment. The acceptability of SCP when presented as a human food does not depend only on its safety and nutritional value. In addition to the general reluctance of people to consume material derived from microbes, the eating of food has many subtle psychological, Sociological and religious implications.

The critical parameters of SCP processes are strongly interdependent. The choice of substrate will reflect local political and economic factors and the availability of alternative outlets. The choice of organism will partly determine the process technology and the nature of the product. Acceptability of the product will depend in part on the substrate. Because of the large volumes that will be involved in SCP processes, continuous culture techniques will be widely selected for economic reasons.

SCP Derived from High Energy Sources[27]

Materials with high commercial value as energy sources or derivatives of such chemicals e.g. gas oil, methane, methanol, methanol and n-alkanes have found wide commercial interest. The microbes involved are mostly bacteria and yeast, and several processes are now in operation. As would be expected, most oil companies have been or are still involved in this field. The wisdom of using such high-energy potential compounds for food production has been questioned by many scientists.

Methane as a SCP source has been extensively researched but is now considered to present too many technical difficulties to warrant exploitation. In contrast, methanol offers great economic SCP interest. A large-scale fermentation plant for producing the methanol-utilizing bacterium *Methylophilus methtlotrophus* was constructed by ICI, UK. The ICI SCP protein was used exclusively for animal feeding. Methanol as a carbon source for SCP has many inherent advantages over n-paraffins, methane gas and even carbohydrates composition is independent of seasonal fluctuations. There are no possible sources of toxicity in methanol; methanol dissolves easily in the aqueous phase in all concentrations.

The ICI Pruteen plant was the only process of its kind in the Western world but could not operate economically at present methanol prices and has ceased production. Methanol represents approximately 50% of the costs of the product. In the USA the cost of SCP derived from methanol is two- to five- folds the cost of fishmeal. In the Middle East the low cost of methanol and higher costs of fishmeal coupled with a need to produce more animal products could make SCP an attractive proposition.

Ethanol is a particular suitable source if the SCP is intended for human consumption. In the foreseeable future the comparative status of ethanol SCP will depend on local factors: over-capacity in ethylene crackers, agricultural carbohydrates surpluses and political decisions about regional economic independence and foreign trade balances.

The use of n-alkanes as substrate for SCP has been extensively studied many countries and represents a very complex biotechnological process. However most of these processes have now ceased operation because of suspected health hazards resulting from the presence of carcinogens in the SCP. The massive technology developed in this field in Japan and other Eastern countries has been turned over to the study of alcohol- based SCP and SCP form organic wastes.

SCP from wastes [28]

The materials that make up wastes should normally be recycled back into the ecosystem, e.g. straw, bagasse, citric acid, olive and date wastes, whey, molasses, animal manures and sewage. The amount of these wastes can be locally very high and may contribute to a significant level of pollution in watercourses. Thus, the utilization of such material in SCP processes serve two functions- reduction in pollution and creation of edible protein. Of particular interest have been the extensive programmes to convert cattle and pig waters to feed protein. However, these studies have been largely unsuccessful because of technical and sanitary difficulties.

The world-wide trend towards stricter effluent control measures, and parallel increases in effluent disposal charges, has led to the concept of waste as a negative cost raw material. However, the waste may not be suitable for SCP or its composition or dilution may be so dispersed that transport to a production centre may be prohibitive. SCP processes utilizing waste substrates have been carried out on a commercial scale using various yeast organisms in sophisticated bioreactor systems. Substrates used and producer organisms include molasses and cheese whey.

A new development for SCP waste is mushroom Fermentation, the biotechnological innovation is only now seriously being involved in this field but the rewards will be great. Biotechnology need not always be high technology. To developing nations, where highly expensive systems may be impractical from the point of view of cost and lack of skilled operators, many of the new biotechnological discoveries may well lead to improvement in traditional microbial processes.

Livestock of SCP

Single cell protein has a potential to be developed into a large source of supplemental protein that could be used in livestock feeding. This source of feeding has the opportunity to develop because microbes can be used to ferment vast amounts of waste materials. For the producing and harvesting of microbial proteins cost is a major problem. Where a high rate of production of the single cell protein would occur it would be found in dilute solutions rather than concentrated solutions, usually less than 5% solids. There are many methods available for concentrating the solutions these includes filtration, precipitation, centrifugation, and the use of semi-permeable membranes. The equipment used for these methods of de-watering is expensive and so would not be suitable for small scale productions and operations. The removal of the amount of water that is necessary to make the material stable for mass storage is not economically viable. Single cell proteins need to be dried to 10% moisture or they can be condensed and denatured to prevent spoilage.

As mentioned before microbial proteins and single cell proteins have a high nucleic acid content for this reason the amount of these proteins allowed in the diets of animals such as the livestock feeding they could be used for need to limited. Some organisms could produce mycotoxins this is a toxin that can be produced when grains or other products become moldy. Single cell protein can also be produced on various different substrates this is sometimes done to reduce the biological oxidation demand (BOD), which is present in streams coming out of agricultural processing plants.

Advantages of SCP production

1. First of all, it's a promising industry, because the raw materials are free, at least can buy at a very cheap price, but the product to sell are relatively expensive. Not only that. It helps to reduce the environmental pollution and promote recycling.

2. It has high protein and low fat content. SCP organisms grow faster and produce large quantities of SCP from relatively small area of land and time. The scientist can alter the component of amino acids from SCP by genetic engineering.

Advantages of Production of SCP from microorganism[29,30,31,32]

In many countries, use of microorganisms or biomass of microorganisms as a diet supplement has met with scepticism because of certain psychological barriers. But in the future even in these countries microbial biomass will play a major role via single cell protein feeds to the animals which will in turn be consumed by humans. Large-scale production of microbial biomass has many advantages over the traditional methods for producing proteins for food or feed.

1. Microorganisms have a high rate of multiplication and, hence, rapid succession of generations (algae: 2–6 hours, yeast: 1–3 hours, bacteria: 0.5–2 hours)

2. They can be easily genetically modified for varying the amino acid composition.

3. A very high protein content 43–85% in the dry mass.

4. They can utilize a broad spectrum of raw materials as carbon sources, which include even waste products. Thus, they help in the removal of pollutants also.

5. Strains with high yield and good composition can be selected or produce relatively easily.

6. Microbial biomass production occurs in continuous cultures and the quality is consistent, since the growth is independent of seasonal and climatic variations.

7. Land requirement is low and is ecologically beneficial.

8. A high solar-energy-conversion efficiency per unit area.

9. Solar energy conversion efficiency can be maximized and yield can be enhanced by easy regulation of physical and nutritional factors.

10. Algal culture can be done in space that is normally unused and so there is no need to compete for land.

The Single Cell Protein resulting from the U-Loop technology belonging to UniBio in Denmark provides significant additional benefits when used in animal feed mixes, as compared to traditional feed mixes. Inter alia, these benefits are: faster growth and better feed conversion for chickens and pigs and reduced mortality for salmon.

Disadvantages of Single Cell Protein

There are some disadvantages also, of using microorganisms or microbial biomass as diet supplement or as single cell protein.

1. Many types of microorganisms produce some substances which are toxic to the human and also to the animals. Therefore it has to be made sure that the produced microbial biomass does not contain any of these toxic substances.
2. Sometimes the microbial biomass when taken as diet supplement may lead to indigestion.
3. Sometimes the microbial biomass when taken as diet supplement may lead to allergic reactions in humans.
4. The high nucleic acid content of many types of microbial biomass products is also undesirable for human consumption as single cell protein. Sometimes this high level of nucleic acid content in microbial biomass will lead to kidney stone formation or gout.
5. The high nucleic acid content of many types of microbial biomass may lead to poor digestibility, gastrointestinal problem and also some skin reactions in humans.
6. The possibility of presence of toxins or carcinogenic compounds may lead to some serious health problems in humans as well as in animal stock.
7. Single cell protein production is a very expensive procedure as it needs high level of sterility control in the production unit or in the laboratory.
8. Single cell protein grown as animal feed on agricultural residues will be beneficial in the future economy of developing nations.

Further research and development will ensure usage of microbial biomass as single cell protein or as diet supplement in developing countries. However it is noteworthy that the company called as Dabur in India is manufacturing and also selling spirulina as diet supplements for humans.

CONCLUSION

For economic, political and technical reasons SCP has not become the important source of food protein that was forecast originally. The developed countries do not need SCP for they have plentiful supply of high quality protein as a result of the agricultural improvements of the last forty years. Evidence of this is provided by the butter and grain mountains, which exist in the EEC and the USA[33]. SCP would be a useful food additive in tropical countries where traditional food products are high in carbohydrate and low in protein. This chronic shortage of protein leads to physical and mental deterioration. In countries of the Middle East, and in the some regions of Africa, the land is too rigid to produce sufficient food of any type regardless of its protein content. Thus in both the arid and tropical regions the production of SCP would be advantageous but the countries concerned cannot afford the initial capital investment. They also lack the technical expertise and support facilities to maintain production once established. Even as a feed supplement SCP has not been a success because of costs considerations.[34] Feedstock, particularly those associated with oil production, generally have increased in price, whereas those from competitive sources of protein, such as soy bean meal or fishmeal, have decreased in price. Even if oil prices drop they can just as easily rise again because of world politics which has become apparent in the last six months. Fluctuating commodity prices do not encourage large capital investment

SCP production facilities have been constructed in most of the developed countries but many of these are no longer operating for the reasons stated above. The most impressive is the one built by imperial chemical industries in the north of England. In this plant, which has the world's largest continuous operating fermenter, the bacterium *Methylophilus methylotophus* is grown on methanol and ammonia. The product, which is called Pruteen contains 80% crude protein and has a high vitamin content. Although twice as nutritious as soybean meal it is not economic to produce. So far, single cell proteins have shown the following possibilities of application: [35]

In Animal Nutrition

- Fattening calves
- Fattening poultry
- Feed for laying hens
- Fish breeding
- Fattening pigs
- Feed off domestic animals

In the Foodstuffs Area

- As aroma carriers
- As vitamin carriers
- As emulsifying aids
- To improve the nutritive value of baked products
- In soups
- In ready-to-serve meals
- In diet recipes

In the Technical Field

- In paper processing
- In leather processing
- As foam stabilizers

In addition to the production of microbial biomass that has been described, it may be mentioned, finally, that the production of bakers, brewers, and wine yeast, of starter cultures, of definite strain for research and therapy, and of humus cultures for soil inoculations, and also cultures of edible fungi, must be included in the production of microbial biomass [36].

The world wide, large-scale development of SCP processes has contributed greatly to the advancement of present day biotechnology. Research and development into SCP processes has involved work in the fields of microbiology, biochemistry, genetics, chemical and process engineering, food technology, agriculture, animal nutrition, ecology, toxicology, medicine and veterinary science and economics. In developing SCP processes new technology SCP processes new technical solutions for other related technologies have been discovered, e.g. in waste water treatment, production of alcohol, enzyme technology and nutritional science [37,38].

The future of SCP will be heavily dependent on reducing production costs and improving quality. This may be achieved with lower feedstock cost, improved quality. This may be achieved with lower feedstock costs, improved fermentation and downstream processing and improvement in the producer organisms as a result of conventional applied genetics together with recombinant DNA technologies. However, the main limitations of SCP products for human use are sociological rather than technological role of microbial biomass will be in animal feed supplement.

Further research and development will ensure usage of microbial biomass as single cell protein or as diet supplement in developing countries. However it is noteworthy that the company called as Dabur in India is manufacturing and also selling spirulina as diet supplements for humans.

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