LECTURE-9

SINGLE CELL PROTEINS

➢ INTRODUCTION

- single cell protein (SCP) refers to dead, dry cells of microorganisms, such as yeast, fungi, bacteria and algae
- these microorganisms grow on various carbon sources for their protein content
- the term, 'single cell protein' was firstly used by Carol Wilson in 1967 by replacing the less aesthetic terminology, 'petro protein' , 'microbial protein'
- the majority of microorganisms used are unicellular, the protein content from them is called , 'single cell protein'
- because of its superior nutritional quality (**Table-5**) in terms of protein content and a very good supplement for animal feed, yeast is mostly chosen for SCP
- SCP do contain contents, such as vitamins, fats and minerals etc.
- protein shortage in the Thirld World nations prompted in the cultivation of SCP on large scale which resulted in the development of SCP technology for livestock and human consumption
- it is estimated that SCP fermenters covering one third of a square mile can provide 10% of the World's protein requirement

➢ NEED FOR MICROBIAL PRODUCTION OF SCP

- it is an idea to solve global food scarcity
- SCP can give relief to the agriculture sector which uses large area for production of protein crops
- production per unit area in the agriculture sector is low,
- 10% of the World's protein requirement can be met by SCP technology by using only one third of a square mile for SCP production
- climatic factor effects agriculture, whereas SCP technology is not affected by climate
- scenario is also not so encouraging for animal protein too
- SCP has many advantages, such as
  - ✓ high protein content
  - ✓ contains all the essential amino acids
  - ✓ some microorganisms are highly rich in vitamins
  - ✓ high ratio of surface area to volume
  - ✓ small doubling time
  - ✓ high growth rate
  - ✓ flexibility in the use of substrate
  - ✓ independence of cultivable land and climate
  - ✓ works on continuous basis
  - ✓ eco-friendly
  - ✓ cost effective
  - ✓ energy efficient
  - ✓ can also be genetically controlled

➢ SOURCES OF MICROORGANISMS AND THE SELECTION CRITERIA

- microorganisms, such as algae, fungi, protozoa and bacteria are used for production of SCP

- the basis for their selection are:
  - ✓ ability to utilize carbon and nitrogen sources
  - ✓ moderate growth conditions
  - ✓ tolerance to pH, temperature, and mineral concentrations
  - ✓ resistance against viral infection
  - ✓ non-toxicity
  - ✓ non-pathogenicity
  - ✓ acceptable nutritive value of cell mass
- among algae, *Spirulina* is used most extensively
- biomass from *Chlorella*, *Senedesmus* and *Dunalliella* used on large scale
- main problems for SCP from algae are their foul odor and tastelessness
- fungi species, such as *Spergillus*, *Fusarium*, *Candida*, *Chaetomium*, *Trihoderma*, *Penicillium* etc are good candidates for SCP production, due to:
  - ✓ wide range of substrate utilization
  - ✓ ability to withstand abiotic conditions
- bacteria, such as *Bacillus*, *Lactobacillus*, *Pseudomonas*, *Aesonomas* are used for SCP but the success is not so encouraging
- mixed cultures have shown better results with respect to stability and resistance to contamination
- Sources for single cell proteins have been shown in **Table-1**

Table-1: Sources for Single Cell Proteins

SCP sources	Protein content range (%)	Special characteristics	Specific organisms – examples	Challenges
Microalgae	60 to 70	Phototrophic growth	Chlorella vulgaris	Economical scale-up
Microalgae	60 to 70	Production of omega-3 fatty acids	Desmodesmus sp.	Cell disruption to release nutrients
Yeasts	30 to 50	Use of a variety of feedstocks	Saccharomyces cerevisiae	Improve protein and EAA
Yeasts	30 to 50	Production of vitamins and micronutrients	Candida utilis	EAA content
Bacteria	50 to 80	High protein content	Methylococcus capsulatus	Palatability issues
Bacteria	50 to 80	Growth on C1 substrates	Cupravidus nectar	–
Protists	10 to 20	Production of omega-3 fatty acids	Schizochytrium limacinum	Improve protein content

➢ SUBSTRATES SUITABLE FOR SCP PRODUCTION

- carbon dioxide (CO_2) and sunlight are the main source for growth of algae
- fungal species are grown on various substrates, such as
  - ✓ sulfite waste liquor
  - ✓ prawn shell wastes
  - ✓ dairy waste, whey
  - ✓ molasses, etc.
- lignocellulosic wastes based on composition have also been used for specific fungi for SCP
- for bacteria

- ✓ $C_1 - C_4$ compounds
- ✓ agricultural, animal and food processing wastes
- ✓ methane, methanol etc. have also been used

- according to the latest research the potential feedstocks for SCP production have been shown in the Table-2, below:

Table-2: Potential Feedstocks for SCP Production

Potential feedstocks for SCP production			
Feedstock sources	Examples	Advantages	Disadvantages
Wastewaters	• Municipal waste [28] • Industrial wastewater [65]	• Potential for tipping fees • Most circular economy appeal	• Limited control or significant processing • Supply constrained and defined in scale • Major regulatory challenges
Industrial & Agricultural Residues	• Off-gases (e.g. steel mill) • Biogas [66] • Agricultural wastes [22,26,29,67] • Cellulosic biomass	• Lowest cost • Enhanced valorization • Bio-potential • Circular economy appeal	• Less control or significant processing • Supply constrained and defined in scale • Significant regulatory challenges
Bioindustry By-Products	• Brewery residues [24] • Dry-grind ethanol co-products • Starch processing waters • Biogas • CO_2 [68*]	• Lower cost • Enhanced valorization • Large quantity point sources • Established processing and infrastructure	• Limited supply • Processing often required • Variable composition • Output of other processes that could change • Regulatory challenges
Fit for Purpose	• Dextrose • Sucrose • Corn starch • Molasses • Soybean meal • Methane • Methanol • Ethanol • Syngas • $H_2 + CO_2$	• Low cost • Best defined • Most controlled • Abundant and expandable supply • More regulatory certainty • More conversion options • Developed infrastructure	• Higher comparable cost • More limited to locations with developed supply logistics • Less circular economy appeal

- Carbon Sources and the Concerned Microorganisms used for SCP production are shown in Table-3

Table 3: Microorganisms used for SCP Production according to Carbon Sources

Source of carbon	*Microorganisms*
	Algae
CO_2	*Chlorella pyrenoidosa, C. regularis, C. sorokiniana, Oocystis polymorpha, Scenedesmus quadricauda, Spirullina maxima, Spirullina platensis, Dunaliella bardawil*
	Bacteria and Actinomycetes
n-Alkanes	*Acinetobacter cerificans, Achromobacter delvacuate, Mycobacterium phlei*., *Nocardia* sp., *Pseudomonas* sp.
Methane	*Corynebacterium hydrocarbonoclastus, Nocardia paraffinica, Acinetobacter* sp.,*Flavobacterium* sp., *Hyphomicrobium* sp., *Methylomonas methanica, Methylococcus capsulatus*.
Methanol	*Methylomonas methylovora, M. clara, M. methanolica, Flavobacterium* sp., *Methylophilus methylotrophus, Pseudomonas* sp., *Streptomyces* sp., *Xantomona* sp.
Ethanol	*Acinetobacter calcoaceticus*
Cellulosic wastes	*Thermomonospora fusca*
Sulfite waste liquor	*Pseudomonas denitrificans*
	Yeasts
n-Alkanes, *n*-paraffins	*Candida lipolytica, C. tropicalis, C. guilliermondii, C. maltosa, C. paraffinica, C. oleophila, Yarrowia lipolytica*
Methanol	*Candida utilis, Hanseniaspora* sp., *Pichia pastoris, Hansenula* sp., *Kloeckera* sp.
Ethanol	*Candida enthanothermophilum, C. utilis, C. kruzei*
Whey	*Kluyveromyces fragilis, Candida intermedia*
Cane molasses	*Saccharomyces cerevisiae*
Starch	*Schwanniomyces alluvius, Lipomyces kononenkoe*
Lipids	*Candida rugosa, C. utilis, C. lipolytica, C. blankii, C. curvata, C. deformans, C. parapsilosis*
Cellulose	*Candida utilis*
Sulfite waste liquor	*Candida utilis, C. tropicalis*
	Fungi
Glucose	*Agaricus blazei, A. campestris*
Malt – molasses	*Agaricus campestris*
Starch	*Aspergillus niger, Fusarium graminearum*
Sulfite waste liquors	*Paecilomyces variotii*
Cellulose	*Chaetomium cellulolyticum, Trichoderma viride*
Brewery waste	*Calvatia gigantean*

➢ NUTRITIONAL ASPECTS OF SCP

- nutritional values vary with microorganisms and substrates used
- for assessment amino acid, protein, carbohydrate and lipid profiles, minerals and vitamins contents are important
- palatability, allergies and gastrointestinal effects are also seen
- long-term feeding trials, toxicological and carcinogenisis effects are to be monitored
- protein efficiency ratio (PER), biological values (BV), net protein utilization (NPU), protein digestibility value (PDV) are also considered for nutritional aspects
  - ✓ protein efficiency ratio (PER) = $\frac{\text{weight gained by microorganisms in } g}{\text{protein intake by microorganisms in g}}$
  - ✓ biological value (BV) = $\frac{\text{retained nitrogen}}{\text{absorbednitrogen}}$
  - ✓ net protein utilization (NPU) = $\frac{\text{retained nitrogen}}{\text{geed nitrogen intake}} \times 100$
- algae are rich in proteins (40 – 60%), fats (5 – 20%), vitamins A, B, C, D, E; minerals (7%) , nucleic acid (4 – 6 %)
- fungi contains the B-complex group of vitamins, and the amino acid content is reasonably high
- dry yeast contains about 50% proteins and 20% non-proteins
- yeasts contain lysine, thiamine, biotin, riviflavin, niacin, folic acid, but deficient in methionine
- *Aspergillus niger* is well balanced and at par with the standard prescribed by WHO
- in bacteria the crude protein content is around 80% of the dry weight
- in general SCP products contain approximately 50 – 70% crude proteins
- as per recent report SCP sources, their protein contents and other characteristics are given in the Table-4, below:

Table-4: SCP Sources, Protein Contents, Special Characteristics, Organisms, Challenges

Summary of SCP sources and current examples

SCP sources	Protein content range	Special characteristics	Example of specific organisms	Challenges	Current commercial activities
Microalgae	60–70% [2•,10••]	• Phototrophic growth • Production of omega-3 fatty acids	• *Chlorella vulgaris* • *Desmodesmus* sp.	• Economical scale-up • Cell disruption to release nutrients	• Cellana • Pond Technologies • BioProcess Algae
Yeasts	30–50% [10••]	• Use of a variety of feedstocks • Production of vitamins and micronutrients	• *Saccharomyces cerevisiae* • *Candida utilis*	• Improve protein and EAA content	• ADM • Alltech • Flint Hills Resources • ICC Brazil • Pacific Ethanol
Bacteria	50–80% [10••]	• High protein content • Growth on C1 substrates	• *Methylococcus capsulatus* • *Cupravidus nectar*	• Palatability issues	• Calysta • Kiverdi • KnipBio • NovoNutrients • White Dog Labs
Protists	10–20% [63,64]	• Production of omega-3 fatty acids	• *Schizochytrium limacinum*	• Improve protein content	• Veramaris

- Average composition (Nutritional Values) of different microorganisms used for SCP production has been shown in the following Table-5:

Table-5: Average Diffenent Composition of the Main Group of Microorganisms

Composition	Fungi	Algae	Yeast	Bacteria
Protein	30-45	40-60	45-55	50-65
Fat	2-8	7-20	2-6	1-3
Ash	9-14	8-10	5-10	3-7
Nucleic acid	7-10	3-8	6-12	8-12

- Essential amio acid content of microorganisms for SCP production (g per 16 g N) has been reflected in the Table-6, below:

Table-6: Essential Amio Acid Content of Microorganisms for SCP

Protein source	*Cys*	*Ile*	*Leu*	*Lys*	*Met*	*Phe*	*Thr*	*Try*	*Val*
Algae									
Chlorella sorokiniana	3.4	4.0	7.8	1.8	2.7	3.2	1.4	5.1	-
Spirullina maxima	0.4	5.8	7.8	4.8	1.5	4.6	4.6	1.3	6.3
Bacteria and Actinomycetes									
Cellulomonas alcaligenes	5.4	7.4	7.6	2.0	4.7	5.5	7.1	-	-
Methylophilus methylotrophus	0.6	4.3	6.8	5.9	2.4	3.4	4.6	0.9	5.2
Thermomonospora fusca	0.4	3.2	6.1	3.6	2.0	2.6	4.0	13.0	-
Fungi									
Candida lipolytican-	1.1	4.5	7.0	7.0	1.8	4.4	4.9	1.4	5.4
Candida utilis	-	0.4	4.5	7.1	6.6	1.4	4.1	5.5	1.2
Kluyveromyces fragilis	4.0	6.1	6.9	1.9	2.8	5.8	1.4	5.4	-
Saccharomyces cerevisiae	1.6	5.5	7.9	8.2	2.5	4.5	4.8	1.2	5.5
Aspergillus niger	1.1	4.2	5.7	5.9	2.6	3.8	5.0	2.1	5.2
Morchella crassipes	0.4	2.9	5.6	3.5	1.0	1.9	3.0	1.5	3.0
Paecilomyces variotii	1.1	4.3	6.9	6.4	1.5	3.7	4.6	1.2	5.1

➢ FACTORS AFFECTING SCP PRODUCTION

SCP production is a complex and costly process. The production is greatly affected by the factors such as:

- **Selection of kind of microorganisms**

  Selection of a suitable microbial strain for SCP production must take several characteristics into account, including:
  - ✓ growth rate, productivity and yields on the specific, low-cost, substrates to be used
  - ✓ temperature and pH tolerance
  - ✓ oxygen requirements, heat generation during fermentation and foaming characteristics;
  - ✓ growth morphology and genetic stability in the fermentation; process
  - ✓ ease of recovery of SCP and requirements for further downstream processing
  - ✓ structure and composition of the final product, in terms of protein content, amino acid profile, RNA level, flavor, aroma, color and texture etc.
- **Other major factors are safety and acceptability**
  - ✓ most SCP products are used as animal feed and not for human consumption
  - ✓ these products must meet safety requirements
  - ✓ obtaining regulatory approval for the production of proteins for human consumption is an even lengthier and more expensive process, and obviously influences the choice of production organism
  - ✓ a safety aspect that must be considered for all SCP products is nucleic acid content

- ✓ many microorganisms have naturally high levels of nucleic acid, because fermentation conditions favoring rapid growth rates and high protein content also promote elevated RNA levels
- ✓ this can be problematic as the digestion of nucleic acids by humans and animals leads to the generation of purine compounds
- ✓ their further metabolism results in elevated plasma levels of uric acid, which may crystallize in the joints to give gout-like symptoms or forms kidney stones
- ✓ slow digestion or indigestion of some microbial cells within the gut and any sensitivity or allergic reactions to the microbial protein must also be examined
- ✓ an additional concern is the absorption of toxic or carcinogenic substances, such as polycyclic aromatic compounds, which may be derived from certain growth substrates

- **Economic aspects**

For SCP production large-scale fermenters are required. So with high biomass production, high oxygen transfer rates and high respiration rates which in turn increase metabolic heat production and the need of an efficient cooling system ensued. In 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.

Substrate costs: The substrate costs are the largest single cost factor. Simplifying the manufacture and purification of raw material can save costs. Moreover the manufacture of raw materials is more economical in larger plants. Factors involved in the raw materials costs are site, raw material production, process capacity of the plant and substrate yield.

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.

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. 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 upgrading of the product may consist of purification and separation of the microbial biomass.

- fermenter design (types of the fermenter used
- heat management
- waste disposal
- environmental concerns

➢ SINGLE CELL PROTEIN PRODUCTION PROCESSES

Cultivation methods

The production of single cell protein takes place in fermentation. This is done by selected strains of microorganisms which are multiplied on suitable raw materials in technical cultivation process directed to the growth of the culture and the cell mass followed by separation processes. Process development begins with microbial screening, in which suitable production strains are obtained from samples of soil, water, 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 done and all metabolic pathways and cell structures will be determined. Besides, process engineering and apparatus technology adapt the technical performance of the process in order to make the production ready for use on the large technical scale. Here is where the economic factors (energy, cost) come into play. Safety demands and environmental protection is also considered in the production of 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.

- **Submerged fermentation**

In submerged process , the substrate used for fermentation is always in liquid state which contains the nutrients needed for growth. The fermentor which contains the substrate is operated continuously and the product biomass is continuously harvested from the fermentor by using different techniques then the product is filtered or centrifuged and then dried. Aeration is an important operation in the cultivation, heat is generated during cultivation and it is removed by using a cooling device. The microbial biomass can be harvested by various methods. Single cell organisms like yeast and bacteria are recovered by centrifugation while filamentous fungi are recovered by filtration. It is important to recover as much water as possible prior to final drying done under clean and hygienic conditions.

- **Semisolid fermentation**

In semisolid fermentation, the preparation of the substrate is not cleared and it is also more used in solid state e.g. cassava waste. Submerged culture fermentations require more capital investment and have high operating cost. The cultivation involves many operations which include stirring and mixing of a multiphase system, transport of oxygen from the gas bubbles through the liquid phase to the microorganisms and the process of heat transfers from liquid phase to the surroundings. A special bioreactor is designed for identifying mass and energy transportation phenomena, called U-loop fermentor. Production of single cell protein involves basic steps of preparation of suitable medium with suitable carbon source, prevention of the contamination of medium and the fermentor, production of microorganisms with desired properties and separation of synthesized biomass and its processing. Carbon source used can be n-alkenes, gaseous hydrocarbons, methanol and ethanol, renewable sources like carbon oxide molasses, polysaccharides, effluents of breweries and other solid substances.

- **Solid state fermentation**

Solid state fermentation (SSF) has been extensively studied with thousands of publications describing various types of bioreactor designs, process conditions and microorganisms for the production of various value added products like SCP, feeds, enzymes, ethanol, organic acids, Bcomplex vitamins, pigments, flavours. This process consists of depositing a solid culture substrate, such as rice or wheat bran, on flatbeds after seeding it with microorganisms; the substrate is then left in a temperature-controlled room for several days. Liquid state fermentation is performed in tanks, which can reach 1,001 to 2,500 square metres (10,770 to 26,910 sq ft) at an industrial scale. Liquid culture is ideal for the growing of unicellular organisms such as bacteria or yeasts. To achieve liquid aerobic fermentation, it is necessary to constantly supply the microorganism with oxygen, which is generally done via stirring the fermentation media. Accurately managing the synthesis of the desired metabolites requires regulating temperature, soluble oxygen, ionic strength and pH and control nutrients.

The main steps involved are: medium preparation, fermentation, separation and downstream processing.

A simple common flow diagram of SCP production by fermentation has been shown in the Figure-1.

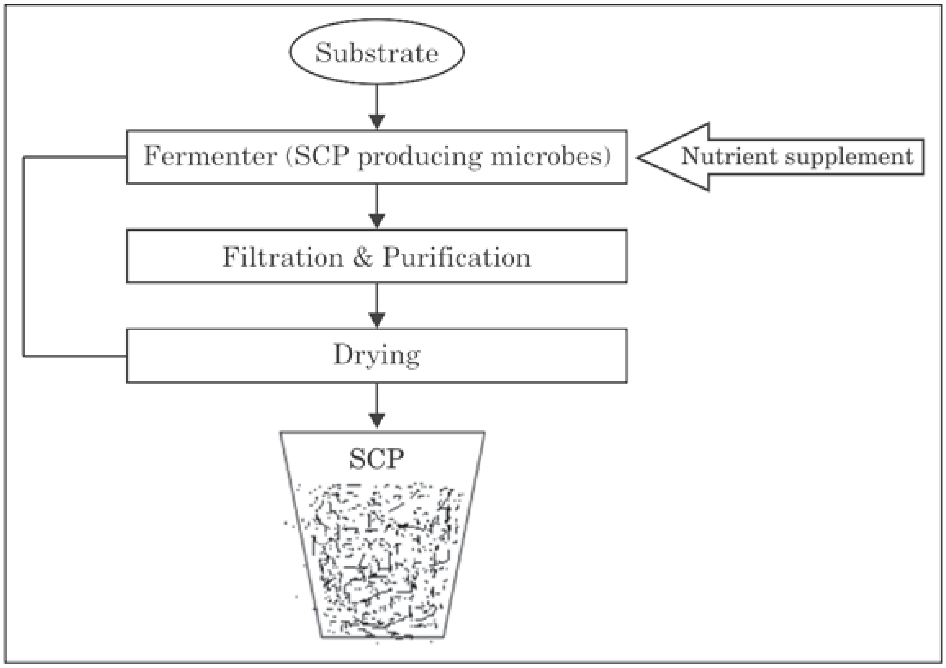


Figure-1: Flow chart of single cell protein production.

STEPS INVOLVED AND THE VARIOUS TECHNOLOGIES USED WORLWIDE

- **Most Important Steps:**
  - ✓ for producing quality SCP, one has to take care in every step
  - ✓ the first and foremost important step is the selection of microorganisms
    - the selected microorganism should be fast growing
    - wide substrate utilizing capacity
    - should be non-pathogenic, and
    - do not produce any type of toxin
    - should produce protein not only of high quality but also in good quantity, and
    - should contain limited quantity of nucleic acid etc
  - ✓ the next step would be selection of sub-stratum
    - the sub stratum is not only cheaper, but readily utilizable
    - the organisms employed do not contribute for liberation of toxic substances
    - then the growing condition of organism should be ambient
    - the incubation period should be short and downstream process should be simple and in apposition to yield pure protein with minimum number of steps
  - ✓ post harvest step
    - the purification and drying of protein should be a simple and should not affect the quality of protein
    - if protein is deficient in some respects, that can be improved by supplementation of required substances
    - thus the post-harvest stage of SCP should do simple and amenable for processing
    - this will help to get a quality SCP and will be useful as feed additive for other purposes

- **Technologies (processes) used Worlwide**

  Some of the processes are: Bel process, Pekilo process, Bioprotein process, Pruteen process, Quorn production, Symba process, Waterloo process, High-rate algal ponds. The Pruteen process has been discussed below:

  Pruteen Process

  ✓ attempts to develop methanol based processes were made in Europe, the former society union, Japan and the USA

  ✓ they involved bacterial species (*Hyphomicrobium*, *Methylococcus*, *Methylophilus* and *Methylotrophus*), yeasts (*Candida boidinii*, *Pichia angusta* and *P.pastorn*) and even filamentous fungi (*Gliocladium deliquescans*, *paecilomyces variotii* and *Trichoderma linganus*)

  ✓ the most adventurous process was developed by ICI in UK in 1980

  ✓ this process used the methylotrophic bacterium, *M.methylotrophus*, to produce a feed protein for chicken and pigs called pruteen

  ✓ it is a world largest continuous aerobic bioprocess system involving 3000 m pressure cycle airlift fermenter with inner loop and working fluid volume of 1.5 × 10 L. capable of producing upto 50,000 tonnes of pruteen protein (Figure-2)

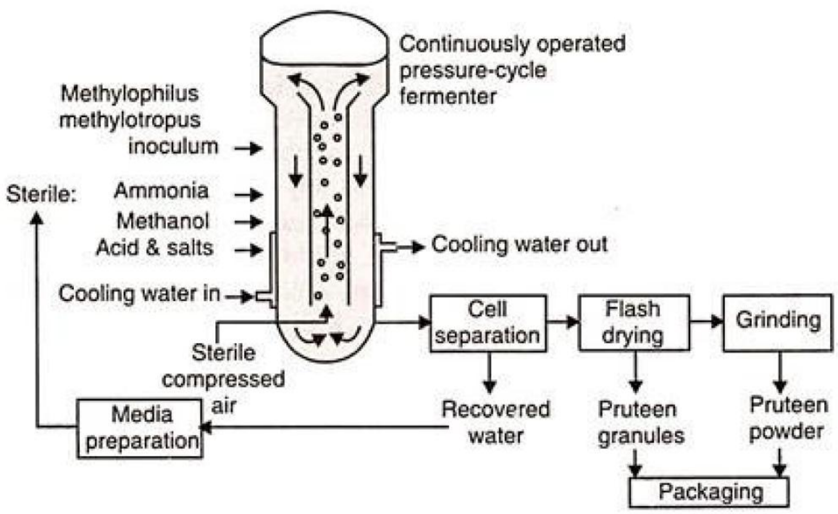


Figure-2: SCP production through pruteen process.

Figure-3: Pruteen plant for manufacturing SCP

PARAMETERS FOR OPTIMUM SCP PRODUCTION

The parameter are:

- Microorganisms used
- Culture condition
- Pre-treatment of substrates
- Nutrient supplementation
- Types of fermentation processes
- Strain improvement
- Genetic engineering techniques

USES (APPLICATIONS) OF SCP

- provides instant energy
- it is extremely good for healthy eyes and skin
- provides the best protein supplemented food for undernourished children
- serves as a good source of vitamins, amino acids, minerals, etc.

Used in therapeutic and natural medicines for

- controlling obesity
- lowers blood sugar level in diabetic patients
- reducing body weight, cholesterol and stress
- prevents accumulation of cholesterol in the body.

Used in Cosmetics products for

- maintaining healthy hair
- production of different herbal beauty products, like- Biolipstics, herbal face cream, etc.

Used in Poultry and dairy farms

- as it serves as an excellent and convenient source of proteins and other nutrients, it is widely used for feeding cattle, birds, fishes, etc.

TECHNOLOGICAL ADVANTAGES OF SINGLE CELL PROTEIN

Single cell protein basically comprises proteins, fats carbohydrates, ash ingredients, water, and other elements such as phosphorus and Potassium. Aside from the nutritional benefits of single cell protein, another benefit of single cell protein technology is

- throughout the year production
- it plays its role in waste management as waste materials are used as substrate
- small area of land is required and SCP is made in less time
- helpful in wake of food crisis
- cultivation of SCP on the one hand provides alternative substrates, and on the other hand helps in solving problems of disposal caused during the process
- helpful in recycling of waste

SIDE EFFECTS / DRAWBACKS OF SCP TECHNOLOGY

Despite very striking features of single cell protein as a nutrient for humans and animals there are various problems associated, that deters its adoption globally. Such problems include:

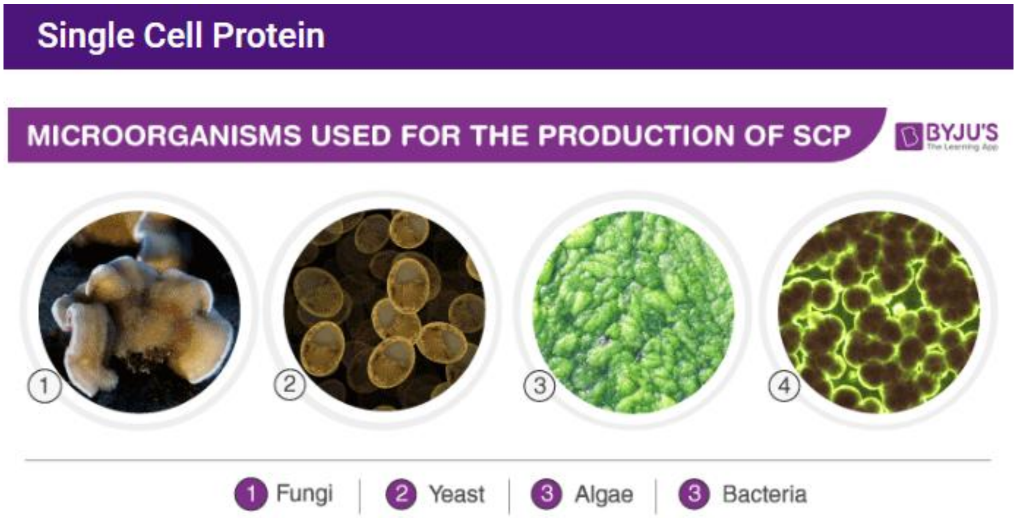
- the concentration of nucleic acid is higher than other conventional protein sources and it is the characteristics of all rapidly growing organisms

- the problem which occurs with the consumption of high nucleic acid containing protein (18-25 g/100g protein dry weight) is the production of high concentration of uric acid level in the blood causing health disorders such as gout and kidney stone
- single cell protein from bacteria has also been found to be associated with these pitfalls which include: high ribonucleic acid content, high risk of contamination during the production process and recovering the cells is a bit problematic
- about 70 to 80% of the total nitrogen is represented by amino acids while the rest occur in nucleic acids
- it is also the point to be noted that the microbial cell wall may be indigestible
- there may be intolerable colour and flavours (especially in algae) and in yeast there may also be possible skin reactions from consumption of foreign protein and gastrointestinal reactions may occur resulting in nausea and vomiting
- single cell protein from algae may not be suitable for human consumption because they are rich in chlorophyll (except *Spirullina*)
- it has low density *i.e.* 1-2 gm dry weight/litre of substrate and there is lot of risk of contamination during growth
- the filamentous fungi show slow growth rate than yeasts and bacteria there is high contamination risk and some strains produce mycotoxins and hence they should be well screened before consumption

CONCLUDING REMARKS

- *SCP shows very attractive features as a nutrient supplement for humans*
- *SCP has various benefits over animal and plant proteins in that its requirement for growth are neither seasonal nor depends on the climatic conditions and can be produced round the year*
- *SCP has a high protein content with wide amino acid spectrum, low fat content and higher protein carbohydrate ratio than forages*
- *it can be grown on waste and is therefore environment friendly*
- *the use of SCP as an alternative nutrient supplement can solve the problem of food scarcity for the rapidly growing population especially in a developing country like India*
- *however, the benefits SCP production has gained less importance because of lack of acceptability as a nutrient supplement among people*
- *moreover, high nucleic acid content, presence of non-digestible cell wall, unacceptable colours and flavours and a high risk of contamination and cell recovery further restricts their use as a global food*
- *therefore, efforts should be made to minimize the pitfalls which may improve acceptability of SCP among the masses*

THE PLANT AND THE PRODUCTS

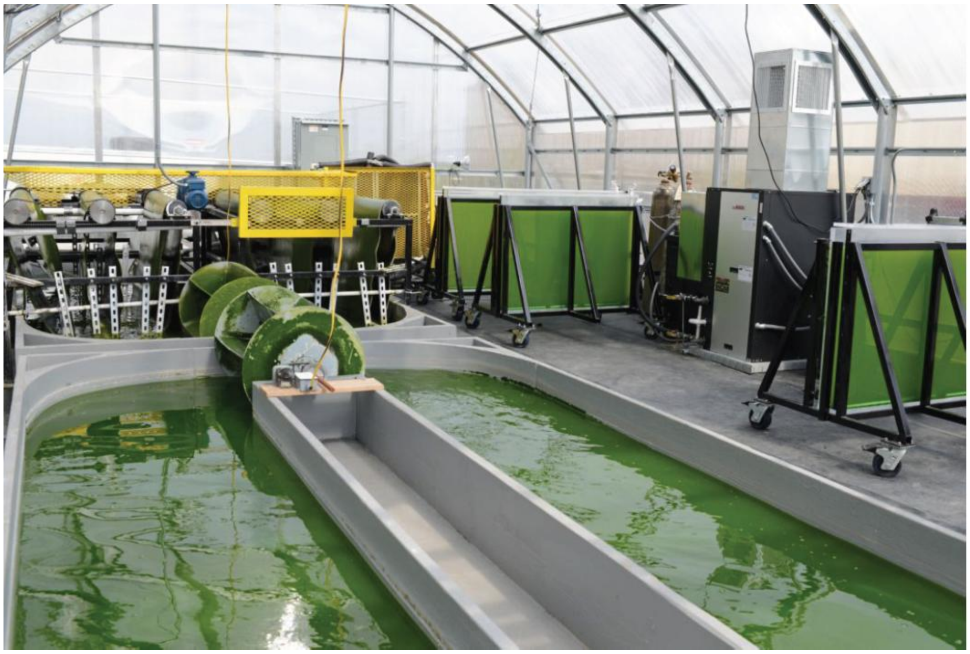


SCP Processing Plant

Single-cell protein from the new plant will be commercially available to the aquafeed sector in August 2019

The facility in Shandong is the second full-scale single-cell protein production facility established by iCell in China, which increases their production capacity to several thousand tonnes per year. The company that holds more than 50 patents throughout the world for the production and use of SCPs in animal and plant nutrition.

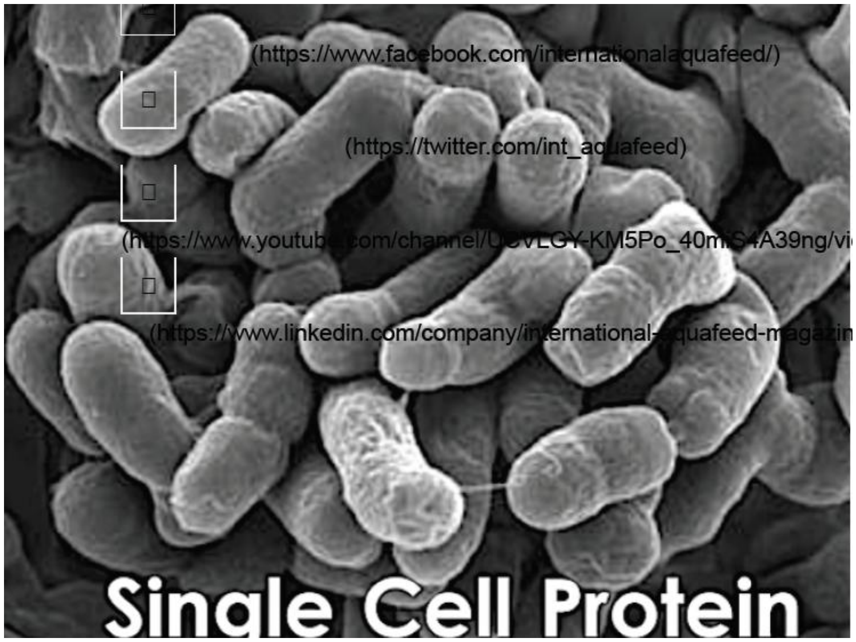
iCell now has the capacity to produce "thousands of tonnes" of SCPs (China)

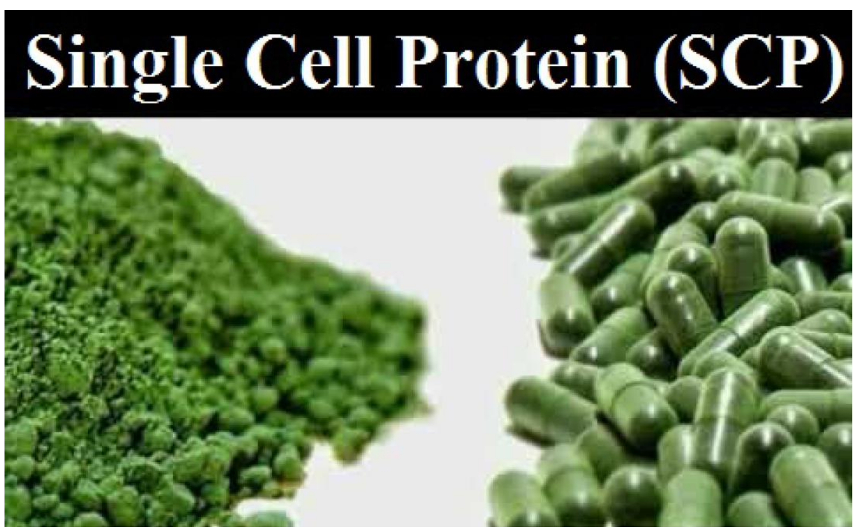


SCP Proceesing Unit using algae

Spirullina Powder (SCP)

Second Generation (SCP) Product in the form of Tablet


Single Cell Protein


Single Cell Protein (SCP)

A processing unit for SCP