Single cell protein (SCP)

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Single cell protein

- The recycling of biodegradable waste into environmentally harmless compounds is one of the bases for waste management.
- However, simply treating biodegradable waste is no longer considered efficient waste management practice.
- Depending on the type of waste used, nowadays it is possible to produce a range of value added products that make waste management not only an environmentally friendly endeavour, but also a promising business activity.
- One such high-value added product is single-cell protein (SCP).
- The term SCP refers to dead, dry microbial cells or total proteins extracted from pure microbial cell culture and is produced using a number of different microorganisms including bacterium, fungus and algae.
- The word SCP is considered to be appropriate since most of the microorganisms grow as single or filamentous individuals.

...Single cell protein

- SCP can be used as protein-rich foods or food ingredients or dietary supplements, but they are mainly used as food for human and animal consumption.
- SCPs are a good alternative to replacing protein of agricultural origin, since:
  - SCP production is not characterized by high water consumption
  - it does not cover large areas of land
  - does not endanger environmental diversity
  - does not contribute to climate change
  - does not produce high greenhouse gas emissions
- Besides high protein content (about 60-82% 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 like lysine, methionine which are limiting in most plant and animal foods.
- This protein can be used as additive added to the main diet instead of sources known very expensive such as soybean and fish.

...Single cell protein

- Various microorganisms used for the production of SCP are bacteria (*Cellulomonas*, *Alcaligenes*, etc.), algae (*Spirulina*, *Chlorella*, etc.), molds (*Trichoderma*, *Fusarium*, *Rhizopus*, etc.) and yeast (*Candida*, *Saccharomyces*, etc.).
- Yeast was the first microorganism whose importance as animal feed supplement was recognized almost a century ago.
- During World War I, Germany replaced half of imported protein sources by yeast.
- Pruteen was the first commercial single cell protein used as animal feed additive.
- It has been calculated that 100 lbs of yeast will produce 250 tons of proteins in 24 h.
- Algae grown in ponds can produce 20 tons (dry weight) of protein, per acre, per year.
- Bacteria are usually high in protein (50 to 80%) and have a rapid growth rate.

Average different compositions of the main groups of microorganisms (% dry weight)

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

Yeast as SCP

- Yeast is suitable for SCP because of its superior nutritional quality.
- The supplementation cereals with single cell proteins, especially yeast, make them as good as animal proteins.
- High nucleic acid content and low cell wall digestibility are the most important factors limiting nutritional value of yeast for animal/ human consumption.
- The external mannoprotein layer of the yeast cell wall is probably the major barrier to digestion.
- As constituents of nucleic acid, purine compounds in diet mostly metabolized to yield uric acid whose high concentration may lead to gout or renal stones.
- Yeasts have advantages such as their larger size (easier to harvest), high lysine content and ability to grow at acidic pH.
- However, the most important advantage is familiarity and acceptability because of the long history of its use in traditional fermentations.
- Disadvantages include lower growth rates, lower protein content (45 to 65%) and lower methionine content than in bacteria.
- The substrates which have been used for SCP production by yeasts so far include sorghum hydrolysate, sulfate waste liquor, pawn-shell wastes, dairy wastes, methanol, molasses, starch and plant origin liquid waste.

...Yeast & other fungi as SCP

- Filamentous fungi have advantages in ease of harvesting, but have their limitations in lower growth rates, lower protein content and acceptability.
- Several fungi like *Fusarium oxyporum* var., *lini* and *Chetomium cellulolyticum*, yeast like *Candida lipolytica* and *Saccharomyces cereviciae* had been explored for SCP.

Microorganism	Substrate
Fungi	
Aspergillus fumigatus	Maltose, Glucose
Aspergillus niger, A. oryzae, *Cephalosporium eichhorniae*, *Chaetomium cellulolyticum*	Cellulose, Hemicellulose
Penecillium cyclopium	Glucose, Lactose, Galactose
Rhizopus chinensis	Glucose, Maltose
Scytalidium aciduphlium, *Thricoderma viridae*, *Thricoderma alba*	Cellulose, pentose
Yeast	
Amoco torula	Ethanol
Candida tropicalis	Maltose, Glucose
Candida utilis	Glucose
Candida novellas	n-alkanes
Candida intermedia	Lactose
Saccharomyces cereviciae	Lactose, pentose, maltose

Bacteria as SCP

- Bacteria are usually high in protein (50 to 80%) and have a rapid growth rate. The principal disadvantages are as follows:
  - Bacterial cells have small size and low density, which makes harvesting from the fermented medium difficult and costly
  - Bacterial cells have high nucleic acid content relative to yeast and fungi.
  - To decrease the nucleic acid level additional processing step has to be introduced and this increases the cost
  - The general public thinking is that all bacteria are harmful and produce disease.
  - An extensive education program is required to remove this misconception and to make the public accept bacterial protein

Microorganism	Substrate
Bacteria	
Aeromonas hydrophylla	Lactose
Acromobacter delvacvate	n-Alkanes
Acinetobacter calcoacenticus	Ethanol
Bacillus megaterium	Non-protein nitrogenous compounds
Bacillus subtilis, Cellulomonas sp., *Flavobacterium* sp., *Thermomonospora fusca*	Cellulose, Hemicellulose
Lactobacillus sp.	Glucose, Amylose, Maltose
Methylomonas methylotrophus, M. clara	Methanol
Pseudomonas fluorescens	Uric acid and other non-protein nitrogenous compounds
Rhodopseudomonas capsulata	Glucose

Algae as SCP

- To date, world-wide various sophisticated technologies are employed for mass production and processing of photoautotrophic microalgae.
- The annual world production of all microalgae species is about 10,000 tons year.
- The algal biomass as sun dried or in compressed form as pastilles is the predominant product in microalgal biotechnology .
- More than 75% of the annual microalgal biomass production is used for the manufacture of powders, tablets, capsules, or pastilles.
- This biomass is harvested from natural waters or artificial ponds or photobioreactors (PBR) and subsequently separated from the growth media followed by drying.
- The two major species cultivated for this purpose are the unicellular green alga, *Chlorella* and more recently, filamentous blue-green alga (Cyanobacterium), *Spirulina* .
- Algal proteins are of high quality and comparable to conventional vegetable proteins.

... Algae as SCP

- The celluloid cell wall, which represents about 10% of the algal dry matter, poses a serious problem in digesting/utilizing the algal biomass, since it is not digestible for humans and other non-ruminants.
- Hence, effective treatments are necessary to disrupt the cell wall to make the protein and other constituents accessible for digestive enzymes.
- Another problem is, they also concentrate heavy metals.

Microorganism	Substrate
Algae	
Chlorella pyrenoidosa, *Chlorella sorokiana*, *Chondrus crispus*, *Scenedesmus* sp., *Spirulina* sp., *Porphyrium* sp.	Carbone dioxide through photosinthesis

SCP production advantages & disadvantages

- Large-scale processes for SCP production show interesting features, including:
  - The wide variety of methodologies, raw materials and microorganisms that can be used for this purpose
  - High efficiency in substrate conversion
  - High productivity, derived from the fast growth rate of microorganisms
  - Independence of seasonal factors
- Microorganisms can utilize a variety of substrate like agricultural wastes and effluents, industrial wastes, natural gas like methane, etc. that also help in decomposing pollutants.
- However, from a nutritional viewpoint, Nucleic Acids (NA) content and low cell wall digestibility in SCP is one of the main factors hindering its utilization as food.
- Excessive intakes of NA lead to uric acid precipitation, causing health disorders, such as gout or kidney stone formation.
- So, in human their NA contents must be reduced below 2%.
- Several technologies have been reported to reduce the NA content of microbial cells, including both chemical and enzymatic procedures.
- Several methods have been developed to improve the digestibility of SCP products: mechanical disruption, autolysis and enzymatic treatment.
- Chemical and enzymatic methods have disadvantages.

Industrial waste applicable for SCP production

- The use of waste products in the production of SCP can reduce the production costs and waste treatment reduces the negative environmental impact of these residues.
- Biodegradable industrial wastes such as sludge, paper waste and production residues, specific industrial and chemical by-products and waste gases can be used for microbial fermentation.
- Polymers, especially lignocellulosic waste, are the most widely available industrial waste.
- However, polysaccharides and other complex compounds require a thorough mechanical (steam explosion or even x-ray radiation), chemical (alkali or acid treatment) or enzymatic pre-treatment (or combination of treatments) before the SCP producing microorganisms can ferment them.
- Consequently, the use of polysaccharides increases the cost of SCP production.
- Spent sulphite liquor (SSL) is a by-product of the sulfite process, which produces wood pulp from wood chips, can be used effectively in the cultivation of microorganisms.
- Latex is a complex mixture of substances consisting of proteins, saccharides, alkaloids, oils, resins, gums and tannins.
- the use of latex rubber sheet wastewater in the production of SCP can yield high protein concentrations in the microbial biomass and also considerably reduce chemical oxygen demand (COD) values.
- Under industrial conditions, methane, acetic acid, formic acid accumulate during storage or processing of various resources and waste product can be used for SCP production.

...Industrial waste applicable for SCP production

Polymer-rich sources	Microorganisms	Protein content, %
Waste paper	*Scytalidium acidophilum*	47
Sulfite waste liquor	*Paecilomyces variotii*	55
	Fusarium venenatum	55
	Candida utilis	-
Lignin residues	*Chrysonilia sitophila*	39.2
Latex rubber sheet wastewater	*Rhodopseudomonas palustris*	65
Carbon compounds		
Methane	*Mehtylomonas sp.*	69.3
	Bacteria isolated from soil	71
Methanol	*Methylophilus methylotrophus*	-
	Pichia pastoris	35
Acetic acid Formic acid	Bacteria isolated from soil	71
Waste gases	*Methylococcus capsulatus*	-
	Rhodobacter capsulatus	-
Glycerol	*Acinetobacter baylyi*	-
	Aurantiochytrium limancinum	-
	Schizochytrium limacinum	-
Gas oil	BP yeast	67–69
n-paraffins		63

... Industrial waste applicable for SCP production

- Waste gases CO, CO_2 and CH_4 are generated from steel and oil refining, coal, natural/shale gas and syngas industries, can also be used for cultivation of photosynthetic microorganisms.
- Crude glycerol, which is generated during production of biodiesel. The use of glycerol in the production of SCP would provide the opportunity to produce a high value added product and allow the biodiesel industry to get additional revenue by using glycerol more economically efficiently.
- SCP producing microorganisms can use fuel oil and other n-parafins, which are distillates or residues from petroleum distillation.

Polymer-rich sources	Microorganisms	Protein content, %
Sources for photosynthetic microorganisms		
Effluents of biogas plants	*Rhodopseudomonas capsulate*	69.4
	Rhodopseudomonas spp.	49–68
Saline sewage effluents	*Chlorella salina*	51
Wastewater effluents	*Micractinium, Scenedesmus*	
	Oocystis, Franceia	40–60
	Euglena	

Fermentation process

- The fermentation process requires:
  - a pure culture of the chosen organism,
  - sterilization of the growth medium which is used for the organism,
  - a production fermentor 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
- The physiological features of microbial organisms recommend the control of the carbon source concentrations, as a limiting substrate, as well as an adequate supply of oxygen for the maintenance of balanced growth under an oxidative metabolic pattern.
- Fed-batch fermentations are better suited for the purpose of biomass production, since they involve the control of the carbon source supply through feeding rates.
- Production periods as long as six weeks have been implemented in many fungal and yeast.
- The biomass from yeast and bacteria fermentation processes is harvested normally by continuous centrifugation.
- Filamentous fungi are harvested by filtration .
- The biomass is then treated for RNA reduction and dried in steam drums of spray driers.
- Algae are cultivated in special ponds or lagoons.
- These microorganisms bind and use the inorganic nitrogen and phosphorus in the residue.
- Depending on the selected strain, microorganisms can grow on either freshwater or high salinities sewage effluents.

Questions

- What is single cell protein? How SCP can be produced using waste materials?
- Write a short note on:
  - SCP
  - Waste products applicable for SCP production
  - Types of SCP, their advantages and disadvantages
  - Yeast as SCP