NUTRITION - SINGLE CELL PROTEIN, TWENTY YEARS LATER

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The term single cell protein (SCP) refers to dead, dry cells of micro-organisms such as yeast, bacteria, fungi and algae which grow on different carbon sources. The name "single cell protein" was used for the first time, twenty years ago by the M.I.T. professor Carol Wilson to give a better image than "microbial protein".([17])

About 50 years ago (1934-1938) the less developed areas of the world, Asia, Africa and South America, were the main exporters of grain to the developed world. Since 1948 the food flow has reversed, from the developed world to the less developed, mainly due to the rate of growth of the world's population which was much higher in the less developed countries. ([3]) Based on present trends United Nations (UN) population experts project that there will be 8 billion people living on this planet by 2015 and 10.5 billion by the year 2110. This means that during the 35-year period (1980-2015) we must produce as much food as we have since the dawn of agriculture about 12000 years ago. ([12])

The U.S.D.A. declared in the 1970's that the world could not depend on American aid to cover the differences in food production between developed and underdeveloped countries and that the US had to face its own problems. ([1])

In the 1950's many people predicted a future protein mortgage in the world, due in 30-40 years. We now see that these predictions were rather pessimistic for the developed countries. However death from starvation, malnutrition and related diseases is a reality in many countries today. The World Health Organisation (WHO) estimates that 12,000,000 people die of hunger and starvation related diseases every year. Half are children under the age of 5. ([12])

Due to such a great population growth man could not have depended only on agriculture husbandry and fisheries for food. An energy crisis has an immediate impact on agriculture and hence man should have searched for other types of food for his survival.

During the sixties the idea that the single cell protein could help the less developed countries in future food shortages was gaining research interest among scientists in universities and industry, particularly in oil. The result was the development of SCP technology either for livestock or for human consumption.

Although man has been familiar with the food and feed usage of micro-organisms for centuries, SCP technology for food was developed over the last 100 years while large scale production has developed in the 20th century and particularly after the First World War. This was in Berlin with the growth of S. cerevisiac on a production level to replace as much as 60% of the foodstuffs Germany had been importing after the war. ([13]) Also yeast storing of *Candida arborea* and *C. utilis* made an important contribution to the diet in Germany in World War II. After World War II, growth of fungi in submerged cultures for the production of antibiotics led to an investigation of the potential microfungi as flavour additives to replace mushrooms.

In the 1950's some oil industries became interested in the growth of micro-organisms on alkanes. The micro-organisms which were used developed into a potential diet for feed and food. Many companies producing SCP including BP (UK), Kanegafuichi (Japan), and Liquichimica (Italy) appeared on the scene. In the USSR 12 out of 86 plants making SCP were said to rely on hydrocarbons as the source of carbons and energy for the micro-organisms. Other potential substrates for SCP include bagasse, citrus wastes, sulphite waste liquor, molasses, animal manure, whey, starch, sewage, etc.

In general the more reduced the substrate, the greater the cell yield (Yx/s) and the m ore oxygen required for the oxidation of the substrate. (10) In this case a serious problem is the great heat which is produced, i.e. the cost which is required for cooling off the fermentors. Finally the cost of the substrate in connection with feasibility of the process.

This article attempts to re-evaluate the applications of SCP and discuss its future prospects.

Properties of SCP

One of the main advantages of SCP compared to other types of protein is the small doubling time of cells (td) as shown in Table 1.

Table 1

Mass doubling time (S)

Organism	Mass Doubling
Bacteria and yeast	10-120 min
Mold and algae	2-6 h
Grass and some plants	1-2 wk
Chickens	2-4 wk
Pigs	4-6 wk
Cattle	1-2 mo
People	0.2-0.5 yr

Due to this property, the productivity of protein production form micro-organisms is greater than that of traditional proteins (Table 2).

Table 2

Efficiency of protein production of several protein sources in 24 hours ([16])

Organism (1,000 kg)	Amount of protein
Beef cattle	1.0 kg
Soybeans	10.0 kg
Yeast	100.0 tn
Bacteria	100x10,000,000 tn

It is assumed that the growth occurs without any restriction. Other advantages of SCP over conventional protein sources are:

a. it is independent of land and climate;
b. it works on a continuous basis;
c. it can be genetically controlled;
d. it causes less pollution.

There are five factors that impair the usefulness of SCP:

a. non digestible cell wall (mainly algae);
b. high nucleic acid content;
c. unacceptable coloration (mainly with algae);
d. disagreeable flavour (part in algae and yeasts);
e. cells should be killed before consumption.

Thus SCP is treated with various methods in order to:

1. kill the cells;
2. improve the digestibility;
3. reduce the nucleic acid content.

Nutritional Value of SCP

For the assessment of the nutritional value of SCP, factors such as nutrient composition, amino acid profile, vitamin and nucleic acid content as well as palatability, allergies and gastrointestinal effects should be taken into consideration ([9]). Also long term feeding trials should be undertaken for toxicological effects and carcinogenesis.

Table 3 shows the average cell composition of the major groups of micro-organisms.

Table 3

Average composition of the main groups of micro-organisms (% dry weight) ([2])

	Fungi	Algae	Yeasts	Bacteria
Protein	30-45	40-60	45-55	50-65
Fat	2-8	7-20	2-6	1.5-3.0
Ash	9-14	8-10	5-9.5	3-7
Nucleic acids	7-10	3-8	6-12	8-12

Bacterial protein is similar to fish protein, yeast's protein resembles soya and the fungi protein is somewhat lower than the yeast's. Of course microbiological proteins are deficient in the sulphur amino acids cysteine and methionine and require supplementation, while they exhibit better levels of lysine (Table 4).

Table 4

Essential amino acid content of the cell protein in comparison with several reference proteins (grams of amino acid per 100 grams of protein) ([4])

Amino acid	Chlamydomonas	Saccharomyces cerevisiae	Spirulina maxima	Penicillium notatum	BP (SCP)	Wheat	Egg	Cow milk
Lysine	7.6	7.7	4.6	3.9	7.0	2.8	6.3	7.8
Threonine	5.4	4.8	4.6	–	4.9	2.9	5.0	4.6
Methionine	2.0	1.7	1.4	1	1.8	1.5	3.2	2.4
Cysteine	–	–	0.4	–	–	2.5	2.4	–
Tryptophane	–	1.0	1.4	1.25	–	1.1	1.6	–
Isoleucine	5.3	4.6	6.0	3.2	4.5	3.3	6.8	6.4
Leucine	7.3	7.0	8.0	5.5	7.0	6.7	9.0	9.9
Valine	7.1	5.3	6.5	3.9	5.4	4.4	7.4	6.9
Phenylalanine	4.6	4.1	5.0	2.8	4.4	4.5	6.3	4.9
Histidine	7.8	2.7	–	–	2.0	–	–	–
Arginine	6.4	2.4	–	–	4.8	–	–	–

The vitamins of micro-organisms are primarily of the B type, B12 occurs mostly in bacteria, while vitamin A is usually found in algae. Table 5 shows the vitamin content of various food micro-organisms.

Table 5

Vitamin content of various food micro-organisms (mg/100 g dry weight) ([15])

Vitamin	Morchella Hortensis	Candida Utilis	Saccharomyces Cereviviae	Methylomonas Methanica
Thiamine	0.52	0.53	5-36	1.81
Riboflavin	1.31	4.50	3.6-4.2	4.82
Niacin	12.4	41.73	80-100	15-9
Pyridoxine	2.62	3.34	2.5-10	14.3
Pantothenic acid	12.6	3.72	10	2.42
Choline	4.61	-	-	968.0
Folic acid	1.09	2.15	1.5-8.0	-
Inositol	1.78	-	-	-
Biotin	0.015	0.23	0.5-1.8	-
Vitamin B_{12}	0	0	0	0.96
P-aminobenzoic acid	-	1.7	0.9-10	-

Other nutritional parameters which evaluate the quality of a given SCP are:

- the digestibility (D)
- the biological value (BV)
- the protein efficiency ratio (PER)
- the net protein utilisation (NPU)

With microbial cells it is important to note that digestibility is low especially with algae cells because of indigestible cell walls. Although the PER of SCP compares favourably with the PER of conventional protein sources, acceptability and palatability results on nutritional trials were not always encouraging ([17]). Furthermore we can make no assumptions with regard to human acceptability and tolerance based on results with animal feeding trials.

The Problem of Nucleic Acids

About 70-80% of the total cell nitrogen is represented by amino acids while the rest occurs in nucleic acids. This concentration of nucleic acids is higher than other conventional proteins and is characteristic of all fast growing organisms. The problem which occurs from the consumption of proteins with high concentration of nucleic acids (78-25 g/100 g protein dry weight) is the high level of uric acid in the blood, sometimes resulting in the disease gout ([18]). Uric acid is a product of purine metabolism. Most mammals, reptiles and molluscs possess the enzyme uricase, and the end product of purine metabolism is allantoin.

Man, birds and some reptiles lack the enzyme uricase and the end product of purine degradation is uric acid. The removal or reduction of nucleic acid content of various SCP's is achieved with one of the following treatments ([20]):

a. chemical treatment with NaOH;
b. treatment of cells with 10% NaCl;
c. thermal shock.

These methods aim to reduce the RNA content from about 7% to 1% which is considered within acceptable levels.

SCP from N. Alkanes

In the late 1950's, British Petroleum (BP) became interested in the growth of a micro-organism in C_{12}-C_{20} alkanes. This constitutes the wax fraction of gas oils for treating. Some crude oils contain up to 15% in wax, and these waxes must be removed since they make oil more viscous, precipitate out at low temperatures, block tubes etc.

BP uses two yeasts, *Candidor lipolytica* and *C. tropicals* and built a 16,000 tons/year plant in Cap Lavera, France, and a 4,000 tons/year plant in England. The product produced was called "TOPRINA". In the UK the product "TOPRINA G" was a purer product while the one in France was not separated from alkanes.

Both processes employed NH_3 as N-source and Mg ions to increase yields. No other carbon source was used. For 12 years TOPRINA was tested for toxicity and carcinogenecity and was marketed as a replacement for fish meal in high protein feeds and as a replacement for skimmed milk powder in milk replacers.

There were no signs at all for toxicity or carcinogenicity. In spite of this, people were concerned that aromatic hydrocarbons may be carried over to SCP. The main opposition came from Japan, where environmental groups and university professors condemned SCP as dangerous, and the matter became political. In 1972 a specialised committee decided that SCP was only for animal feeding but later, Japan was the first country to ban petrochemical protein. Meanwhile BP and an Italian company constructed a 100,000 tn/year plant in Sardinia. Following the Japanese attack on SCP, there has been great concern about and opposition to the use of SCP from environmental groups in government. The Italian government ordered further studies which showed that there was no hazard or carcinogenesis due to SCP. Pigs fed on 30% TOPRINA in their diets showed less n-paraffins in their fat tissue than those fed on pasture. Based on this evidence the Italian government agreed to the use of TOPRINA in limited amounts and only for export.

In 1977 Italy stopped the SCP production for alkanes altogether due to the increase in oil prices. The price of soya was more competitive. Now there is no factory which produces any petrochemical protein.

SCP from Methane

Methane is cheap, abundant and without the toxicity problems of alkanes. It is a constituent of North Sea Gas and is also produced during anaerobic digestion. Methane contains the most highly reduced form of carbon and consequently gives high cell yields relative to the amount of gas consumed. The general *Methylomonas* and *Methylococcus* have been recognised as utilising methane as a carbon source. The species which has been extensively studied is *Methylomonas methanica.* Nitrates or ammonium salts can serve as N-source.

Perhaps the most important work in this field was carried out by Shell in England. The process involves methane oxidation by stable mixed cultures. These were

1. a methane utilising G(-) rod;
2. a Hyphomicrobium;
3. two g(-) rods; *Acinetobacter* and *Flavobacterium*

This mixed culture was one of the best examples of symbiosis. The process began in 1970 in a 300 e pilot plant at Sittingbourne, UK. In 1974 Shell announced plans for a construction of a larger pilot-plant in the same area and a development program in Amsterdam with a goal of producing 100,000 tn/year. In spring 1976, Shell stopped commercialisation and its development plans were indefinitely postponed. This decision was based on 3 factors:

1. the low price of soybeans & maize;
2. the potential of many countries for expanding existing protein sources;
3. the difficulty in applying Shell's sophisticated process in underdeveloped countries.

SCP from Methanol

The technology of SCP from methanol has been well studied and the most advanced process belongs to ICI. The fermentation was carried out in a big airlift fermentor with the bacterium. *Methylophilus methylotropha*. This organism was selected among other methanol utilises after screening tests for pathogenicity and toxicity. As a nitrogen source ammonia was used. The product was named "PRUTEEN". Pruteen contained 72% crude protein and was marketed for feed as a source of energy, vitamins and minerals as well as a highly balanced protein source. The methionine and lysine content of Pruteen compared very favourably with white fish meal. ICI has commissioned a 60,000 tn/year plant utilising the single largest fermentor in the world (2 x 10,000,000 l).

Unfortunately Pruteen now cannot compete with soya and fish meal. ICI hopes to be able to sell their technology, because they have given up the idea of making money out of Pruteen. So today Pruteen although a major engineering success is not economical to run.

SCP from Ethanol

Ethanol although expensive as a substrate has been used for SCP. The process comes from the Amoco Company in the US utilising a food grade yeast: "Torula". The product is sold by the name "TORUTEIN" and government clearances have been obtained to market Torutein in Canada and Sweden. The yeast is about 52% protein and due to its relatively low Methionine level has a PER of about 1.7. The PER of wheat from 1.1 to 2.0. Torutein is being marketed as a flavour enhancer of high nutritional value, and a replacement for meat, milk and egg protein. However it is not very successful in the United States since soya which is plentiful and cheap can serve as an alternative or substitute to meat and egg diets.

Mycoprotein

This is a development of Ranks Hovis McDougall and is the only mycoprotein (except edible mushrooms) that has been cleared for human consumption. It uses a *Fusarium graminearum* growing in molasse, or glucose. The medium contains NH_3 for nitrogen source and pH control. The product is heat treated for RNA reduction. The mycelium is separated by vacuum filtration, and can be technologically treated to match food texture. In the UK it is marketed as pies and is considered a success since having less fat than meat, it can be sold at a premium price.

SCP from Lignocellulose

The lignocellulosic wastes, mainly from agriculture, constitute the most abundant substrate for SCP which is also renewable. The world annual production of straw for example reaches 600 million tons every year. In Greece the straw from wheat and rye, the two most important cereals, is an estimated 1.5 million tons per year ([7]).

For the utilisation of lignocellulose, a pre-treatment is usually necessary. Many pre-treatment methods have been reported which vary from alkali or acid treatment, steam explotion or even x-ray radiation ([8]).

To the present time the only economical utilisation of lignocellulosic wastes is in mushroom production ([19]). Besides our well know cultivated mushroom Agaricus bisporus there are many important ones which contain lignocellulolytic enzymes and are cultivated for food mainly in Asia and Africa. Some are of great economic significance and are cultivated on an industrial scale. Examples of important ones include the following species: Volvariella sp., Lentinus edodes and Pleurotus sp ([8,12,14])

SCP's Evaluation and Future Prospects

The development of SCP was really the beginning of biotechnology. Prior to this the industrial fermentation was mainly focused on antibiotics and other products which did not have to compete. This was not the case with SCP which had to compete with similar products in the market. The development was brought up by the oil companies rather than the food companies, because they could take the risk of a highly costly product out with no real expected profit. They also had all the high technology required.

The efforts tried so far by adding dry SCP as a supplement to diets in order to solve the problems of the hungry in the Third World Countries, certainly have not given the expected results. Every new food which appears in the market should have not only high nutritive quality, but also satisfactory organoleptic supplementary element.

Today in most countries where market forces operate. SCP cannot compete with soya, alfalfa or fish meal ([19]). Mushroom production from lignocellulosics seems to be one economical and promising use for SCP. For future success of SCP, first, food technology problems have to be solved in order to make it similar to familiar foods and second, the production should compare favourably with other protein sources.

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