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Microbes as Single-Cell Protein (SCP)

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Despite the constraints, including land, water, and environment, the growing global need for protein demands the utilization of sustainable alternative protein sources. Single-cell protein (SCP), which comes from microbial biomass including bacteria, yeasts, fungi, and algae, could eventually replace regular protein. This article focuses on the various kinds of bacteria that provide SCP, as well as the dietary advantages and practical usage in food as well as feed. The primary emphasis is on advances in gas fermentation, metabolic engineering, and SCP's role in the circular bio economy. It could help address problems related to food security and the effects of climate change, but it requires deliberate action to ensure safety, public perception, and nucleic acid content.

Introduction

The global demand for protein is increasing nowadays due to the rise in population, changing dietary habits, urbanization, and increasing health awareness. Traditional protein sources derived from animals face several limitations, including environmental degradation, excessive land and water use, greenhouse gas emissions, and susceptibility to climate change. According to the Food and Agriculture Organization (FAO), global meat production must increase by more than 70% by 2050 to meet the upcoming demand, yet such growth is neither sustainable nor feasible under the current agricultural system. At the same time, exploration of eco-friendly protein sources has gained considerable scientific attention in recent years. A potential remedy for the approaching global protein crisis is single-cell protein (SCP), which serves as the collective term for the dried biomass of microbial cells (including bacteria, yeasts, fungi, and algae). Rapid biomass accumulation, high protein content (up to 80% in some species), low land requirements, the capacity to grow on a wide range of low-cost substrates (including industrial and agricultural waste), and year-round production independent of climate variations are just a few of the many alluring benefits that SCP has to offer. Microbes can be grown in regulated, space-efficient, and sustainable settings utilizing fermentation or phototrophic systems, and they proliferate exponentially, unlike traditional crops or livestock.

The concept behind SCP is not new. It emerged in the early 20th century and acquired commercial traction in the 1960s when single-cell proteins derived from petroleum were investigated during the petroleum crisis and periods of food scarcity. Its broad acceptance was, limited by technological barriers and safety concerns. SCP research has been renewed by the latest advances that take place in metabolic engineering, system biology, and biotechnology. Enhanced downstream processing technologies, efficient bioreactor designs, and engineered microbial strains have paved the way to develop SCP which is not only scalable and economically viable but also nutritionally similar to animal protein. SCP facilitates the conversion of organic leftovers and waste gases (such as carbon dioxide, methane, and carbon monoxide) into sources for protein, useful biomass, and other substances that support the circular bio economy. Methane or hydrogen-fed microbial fermentation has been utilized in the setting up of a large-scale SCP production system by companies including Calysta (USA), UniBio (Denmark), and Solar Foods (Finland). Furthermore, researchers are currently looking at a wide variety of substrates, which incorporate lignocellulosic biomass, food processing wastes, and even plastic derivatives. SCP adoption still faces challenges despite its potential, including government approvals, public perception, nucleic acid concentration (especially with respect to bacterial biomass), digestibility and flavour issues, and scalability for particular applications. However, SCP is a revolutionary discovery globally, the protein sourcing sector considering the rising demand for sustainable proteins in the functional food, animal feed, and aquaculture sectors. Various microbiological sources showing SCP's production processes, nutritional and biochemical properties, practical uses, current developments, and the future course of SCP in global food and feed systems are all carefully reviewed in this article. Microbial diversity, strain improvement, gas fermentation technologies, safety standards, and integration into climate-resilient food and agriculture systems are given special focus.

What is Single Cell Protein?

Single cell protein is a form of dried or refined protein-rich biomass derived from pure microbial cultures. These microorganisms metabolize carbon and nitrogen sources available in substrates like agricultural residues, by-products derived from industry, or from waste materials. It transforms them to high-quality proteins. The protein content in biomass varies from 40% to 80% of dry weight, which is higher than traditional protein sources such as soy or meat. SCP offers a balanced amino acid profile and it is rich in vitamins (particularly B-complex), minerals, and crude fibres. Sometimes it may be deficient in certain amino acids like methionine, which can be supplemented if needed.

Average Compositions

GROUPS	PROTEIN	FAT	NUCLEIC ACID
FUNGI	30–40%	9–14%	7–10%
ALGAE	40–60%	8–10%	3–8%
YEAST	45–55%	5–10%	6–12%
BACTERIA	50–65%	3–7%	8–12%

Microorganisms in SCP Production

Bacteria, yeasts, fungi, and algae are the major microorganisms used for SCP production. Each group has their own characters valuable for SCP synthesis:

Bacteria: They possess very rapid growth rates and have short generation times. It enables quick biomass production. Bacteria has the capacity to metabolize a wide range of substrates, including carbohydrates (like starch and sugars), hydrocarbons (like petroleum fractions, methanol) and gaseous substrates like methane. Methanotrophic bacteria use methane as a carbon source which is particularly noted for sustainable SCP production. Bacterial SCP can have protein content as high as 80%. But harvesting can be a challenge due to their small cell size and low density.

Bacteria used for SCP production

Bacteria SCP	Organism Used	Substrate Used	Use
Pruteen	*Methylophilus methylotrophus*	Methanol, methane	Pig feed
UniProtein	Methanotrophic bacteria	Methane	Animal feed
FeedKind	Methanotrophic bacteria	Methane	Animal feed
KnipBio Meal	*Methylobacterium extorquens*	Methanol, methane	Fish feed
Novacq	Bacteria and Microalgae		Animal feed

Yeasts: Yeasts such as *Saccharomyces cerevisiae* and *Candida utilis* are popular SCP producers because of their rapid growth on a variety of substrates and favourable amino acid profiles. Yeasts generally yield 30-50% protein content in their biomass. They have the added benefit of producing vitamins alongwith proteins.

Fungi: Filamentous fungi like *Fusarium venenatum* and *Aspergillus* species are also widely used, for producing mycoproteins. Fungal SCP contains 30-50% protein and essential amino acid. They have higher nucleic acid content. Fungi flourish efficiently on lignocellulosic materials and agricultural residues, which are found abundant and low cost.

Selected fungi & their reported advantages for use as SCP

Fungi	Advantages
Candida intermedia FLO23	• High protein content (48.4% of dry weight) • Efficient utilisation of lignocellulosic materials and xylose
Geotrichum candidum	• High protein content (40%) • Good digestibility potential • Low-cost method of recovery
Pleurotus florida	• High protein content (63%)
Saccharomyces cerevisiae	• High protein content (24% - 50%)
Yarrowia lipolytica (Genetically engineered strains)	• High protein content (53.7%, 151.2g/L of SCP) • Synthesis of inulinase

Algae and Cyanobacteria: The photosynthetic microorganisms like Spirulina and Chlorella, are noted for the presence of very high protein content (60-70%). They are used as direct dietary supplements due to their rich nutrient profile, including vitamins and antioxidants.

Algae genera utilised as single-cell protein

Genera	Use
Chlorella sp.	Microalga species used in human diet food
Arthrospira sp (Spirulina)	Used as human food
Dunaliella sp., *Nostoc* sp.	Food and Supplement
Spirogyra, *Oedogonium*	Food additive
Porphyra sp., *Sargassum* sp., *Alaria* sp.	Food
Scenedesmus sp.	Biofuel and food

Substrates for SCP Production

SCP production utilizes both first-generation and second-generation substrates:

First-generation substrates: These are typically food-grade and consist of mainly sugars and carbohydrates, which are derived from crops like sugarcane molasses or starches. Microbes usually ferment in these easily accessible and refined substrates to produce biomass.

Second-generation substrates: These include non-food biomass like agricultural residues (e.g., straw, corn husks, and wheat bran), industrial by-products (e.g., whey, distillery waste), lignocellulosic materials, food processing waste, and even hydrocarbons or methane. Utilizing these substrates is ecologically and economically advantageous because it valorizes waste streams, promoting sustainability.

Production process of Single Cell Protein

Substrate Preparation

The first phase is the preparation of the substrate. It serves as a nutrient source for the microorganisms. When lignocellulosic materials or agricultural residues are used, physical and chemical treatments are necessary to make the nutrients accessible. It includes grinding, milling, acid or enzymatic hydrolysis, and washing processes. It converts down complex polymers into simpler sugars and nutrients that are suitable for microbial consumption. For wet substrates like fruit or vegetable waste wet preparation method is used. It involves the techniques like washing, pulverizing, filtering, and sterilizing, etc. Dry substrates undergo drying, grinding, sieving, and rehydration. It creates a sterile medium suitable for fermentation. The efficacy of substrate preparation directly influences microbial growth rate and final protein yield.

Sterilization

This is done to eliminate contaminants which may compete with or inhibit the desired microbial culture which is obtained by autoclaving at high temperature (121 °C) and pressure (around 15-60 minutes), depending on substrate composition and volume. Proper sterilization is inevitable for maintaining a contamination free environment throughout the process of fermentation.

Inoculation

After the sterilization of substrate medium, it is cooled to suitable temperatures; it is inoculated with selected microbial strains. The choice of microbe (like bacteria, yeast, fungi, or algae) depends on factors like the type of substrate, desired level of protein quality, and industrial objectives. Inoculum preparation may involve growing a pre-culture to reach an adequate cell density, ensuring rapid colonization of the substrate and minimizing lag phase during fermentation.

Fermentation

Fermentation is the pivotal process in which microorganisms convert substrates into biomass. It is rich in protein and other nutrients. Fermentation can be carried out as submerged fermentation (SmF) (involving liquid media with dissolved nutrients), or solid-state fermentation (SSF) (using solid substrates with minimum free water). Conditions like temperature, pH, oxygen concentration (aerobic or anaerobic), agitation, and nutrient balance are purposefully controlled to optimize microbial growth and protein synthesis. The duration of fermentation depending on the microbial species and process scale. Mixed cultures are employed for the synergistic effects or broader substrate utilization

Harvesting

After fermentation, microbial biomass is separated from the residual substrate and fermentation broth. Common harvesting techniques include centrifugation, filtration, and flotation, chosen based on cell size, density, and production scale. Efficient harvesting maximizes biomass recovery while minimizing mechanical damage to cells.

Processing and Purification

Harvested biomass undergoes several treatments for increasing the protein quality, safety, and palatability. Methods like cell disruption (to release intracellular proteins), washing (to remove substrate residues), drying (spray drying or freeze drying), and protein extraction or purification can be applied. It depends on whether the SCP is intended for animal feed or for direct human consumption. Additional steps to reduce nucleic acid content, can be high in microbial cells, which are often necessary, especially for food-grade products, to prevent adverse health effects.

Quality Control and Packaging

The final SCP product is subjected to rigorous quality control tests for protein content, amino acid profile, nucleic acid levels, microbial contaminants, toxins, and sensory attributes. After attaining specified standards, SCP is packaged under hygienic conditions for distribution and use in food or feed applications.

Advantages of SCP

The SCP production has many advantages over conventional protein sources. The high rate of microbial multiplication in SCP production allows rapid biomass generation. SCP production also utilises diverse and of low-cost substrates, including wastes. Thus, it promotes circular economy and reduces environmental pollution. The Production is independent of climatic conditions and requires less land and water than traditional agriculture. Moreover, the protein has a favourable nutrient profile that is suitable for supplementing human and animal diets.

SCP can also be used as animal feed in aquaculture, poultry, and livestock industries. It can also be used in potential therapeutic applications which includes controlling obesity, lowering blood sugar in diabetics, reducing cholesterol, and serving as components in cosmetics.

Challenges of SCP

SCP is not free from challenges. The high nucleic acid content in SCP biomass can lead to health issues like elevated uric acid levels and gout if consumed in large amounts. The Possible allergic reactions or presence of secondary toxic metabolites may affect human acceptance. Also, Processing, and refining SCP for direct human consumption require sophisticated technologies and cost. Moreover, Regulatory and safety approvals are still evolving for widespread human food use. It seems that SCP is unable to completely replace conventional proteins soon but can complement global nutrition needs.

Conclusion

Single Cell Protein (SCP) indicates a highly promising and sustainable alternative protein source that can address global nutritional deficiencies and environmental challenges. SCP production utilizes many microorganisms like bacteria, yeast, fungi, and algae, etc. It is capable of converting a wide variety of substrates, including agricultural residues, industrial wastes, and hydrocarbons into nutrient-rich biomass. Advantages include rapid growth, high protein content with balanced amino acids, minimum land and water use, etc. Thus the dependency on traditional agriculture is minimum. Advancements in biotechnology and metabolic engineering are improving with the SCP production efficiency and safety. The continued research and technological development in SCP offers potential to become a key component of global food and feed systems for a sustainable future.

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