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Review Article

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Production of single cell protein: A Review

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ABSTRACT

The escalating global population has necessitated an augmentation in food production. The augmented demand for protein has instigated the exploration for novel and economical protein supplements in lieu of conventional proteins. Single Cell Protein (SCP) is a viable solution for protein quality, and microorganisms such as algae, yeast, fungi, and bacteria can produce substantial quantities of SCP due to their rapid development rate and significant protein content in their chemical structure. SCP production requires a small land area and can be produced throughout the year in a shorter time frame. In addition to proteins, SCP comprises carbohydrates, nucleic acids, lipids, minerals, vitamins, and several crucial amino acids. SCP has proven to be an effective substitute for more expensive protein sources such as fish and soybean products. The key factors in SCP production are the preference for cost-effective substrates and non-toxic or non-pathogenic microorganisms. SCP can effortlessly replace traditional protein sources in human and animal feed. This review article concentrates on various aspects of SCP, including its production, utilization of different microorganisms, nutritional benefits, and challenges.

KEYWORDS: Single Cell Protein, Bacteria, Yeast, Fungi, Algae

INTRODUCTION

The increase in global population has necessitated the exploration of innovative and alternative sources of protein-rich foods (Spalvins *et al.*, 2018). According to current projections, the world will need to produce 1,250 million tonnes of meat and dairy annually to meet the growing demand for animal-derived proteins (Ritala *et al.*, 2017). However, conventional farming methods are unable to meet this demand at the current rate of production. Therefore, alternative approaches are required to achieve sustainable development goals for food security. One promising solution is the use of single cell proteins.

Single Cell Protein (SCP) has been utilized as an unconventional and alternative source of protein-rich food for both animals and humans (Najafpur, 2007). SCP refers to dead or dried microbial cells or total protein produced by pure or mixed cultures of bacteria, fungi, yeast, and algae, including unicellular algae and cyanobacteria (García-Garibay *et al.*, 2014; Suman *et al.*, 2015). SCPs are used as flavor enhancers, fat-binding agents, and protein-rich sources with a wide amino acid spectrum, low-fat content, and a higher protein-to-carbohydrate ratio than forages (Srividya *et al.*, 2013). SCPs contain vitamins, essential amino acids, minerals, nucleic acids, and lipids (Suman *et al.*, 2015; Zhou *et al.*, 2019). SCPs have the potential to replace conventional sources of protein, such as soybean meal or fish meal (Bekatorou *et al.*, 2006; Jamal *et al.*, 2009; Nasseri *et al.*, 2011). Studies have shown that many agricultural and agro-industrial waste products can be used for SCP production. These include orange, papaya, onion, and sugarcane wastes (Hongpattarakere & Kittikun, 1995; Nasseri *et al.*, 2011), rape straw (Ke *et al.*, 2011), wheat straw (Abou-Hamed, 1993), banana waste (Saquido *et al.*, 1981; Khan *et al.*, 2011), and some of these wastes, although biodegradable, may cause environmental pollution. Therefore, utilization of these agro-wastes for SCP production helps in controlling environmental pollution associated with their disposal.

SCPs provide a number of benefits, including quick production that requires a fraction of the time of crop farming and animal husbandry (weeks, months, or even years). SCPs are also less expensive because they may be produced in bioreactors. As a result, they do not require enormous land use or the high water demand associated with traditional agriculture (Sharif *et al.*, 2021). Additionally, industrial production of SCP in bioreactors offers product uniformity and high yields because SCP does not compete with weeds and pests. It's significant to note that SCPs are resistant to diseases brought on by traditional agricultural practices, which are extremely valuable in crop farming and animal production with product loss. Furthermore, the production of SCP has no negative effects on the environment, biodiversity, or greenhouse emissions or climate change (Tilman, 1999). Agricultural waste is continually generated in the food sector and is generally expensive to dispose

(Bogdahn, 2015). Single-cell proteins can be produced from this waste. This conversion of waste to food not only reduces waste and pollution but also ensures that increased demand for food from the ever-growing world population will be met using SCP, which consists of a mixture of proteins, lipids, carbohydrates, nucleic acids, inorganic compounds, and a variety of other non-protein nitrogenous compounds, such as vitamins and minimal carbon fingerprints (Bogdahn, 2015). Additionally, in order to protect the environment, and the general public, and save money, it is crucial to develop creative methods of disposing of waste agricultural goods due to the global growth in agricultural waste. Although the current manufacturing and consumption of SCP only makes up a small portion of human protein intake, the rising need for protein is probably going to make SCPs more significant (Boland *et al*., 2013; Bratosin *et al*., 2021).

Single-cell protein (SCP) can be produced by a greater variety of microbial species in the context of animal feed and can be generated from a variety of substrates, including waste products. SCP meant for human consumption, on the other hand, must be acquired from sources that adhere to regulations for food safety. The distinction is made because SCP meant for consumption by humans must adhere to more stringent regulatory norms, necessitating the use of more expensive substrates as well as more extensive product controls and monitoring. As a result, it might be more advantageous and economical to create SCP from a variety of substrates, including low-cost waste products from forestry and agriculture, as well as the processing of food and beverages (Anbuselvi *et al*., 2014). These have been used as animal feeds in addition to other non-food grade sources, which has decreased the requirement for foliage and feed formulations made from consumable items for animals. The phrase "single-cell proteins" (SCP) refers to the edible biomass of unicellular microorganisms, which can include the complete biomass or protein extract from single or mixed cultures of a variety of microbial species, including yeasts/fungi, bacteria, algae, and others (Nangul & Bhatia, 2013). There is a growing interest in the utilization of SCP to address the global demand for nutritious food, given its various advantages over conventional plant and animal proteins (Amata, 2013). Furthermore, SCP is being produced under different commercial names, such as Quorn®, AlgaVia®, Marmite®, Vitam-R®, Pruteen®, Brovile®, and FermentIQ™, among others (Ugalde, 2002; Wikandari *et al*., 2021). This study aims to review the existing body of research on SCP derived from microorganisms such as bacteria, fungi, yeast, and algae. Additionally, it encourages partnerships with more seasoned research teams and groups in various working areas in order to assist researchers in this subject.

PRODUCTION OF SINGLE CELL PROTEIN

Microorganisms in the production of SCP

Bacteria

Bacteria have a quick generation time, a high protein content, and the ability to grow on a variety of substrates. They have long been utilized in animal feed as a single-cell protein (SCP) (Erdman *et al*., 1977; Anupama & Ravindra, 2000) reported that, on a dry weight basis, bacterial SCP typically includes 50-80% protein, with the essential amino acid content anticipated to be on line with or more than the FAO standards (Erdman *et al*., 1977). Schulz and Oslage (1976) revealed that methionine concentration up to 3.0%, more than that generally found in algal or fungal SCPs, has been documented. Similarly, Øverland *et al*. (2010) reported a similar amino acid composition with methanol or methane-grown bacteria. Bacterial SCP, like fungi, has a high nucleic acid content (8-12%), particularly RNA, and thus necessitates processing before usage as food/feed (Nasseri *et al*., 2011; Strong *et al*., 2015).

Methane is an intriguing substrate as it is a significant by-product of cattle and pig farming (Philippe & Nicks, 2015), as well as being available for biogas production (landfills and waste). Johnson (2013) has reported that using the bacterium *Methylophilus methylotrophus*, Imperial Chemical Industries created a SCP (Pruteen) for animal feed from methanol. Pruteen was used in pig feed and contains up to 70% protein. The manufacture of Pruteen was halted because it could not compete with the more affordable animal feeds that were available at the end of the 1970s.

The ability to grow on a variety of raw materials, including carbohydrates (starch and sugars), gaseous and liquid hydrocarbons (including methane and petroleum fractions), and petrochemicals such as methanol and ethanol, are characteristics that bacteria have that make them suitable for producing microbial proteins (Ukaegbu-Obi, 2016). Additionally, Anupama and Ravindra (2000) and Bhalla *et al*. (2007) reported that *Cellulomonas and Alcaligenes* are the most frequently used bacterial species as SCP sources. Therefore, large quantities of single-cell protein animal feed can be produced using bacteria such as *Brevibacterium* (Adedayo *et al*., 2011), *Methylophilus methylitropous*, *Acromobacter delvaevate*, *Acinetobacter calcoacenticus*, *Aeromonas hydrophilla*, *Bacillus megaterium*, *Bacillus subtilis* (Gomashe *et al*., 2014), *Lactobacillus species*, *Cellulomonas species*, *Methylomonas methylotrophus* (Piper, 2004), *Pseudomonas fluorescens*, *Rhodopseudomonas capsulate*, *Flavobacterium species*, *Thermomonospora fusca* (Dhanasekaran *et al*., 2011). The obtained bacterial cells had a high total protein content (66%, 68%, and 71% for *Escherichia coli*, *Bacillus cereus*, and *Bacillus subtilis*, respectively). The protein derived from the ruminant diet included every amino acid (alanine aspartic acid, cystine glutamic acid, glycine, serine, tyrosine, arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, threonine, tryptophan, and valine (Kurbanoglu & Algur, 2002). Øverland *et al*. (2010) demonstrated that a bacterial culture (*Methylococcus capsulatus*, *Ralstonia sp*., *Brevibacillus agri*, and *Aneurinibacillus sp*.) grown on natural gas as a carbon source and containing mainly the *methanotroph Methylococcus capsulatus* is a promising source of protein (67-73%). *Rhodobacter sphaeroides SS15 and A. marina STW181* (purple non-sulfur bacteria) mixed with commercial shrimp feed as carbon sources were explored by Chumpol *et al*. (2018).

Yeast

The majority of single-cell proteins are produced by yeast, a type of microorganism. *Candida* is one of the yeast species from which yeast single-cell protein (SCP) is generated (Bozakouk, 2002), *Hansenula*, *Pitchia*, *Torulopsis*, and *Saccharomyces*, and is considered a highly nutritious feed substitute, as reported by Burgents *et al.* (2004). Tanveer (2010) reported that similar research has been done on the production of single-cell proteins by *Saccharomyces cerevisiae* grown on various fruit scraps. According to Sengupta *et al.* (2006), the typical oily yeast genera include *Yarrowia*, *Candida*, *Rhodotorula*, *Rhodosporidium*, *Cryptococcus*, *Trichosporon*, and *Lipomyces*. Using submerged fermentation with *Saccharomyces cerevisiae*, the possibility of generating single-cell proteins from cucumber and orange peels was examined.

Only a small fraction of the varied collection of eukaryotic fungi known as yeasts are being used in biotechnological applications. *Candida utilis*, *Kluyveromyces marxianus*, *Yarrowia lipolytica*, *Pichia pastoris*, and the dominating *Saccharomyces cerevisiae* are among these species (Nasseri *et al.*, 2011; Karim *et al.*, 2020; Carranza-Méndez *et al.*, 2022). Yeasts are frequently employed microorganisms due to their ability to grow on a variety of substrates, high protein content (45-55% dry weight), and B-complex vitamins are present, among other beneficial qualities. The main advantages of their familiarity and acceptability are that they have been employed for conventional fermentation for a long time. Additionally, their ability to thrive in acidic environments and their size facilitate harvesting (Nasseri *et al.*, 2011).

Yeasts often contain more lysine than bacteria, but methionine is the opposite for yeasts (Nigam, 1998). Numerous researchers have used the genus *Candida* to produce SCP from a variety of industrial and agricultural wastes and residues, including yellow wine lees (Yao *et al.*, 2018), tuber wastes (Ouedraogo *et al.*, 2017), pineapple cannery effluent (Nigam, 1998), salad oil manufacturing wastewater (Zheng *et al.*, 2005), orange peel residues (Carranza-Méndez *et al.*, 2022), and sugarcane bagasse hemicellulosic hydrolysate (Magalhães *et al.*, 2018). It is important to note that several *Candida* species are opportunistic human pathogens, with *C. albicans*, *C. glabrata*, *C. parapsilosis*, *C. tropicalis*, and *C. krusei* being the most common causative agents of *candidiasis* (Szabó *et al.*, 2021).

Yeasts have been used for human nutrition throughout history, particularly in the brewing of beer, the fermentation of wine, and the baking of bread. The majority of yeasts have been designated as generally regarded as safe (GRAS) and may be included in human diets without any problems. In contrast to other microbial families, yeasts are rarely toxic or pathogenic, making them a more easily absorbed food and feed supplement. Although their protein composition typically does not exceed 60%, they contain a decent concentration of important amino acids such as lysine (6.9%), tryptophan (1.5%), and threonine (46%). However, they are significantly deficient in the sulfur-containing amino acids methionine and cysteine (Boze *et al.*, 1992; Bekatorou *et al.*, 2006). Yeasts are rich in the B group of vitamins and contain 4–10% nucleic acid. In the successful synthesis of single-cell proteins (SCPs), yeast species such as *Kluyveromyces spp.*, *Candida spp.*, and *Saccharomyces cerevisiae* have been employed (Pandey *et al.*, 2000; Schultz *et al.*, 2006).

Fungi

Many fungi species have been investigated for potential single-cell protein (SCP) applications (Anupama & Ravindra, 2000; Rudravaram *et al.*, 2009; Nasseri *et al.*, 2011). According to Ravinder *et al.* (2003), for the manufacture of SCPs, many different fungi species are used. Due to their high protein content, some fungi, including *Pleurotus floria*, *Aspergillus niger*, and *Fusarium venenatum*, make excellent sources. Commercially available fusarium products are available, and the protein content of fungal SCP normally varies from 30-45%. as reported by (Anupama & Ravindra, 2000; Nasseri *et al.*, 2011; Ritala *et al.,2017*). The amino acid content of fungal SCP is favorable compared to FAO recommendations, with high concentrations of threonine and lysine frequently found, although methionine is typically present in low concentrations while still satisfying FAO/WHO standards (Ritala *et al.*, 2017). Due to the high concentration of glucans in fungal cell walls, SCP generated from fungi also provides vitamins, notably the B-complex group, and dietary fiber. However, processing is required to reduce the nucleic acid content of fungi, which is still too high for human consumption (7–10%) (Thrane, 2007; Nasseri *et al.*, 2011; Ritala *et al.*, 2017).

Fungi bred primarily for SCP synthesis have been shown to have up to 63 % protein, and their amino acid profiles also meet FAO criteria, according to Nasseri *et al.* (2011). Lysine and threonine are plentiful in fungi proteins, whereas cysteine and methionine, which contain sulfur, are deficient. B-complex vitamins such riboflavin, niacin, thiamine, biotin, pantothenic acid, choline, pyridoxine, glutathione, amino benzoic acid, streptogramin, and folic acid are also present in SCP generated from fungi (Turnbull *et al.*, 1992). Compared to algae, which only contain up to 6% nucleic acids, fungi contain up to 10% of them (Nasseri *et al.*, 2011; Nangul & Bhatia, 2013). A moderate nucleic acid concentration of 7–10% is predicted in fungi (Nasseri *et al.*, 2011).

Current and ongoing SCP research and development employing various fungal species may lead to new products or production techniques. For instance, Zhao *et al.* (2013) developed a procedure where *Y. lipolytica* would manufacture and secrete antimicrobial peptides, creating a high-value product, while the leftover yeast could be utilized as SCP due to its high protein content. Current research is heavily focused on the use of waste substrates such as sugarcane bagasse, brewery spent grains, hemicellulosic hydrolysate, and mixes of other typical food sector wastes like orange and potato residues, molasses, and malt spent rootlets (White *et al.*, 2008; Rao *et al.*, 2010). *Fusarium venenatum*, the fungus SCP species used to produce the meat replacement QuornTM, is one of the most well-known fungi. Pekilo, a method known as using the filamentous microfungus *Paecilomyces variotii*, was developed in Finland in the 1970s and 1980s to produce feed protein from the sugars present in the sulphite waste liquor of paper mill effluents (Koivurinta *et al.*, 1979; Voutilainen *et al.*, 2011).

While being marketed as animal feed, Ritala *et al.* (2017) highlighted fungal SCP as a supplement for meat-based foods like sausages and meatballs. Additional species of fungus employed for SCP synthesis on diverse substrates include *Aspergillus flavus*, *Aspergillus niger*, *Aspergillus ochraceus*, *Aspergillus oryzae*, *Cladosporium cladosporioides*, *Monascus ruber*, *Penicillium citrinum*, and *Trichoderma viride* (Bhalla & Joshi, 1994; Valentino *et al.*, 2016; Ritala *et al.*, 2017). However, the potential for *mycotoxin* generation with several fungal species, including *Fusarium*, *Alternaria*, and *Aspergillus species*, during cultivation needs to be taken into account (Perincherry *et al.*, 2019). According to Anupama and Ravindra (2000), the choice of *Aspergillus oryzae* or *Rhizopus arrhizus* inoculums was made on the basis of their safety. The nutritional composition of these fungi, including high levels of fats, vitamins, amino acids, and protein, renders them an attractive source of single-cell protein (SCP), as noted by (Anupama & Ravindra, 2000; Nigam, 2000; Gervasi *et al.*, 2018). Furthermore, their ability to thrive in low pH environments facilitates their cost-effective and efficient production, as highlighted by Nasseri *et al.* (2011).

Algae

Algae are autotrophic creatures with a wide variety of genetic makeup. They need water, carbon dioxide, sunshine, and inorganic nutrients, primarily nitrogen and phosphorus, to maintain growth (Radmer & Parker, 1994). Algae are autotrophic creatures with a wide variety of genetic makeup. They need water, carbon dioxide, sunshine, and inorganic nutrients, primarily nitrogen and phosphorus, to maintain growth. According to Wood *et al.* (1991) and Nasseri *et al.* (2011), microalgae have the ability to convert solar energy into cellular biomass, with a significant proportion of single-cell protein (SCP) up to 70%. Gouveia *et al.* (2008) also noted that microalgae grown for human or animal use often have high protein content, ranging from 60% to 70%. Additionally, they provide fats, vitamins A, B, C, and E, mineral salts, and chlorophyll, with ω-3 fatty acids and carotenoids being of particular interest (Chronakis, 2000).

Micro-algae mass cultivation produces high yields, 20- to 50-fold higher than soybean yields (Chronakis, 2000). Microalgae are single-celled microorganisms that develop autotrophically while obtaining their carbon and energy from light and carbon dioxide, respectively. Molasses, manure, or other inexpensive organic resources, including industrial waste, are used as a carbon source in heterotrophic development (García-Garibay *et al.*, 2014). They have relatively low nucleic acid content, ranging from 3% to 8% (Nasseri *et al.*, 2011). Algae are consumed in a variety of ways, and their benefits include easy cultivation, efficient solar energy usage, quick development, and high protein content (Raja *et al.*, 2008).

The most popular algae, *spirulina*, has also been investigated as a potential supplemental protein source. Similar to this, indigenous tribes in several regions of the world harvest and use biomass derived from *Chlorella and Scenedesmus* as a source of sustenance (Arora *et al.*, 1991). However, certain factors, such as the requirement for warm temperatures and lots of sunlight in addition to carbon dioxide, may limit the production of algae. The limited digestibility of algal cells due to their indigestible cell walls is another drawback of employing algae as a single cell protein (Ware, 1977).

Algae is a well-known source of SCP, as reported by several authors, including, Anupama and Ravindra (2000), Chae *et al.* (2006), García-Garibay *et al.* (2014) Ritala *et al.* (2017) and Voutilainen *et al.* (2021). This is due to the fact that algal biomass includes significant levels of proteins with an amino acid profile that is comparable to proteins from traditional sources such soy, eggs, milk, fish, beef, and peanuts (Patias *et al.*, 2018). There has been a surge in the utilization of algae for SCP production and a consequent increase in the different genera being utilized (Anupama & Ravindra, 2000; Gouveia *et al.*, 2010).

It has been demonstrated that microalgae have a high protein content, a distinctive amino acid composition, and are nutritionally acceptable (Patias *et al.*, 2018). There are different considerations to be made when processing algae for single-cell protein, including the end product, the cost of the raw materials, and the characteristics of the starter culture (Gouveia *et al.*, 2008; Bajpai, 2017). The cost of producing SCP utilizing algal cells is decreased by mass producing algae in open ponds using inexpensive substrates, such as waste effluents (Mahapatra *et al.*, 2016). Open ponds can be used to cultivate algae utilizing sewage or agricultural effluent (Hülsen *et al.*, 2018), or in a photobioreactor where environmental variables such as light intensity, temperature, and pH are controlled (Rasouli *et al.*, 2018).

The processing methods generally include the culturing of the algae either in a natural open pond or in an artificial photobioreactor (Ugbogu & Ugbogu, 2018). 5 to 8 days later, the algal biomass is harvested and clarified to produce the finished product. Despite the fact that there have been documented accounts of the direct eating of algae, such as *Spirulina sp.*, in several regions of Africa, Mexico, and India in the early 20th century (Haque *et al.*, 2012), most of these genera are used as feeds and supplements more than they are used as food.

NUTRITIONAL BENEFITS OF SCP

The production of Single Cell Protein (SCP) plays a significant role in waste management, as waste materials are utilized as substrates. A tiny amount of land and a short amount of time can be used to generate SCP. It has a higher concentration of lysine and a lower concentration of cysteine and methionine. The dietary and nutritional properties of SCP vary according to the microorganisms utilized, and the harvesting, drying, and processing techniques have an effect on the nutritional value of the finished product. According to Bhalla *et al.* (2007), Jamal *et al.* (2008) and Bogdahn (2015), in addition to its high protein content, which is relatively less expensive than other plant and animal sources, SCP's nutritional value is entirely dependent on its chemical composition, which includes amino acids, nucleic acids, minerals, enzymes, and vitamins. The year-round generation of single-cell proteins is another advantage. It has been reported that dried cells of *Pseudomonas spp.* grown on petroleum-based liquid paraffin contains protein as high as 69%, while single cell protein obtained by algae processing is about 40%.

According to Olvera-Novoa *et al.* (2002), the composition of single cell proteins (SCPs) is contingent upon the organism and substrate on which it is cultivated. Due to their exceptional nutrient profiles and cost-effective mass production, SCPs have been incorporated into aquaculture diets as a partial substitute for fishmeal. According to Wu *et al.* (2014), the average human protein diet consists of 65% plant-based protein and 35% animal-based protein, with a predicted increase in meat consumption of 29% between 2013 and 2050. As a result, it is anticipated that by 2050, there will be 494 million tons more beef produced globally than there were in 2013. Previous research has suggested that SCPs could be a valuable solution for meeting the global demand for protein due to their low production costs, ease of processing, and nutritional quality (Nasseri *et al.*, 2011; Boland *et al.*, 2013; Suman *et al.*, 2015; Yunus *et al.*, 2015).

SCPs must satisfy particular nutritional standards, such as those for protein content, amino acid composition, and protein digestibility, in order to be appropriate for human consumption or animal feed (Linder, 2019). According to researchers, SCPs must be produced to the highest standards to ensure their safety and efficacy as food and feed. Finnigan *et al.* (2017) identified the macro and micronutrients provided by SCPs, including proteins, lipids, carbohydrates, β-carotene, vitamin A precursor, biotin, folic acid, niacin, pantothenic acid, pyridoxine, riboflavin, thiamine, vitamin B12 (cyanocobalamin), vitamin C, and vitamin E. Bogdahn (2015) reported that the nutritional value of SCPs, in addition to their protein content, is dependent on their chemical composition, including amino acids, nucleic acids, minerals, enzymes, and vitamins. Despite the fact that proteins made by bacteria contain all of the required amino acids, the type of substrate (carbon or nitrogen) and the type of microorganisms that are grown on a particular medium have an impact on how those proteins are made (Ferreira *et al.*, 2010). Similarly, Sharif *et al.* (2021) reported that single cell protein (SCP) produced from various microbes has a high protein content ranging from 30% to 80%, which is significantly higher than that found in different green plants and animal sources.

Microorganisms are known to contain significant quantities of vitamin B12. Furthermore, Spalvins *et al.* (2018) reported that the nutritive value of SCP varies depending on the microorganisms used and the substrate on which they grow. The method of harvesting, drying, and processing conditions also affect the nutritive value of the final product. Kurbanoglu (2001), Attia *et al.* (2003) and Garimella *et al.* (2017), and reported that SCP made from bacteria is rich in protein but deficient in amino acids containing sulfur while being high in nucleic acids. Bacteria and algae are reported to have high vitamin B12 and vitamin A content, respectively (Anupama & Ravindra, 2000). The most common vitamins present in SCP are riboflavin, thiamine, pyridoxine, niacin, choline, folic acid, pantothenic acid, biotin, para-aminobenzoic acid, inositol, and B12 (Anupama & Ravindra, 2000).

Mchoi and Park (2003) reported that Protein content in SCP derived from yeast and fungi ranges from 50 to 55 %, and the protein-to-carbohydrate ratio is high. Additionally, these proteins have a superior amino acid profile, which increases their nutritional value compared to other protein sources. Similarly, García-Garibay *et al.* (2014) reported that SCP is a good source of vitamins A, B group, D, C, and E; the content of some vitamins such as thiamine, riboflavin, folic acid, and carotene is higher in algae than in many vegetable foodstuffs. Gao *et al.* (2008) reported that SCP has a good balance of amino acids and is more suitable as poultry feed due to its high B-complex vitamin content.

Single cell proteins (SCP) from yeast are becoming more and more significant in the development of aquaculture diets. Several yeast varieties, including *Saccharomyces cerevisiae*, have probiotic qualities (Oliva-Teles & Goncalves, 2001) and *Debaryomyces hansenii* (Tovar *et al.*, 2002), boost larval survival either by colonizing the gut of fish larvae, thus triggering the early maturation of the pancreas, or via the immune-stimulating glucans derived from the yeast cell wall (Campa-Córdova *et al.*, 2002; Burgents *et al.*, 2004). Researchers in academia and industry are becoming more interested in the notion that SCP could aid less developed nations during upcoming food crises. In order for SCP to succeed in the future, food technology issues must be resolved to make it resemble known foods and production should favorably compare with those of other protein sources. SCP generated by microorganisms contains vitamins and metabolites with a variety of health benefits in addition to its usefulness as food and feed. Examples include single-cell protein fractions that can be utilized in food to improve palatability and exhibit foaming and gelation capabilities (Cantat *et al.*, 2013).

LIMITATIONS OF SCP

As a source of nutrients for human consumption, single-cell protein demonstrates many highly desirable qualities. Nevertheless, despite its many advantages, there are difficulties and restrictions related to both its manufacture and usage. Mahapatra *et al.* (2016) reported that the qualities and quantities of nutrients derived from organisms used for SCP production vary depending on the organism and extrinsic factors such as the nature and quality of the substrate and the presence of contaminants. While bacteria produce the highest quantity of protein by dry mass, their high nucleic acid content and presence of toxins make fungi and algae preferable sources of SCP (Becker, 2004), The high concentration of nucleic acids, which ranges from 6-10%, elevates serum uric acid levels and can lead to kidney stone formation. According to Bankar *et al.* (2009), all rapidly growing organisms have a concentration of nucleic acids that is higher than that of conventional proteins. Of the total nitrogen present, around 70-80 % is found in amino acids, while the remaining portion is found in nucleic acids.

Furthermore, Adedayo *et al.* (2011) also noted that the lack of public acceptance of SCP as a nutrient supplement has resulted in a decline in the importance of SCP production. The presence of indigestible cell walls is another issue (Esabi, 2001). Consuming algae and yeast presents additional difficulties because of the potential for offensive smells and colors, the requirement to destroy cells before consumption, the possibility of skin reactions from foreign proteins, and gastrointestinal reactions that can cause nausea and vomiting.

According to Nasseri *et al.* (2011), excessive levels of nucleic acids in protein—between 18 and 25 g/100 g protein dry weight—may cause the blood to produce large amounts of uric acid, which can result in diseases like gout and kidney stones. Due to their high chlorophyll content (except *Spirulina*), low density, and significant danger of contamination during growing, SCP from algae may not be acceptable for human consumption. SCP from yeast and fungi also contain a lot of nucleic acids, and filamentous fungi grow more slowly than yeasts and bacteria do. These organisms are also very prone to contamination, and some strains of them can even produce mycotoxins. High ribonucleic acid content, a high danger of contamination during manufacturing, and challenging cell recovery are further characteristics of SCP from bacteria (Adedayo *et al.*, 2011).

SCP generally presents appealing qualities as a nutritional source for humans, but there are many difficulties and restrictions related to its production and ingestion. The suitability of a specific species as food or feed is determined by its pace of growth, the substrate used, contamination, and toxin content (Anupama & Ravindra, 2000). SCP designed for animal feed with a high nucleic acid content is only advised for animals with brief lifespans (Strong *et al.*, 2015).

CONCLUSION

Single Cell Protein (SCP), also known as microbial protein, is reported in this review as having significant potential as a source of protein for both human and animal feeding. In comparison to traditional protein sources, the use of microorganisms in the cultivation of SCP has a number of benefits, such as a rapid rate of doubling, ease of cultivation, the capacity to use a variety of inexpensive and easily accessible substrates as energy sources, a low land requirement for propagation, and climatic adaptability.

However, despite its potential, SCP faces several challenges that currently prevent it from competing with conventional proteins. These challenges include a high nucleic acid content when produced with bacteria, the possibility of causing diseases, poor digestibility, and high production costs due to substrate cost, utilities, capital loads, and product-specific variables. These issues can be mitigated through the application of various physical and chemical treatments during processing, as well as the use of efficient toxicological tests to enhance and improve its acceptability. This will ultimately make SCP more affordable to consumers when compared to conventional proteins. Furthermore, SCP's requirements for growth are not dependent on seasonal or climatic conditions, allowing for year-round production.

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