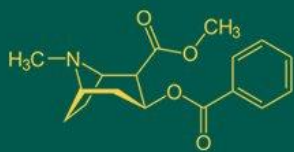


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P Jagadeesan

PG Diploma Student,
Veterinary College and
Research Institute,
Orathanadu, Tamil Nadu,
India

R Kavitha

Associate Professor, Livestock
Farm Complex, Veterinary
College and Research Institute,
Orathanadu, Tamil Nadu,
India

P Vasan

Professor and Head, AFAQAL,
Veterinary College and
Research Institute, Tamil
Nadu Veterinary and Animal
Sciences University, Chennai,
Tamil Nadu, India

M Siva

Assistant Professor,
Department of Animal
Nutrition, Tamil Nadu
Veterinary and Animal
Sciences University, Chennai,
Tamil Nadu, India

S Gobika

M.V.Sc. Scholar, Department
of Animal Nutrition, Tamil
Nadu Veterinary and Animal
Sciences University, Chennai,
Tamil Nadu, India

Corresponding Author:**R Kavitha**

Associate Professor, Livestock
Farm Complex, Veterinary
College and Research Institute,
Orathanadu, Tamil Nadu,
India

Fortified single cell protein as an alternative protein source in dairy cattle: A comprehensive review

P Jagadeesan, R Kavitha, P Vasan, M Siva and S Gobika

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Abstract

India, the world's largest milk producer, contributes nearly 25% of global milk output, with production of 210.96 million tonnes in 2024-25. The dairy sector is central to India's rural economy, supporting over eight crore farmers and contributing significantly to national GDP. Rising feed costs and protein shortages necessitate alternative, sustainable protein sources for dairy production. Single Cell Protein (SCP), derived from microorganisms such as bacteria, yeast, fungi and algae grown on agro-industrial wastes, has emerged as a viable option. SCP is rich in crude protein (45-80% DM), essential amino acids, vitamins and minerals. Produced mainly through fermentation, SCP can partially replace conventional protein sources like soybean meal and groundnut cake. Dietary inclusion of 5-25% SCP has been shown to improve nutrient digestibility, rumen efficiency, milk yield and milk composition. Fortified SCP further enhances antioxidant status, udder health and reproductive performance. However, challenges such as high production costs, compositional variability, nucleic acid content, palatability and regulatory issues limit its large-scale adoption. With suitable technological and economic interventions, SCP holds strong potential as a sustainable protein supplement for India's dairy sector.

Keywords: Dairy production, single cell protein, alternative protein source, ruminant nutrition, milk yield, sustainability

Introduction

The dairy industry has played a significant role in strengthening India's rural economy. It is the single largest agricultural commodity, contributing approximately 5% to the national economy and providing direct employment to over 8 crore farmers. According to the Food and Agriculture Organization (FAO STAT 2024-25), milk production in India reached 210.96 million tons (MMT) in 2024-25, up from 209.96 MMT in 2020-21. India contributes nearly 25% of the global milk production. Single Cell Proteins (SCPs) are derived from microbial cells and are utilized either as dried whole cells or in the form of purified protein extracts. SCPs are considered promising nutrient supplements for both humans and livestock due to their high protein content, balanced amino acid profile, minimum fat levels and superior protein-to-carbohydrate ratio compared to conventional forages. SCPs contain vitamins such as thiamine, riboflavin, pyridoxine, nicotinic acid, pantothenic acid, folic acid, biotin, cyanocobalamins, ascorbic acid, β -carotene and α tocopherol. Further, essential amino acids, represented by lysine and methionine and minerals, nucleic acids and lipids (Suman *et al.*, 2015) ^[12]. SCPs have been used for wide range of purposes from food (aroma carriers, vitamin carriers, emulsifying acids etc.) and feed (pigs, poultry, cattle and fish) production to the paper and lead industry (Nagare *et al.*, 2015) ^[7]. Hence, this review focused on the fortified SCPs as an alternative protein source in dairy production.

Sources of Single cell protein

Common sources for SCPs are represented by waste and raw materials (starch, fruit, fruit waste, molasses etc.) combustible and combustible waste or byproducts (natural gas, petroleum byproducts, ethanol, methanol and biomass etc.) (Suman *et al.* 2015) ^[12]. The cellulose, hemicellulose and lignin of natural waste wood originating from agriculture and forestry sources are attractive natural sources of SCP. However, they must be pretreated chemically (acid hydrolysis) or enzymatically (cellulases) to transform cellulose into fermentable sugars.

Domestic sewage and waste retained from industrial cellulose processing, starch production and food processing can also be utilized. Agricultural waste has been reported to be an excellent substrate for cost-effective SCP production, the resulting protein-enriched product being of good quality and suitable for animal feed. It can even be consumed by humans after further processing

(Yunus *et al.*, 2015) ^[13]. The choice of substrate is made according to cost, availability, oxygen required during fermentation, quantity of heat produced and cooling capacity of the fermenter, but also the cost related to post-treatment processing (Suman *et al.*, 2015 and Raziq *et al.*, 2020) ^[12, 9]. Selected substrates are used as a growth medium by microorganisms such as bacteria, algae, fungi and yeast for increasing their cell mass, which is made up of SCP (Zepka *et al.*, 2008) ^[14].

Production of Single cell protein

Fermentation is the main process responsible for SCP production (Kadim *et al.*, 2015) ^[3] as shown in the above Figure 1. The available biomass is harvested when the fermentation process is completed and can be used as a protein source (Zepka *et al.*, 2008) ^[14]. The biomass is

processed further by purification, cell disruption, washing and protein extraction to provide high production yields with high yields. Among different sources, bacterial SCP contains 50-80% protein by dry weight and is characterized by rich nucleic acid content, low density, small cell size and the capacity to easily multiply (within the interval of 20-120 min) on a wide range of substrates, such as sugar, starches, raw materials, waste (*i.e.*, organic waste and petrochemicals such as methanol and ethanol), and even water resources with a high nutrient and mineral content (Suman *et al.*, 2015 and Overland *et al.*, 2010) ^[12, 8]. Plant-based products are mainly used as a substrate for SCP production. The most suitable waste for SCP production is agricultural waste, because when industrial waste is categorized, it includes some of the agricultural waste that is generated by the food to be processed in industries. Some bacteria (*Methylococcus capsulatus*, *Methylomonas methanica*, *Methylo vibrio soehngenii*) can utilize methane for SCP production. Further the bacterial species like *Methylophilus methylotrophus*, *Rhodopseudomonas palustris*, *Escherichia coli* and *Haloarcula sp.* are very efficient in SCP production, so they have been most often exploited as protein producers.

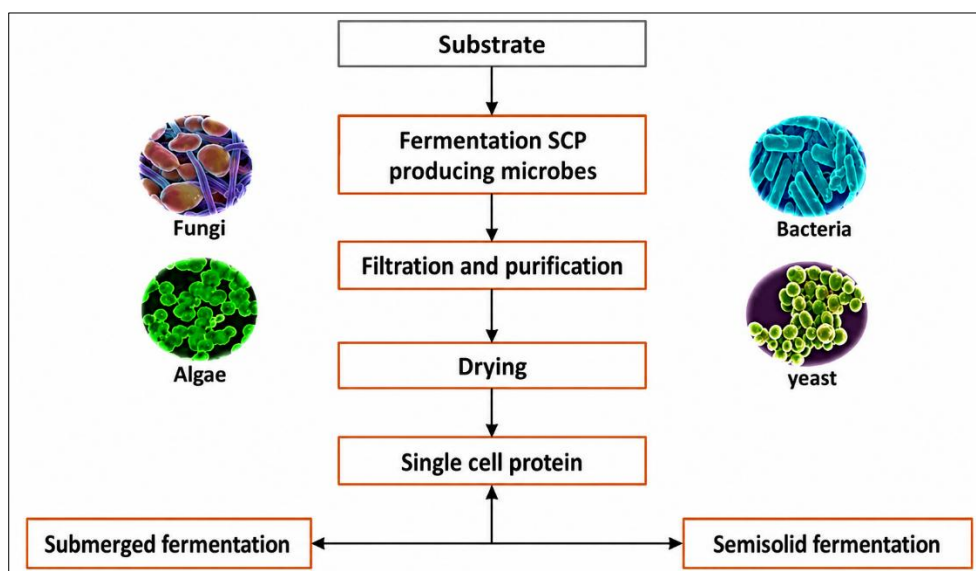


Fig 1: Process of SCP production

Bacterial strains were considered as appropriate for SCP production, they must meet several critical criteria, including optimal reaction conditions (such as temperature, oxygen demand and foam formation); performance metrics (like biomass yield, growth rate, tolerance to pH and temperature); fermentation characteristics (including growth pattern and genetic consistency); and end-product attributes (such as protein quality and structure, efficiency of purification, and recovery rates).

Nutritive value of Single Cell Protein

SCP refers to the dried microbial biomass obtained from various microorganisms such as algae, fungi (yeast and moulds) and bacteria, cultivated on suitable substrates. The composition varies depending on the organism used, the substrate and the processing method. However, general proximate ranges are as follows:

Table 1: Proximate composition of single-cell protein on a dry-matter basis, showing typical ranges for moisture, protein, fibre, fat, ash and NFE.

Composition	% Dry matter Basis	Remarks
Moisture (%)	< 10 in dried form	Shelf stable dried SCP products
Crude protein (%)	45-80	High biological value and rich in essential amino acids
Crude fibre (%)	1-8	Generally low, but may increase due to cell wall components like chitin
Ether extract (%)	1-10	Depends on the source of single cell protein. If it's from <i>methylococcus</i> , lipid content is high.
Ash (%)	5-15	Includes Calcium, Phosphorus etc.,
Nitrogen-Free Extract (NFE)	5-30	Varies; higher in yeast/fungi grown on carbohydrate-rich media

Single Cell Protein in ruminant feeding

Multiple studies have explored the efficacy of SCP as a partial replacement for conventional protein sources such as soybean meal and groundnut cake in dairy cattle diets. Kumar *et al.* (2017) ^[4] demonstrated that substituting 25% of traditional protein ingredients with SCP in the diets of lactating cows led to improved dry matter intake and enhanced nutrient digestibility. Similarly, Chatterjee (2019) ^[1] reported that yeast-derived SCP improved ruminal microbial activity and nitrogen retention, contributing to better overall rumen fermentation. SCP inclusion has been consistently associated with improvements in milk production and compositional quality. Nagalakshmi *et al.* (2012) ^[6] observed that feeding *Candida utilis*-based fortified SCP to lactating cows resulted in an 8-12% increase in milk yield, along with enhancements in milk fat and solids-not-fat (SNF) content. Algal SCP supplementation was found to elevate milk protein and lactose levels, as documented by Mehta and Soni (2020) ^[5]. The underlying mechanisms through which SCP exerts these beneficial effects include: stimulation of microbial protein synthesis within the rumen, enhanced digestibility and nutrient utilization, improved immune response, particularly when SCP is enriched with antioxidants and functioning as both a prebiotic and probiotic, supporting gut health and metabolic efficiency. Fortification of SCP with essential trace minerals and amino acids has further amplified its utility. Sankhala *et al.* (2015) ^[10] reported enhanced antioxidant status and improved udder health in dairy cows receiving selenium-enriched yeast SCP, evidenced by a significant reduction in somatic cell counts (SCC). Likewise, Sharma (2021) ^[11] showed that methionine-fortified SCP improved both reproductive performance and milk quality in lactating cattle. Historically, fortified SCP has been recognized as a high-potential protein supplement for livestock, containing up to 70% protein, is rich in B-complex vitamins and essential amino acids. Inclusion of 24% FSCP in concentrate mixtures was shown to sustain milk yield but altered milk fat composition reducing short-chain fatty acids and increasing long-chain fatty acid content. In small ruminants, earlier studies found that SCP effectively replaced groundnut meal in lactating goat diets, resulting in increased milk output and improved production efficiency. In bovine trials, previous studies reported that Holstein-Friesian cows fed a diet supplemented with 7% SCP produced higher 4% fat-corrected milk compared to those on control or lower-protein diets.

Economics of feeding SCP in cattle

The economic viability of feeding SCP in dairy cattle diets is influenced by factors such as cost of SCP production, milk yield response, feed conversion efficiency and savings in conventional protein sources. Though SCP shows promising nutritional and functional benefits, its commercial use must be economically justified in terms of cost per litre of milk produced and return over feed cost. Studies have shown that inclusion of 5-25% SCP in dairy cattle diets can enhance milk yield by 8-15%, depending on the source and level of inclusion. SCP improves dry matter intake, rumen microbial efficiency, and nutrient digestibility, leading to better feed conversion ratios (FCR). Nagalakshmi *et al.* (2012) ^[6] reported that substituting 25% of soybean meal with *Candida utilis*-based SCP increased milk yield and

improved milk composition, resulting in better economic returns per cow. Sharma (2021) ^[11] found that supplementation with methionine-fortified SCP improved both milk yield and reproductive efficiency, reducing days open and increasing net income.

Limitations and challenges in the use of SCP in ruminant feeding

Despite the nutritional benefits and promising research outcomes, the widespread use of SCP in ruminant diets is constrained by several limitations as follows.

Economic Feasibility and Cost Constraints: Large-scale production and incorporation of SCP into ruminant rations remain economically challenging. The cost of production especially when using high-grade fermentation substrates, energy-intensive drying processes, or fortified additives (*e.g.*, trace minerals or amino acids) can render SCP less competitive than conventional protein sources like soybean meal or groundnut cake. As a result, SCP may be economically viable only in niche markets or during periods of high conventional feed cost.

Risk of over-supplementation and nutrient imbalance:

Excessive inclusion of SCP in ruminant diets can lead to nutrient imbalances, particularly with respect to nitrogen metabolism. High levels of non-protein nitrogen (NPN) or microbial cell wall components such as nucleic acids may lead to metabolic disturbances, including hyperuricemia or increased ammonia production in the rumen. Such imbalances can compromise feed efficiency and animal health (Yunus *et al.*, 2004) ^[13].

Variability in nutritional composition based on source and processing:

The nutritional efficacy of SCP varies significantly depending on the microbial strain (*e.g.*, algae, yeast, fungi, or bacteria), growth substrate (*e.g.*, molasses, methane, whey), and downstream processing (*e.g.*, drying, cell wall disruption). Some SCPs contain high levels of indigestible cell wall components such as chitin or glucans, reducing their digestibility in ruminants. Improper processing can also leave behind residual toxins or contaminants.

Palatability and feed intake issues: Certain SCPs have poor organoleptic properties, such as unpleasant odour or bitter taste, which may reduce voluntary feed intake. Yeast and bacterial SCPs, in particular, can lead to feed refusal if not blended properly with conventional ingredients.

High nucleic acid content and metabolic concerns: Many microbial SCPs contain elevated levels of nucleic acids, particularly RNA. In ruminants, excessive intake of nucleic acids can increase purine metabolism and lead to elevated uric acid levels, potentially affecting kidney function or causing uricemia-related issues. Technologies for nucleic acid reduction add to processing costs.

Regulatory and safety concerns: SCP derived from genetically modified organisms (GMOs), industrial waste streams, or unconventional substrates may raise regulatory concerns regarding animal and human food safety. Monitoring for microbial toxins, heavy metals, and residual solvents is essential, especially when SCP is produced using

agro-industrial or petrochemical by-products.

Lack of standardization and limited Field Data: The inconsistent quality and limited availability of standardized commercial SCP products for livestock use are also hurdles. Moreover, most SCP feeding trials have been short-term and conducted under controlled experimental conditions. Long-term studies on its safety, efficacy and effect on product quality (milk, meat) under field conditions are still scarce.

Conclusion

Single cell protein, particularly in fortified forms, represents a promising alternative protein source for sustainable dairy production, while reducing dependence on conventional protein feeds. Microbial protein sources offer a viable pathway to strengthen protein security in dairy nutrition while supporting efficient milk production. Their strategic inclusion in cattle diets can enhance rumen function and productive performance when appropriately processed and supplemented. However, practical adoption depends on improving affordability, ensuring consistent nutritional quality and generating robust long-term evidence under farm conditions. Addressing these aspects will be crucial for integrating these novel protein sources into mainstream dairy feeding systems.

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