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Biotechnological Importance of *Schizochytrium* sp.

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Abstract – *Schizochytrium* sp. is an alga gaining increasing attention in the biotechnology field due to its diverse applications. This article aims to explore the biotechnological importance of *Schizochytrium* sp. and its potential contributions to various industries. Through its ability to produce valuable compounds such as omega-3 fatty acids, carotenoids, and polysaccharides. *Schizochytrium* sp. offers promising prospects in sectors ranging from pharmaceuticals to food and feed additives. Additionally, its robustness, ease of cultivation, and ability to thrive in diverse environmental conditions make it a promising candidate for sustainable bioprocessing. This article highlights the current research trends and future prospects associated with the biotechnological utilization of *Schizochytrium* sp.

Keywords – Schizochytrium sp., Biotechnology, Omega-3 fatty acids, Carotenoids, Sustainable bioprocessing.

I. INTRODUCTION

Schizochytrium sp. is a species of marine microorganisms belonging to the class Labyrinthulomycetes [1]. These microorganisms have gained significant attention due to their unique lipid metabolism, which enables the accumulation of high levels of docosahexaenoic acid (DHA), an essential omega-3 fatty acid [2]. The genus is characterized by its ability to thrive in diverse environmental conditions, making it a robust candidate for various biotechnological applications. The increase in carbon emissions and rising global warming have serious environmental impacts, but environmental changes can be monitored through remote control systems [3–6]. Algae play a significant role in determining water quality in wetlands [7,8]. Initially discovered for its ecological role in marine environments, *Schizochytrium* sp. has emerged as a valuable resource in biotechnology [2]. The morphological characteristics of *Schizochytrium* sp., a marine microorganism known for its unique lipid metabolism and high levels of docosahexaenoic acid (DHA) production (Fig. 1). Its diverse metabolic capabilities and potential for sustainable bioprocessing have led to significant interest in its use in industries ranging from pharmaceuticals to food and feed additives. The ability of *Schizochytrium* sp. to produce valuable compounds such as omega-3 fatty acids, carotenoids, and polysaccharides further enhances its biotechnological importance [2].

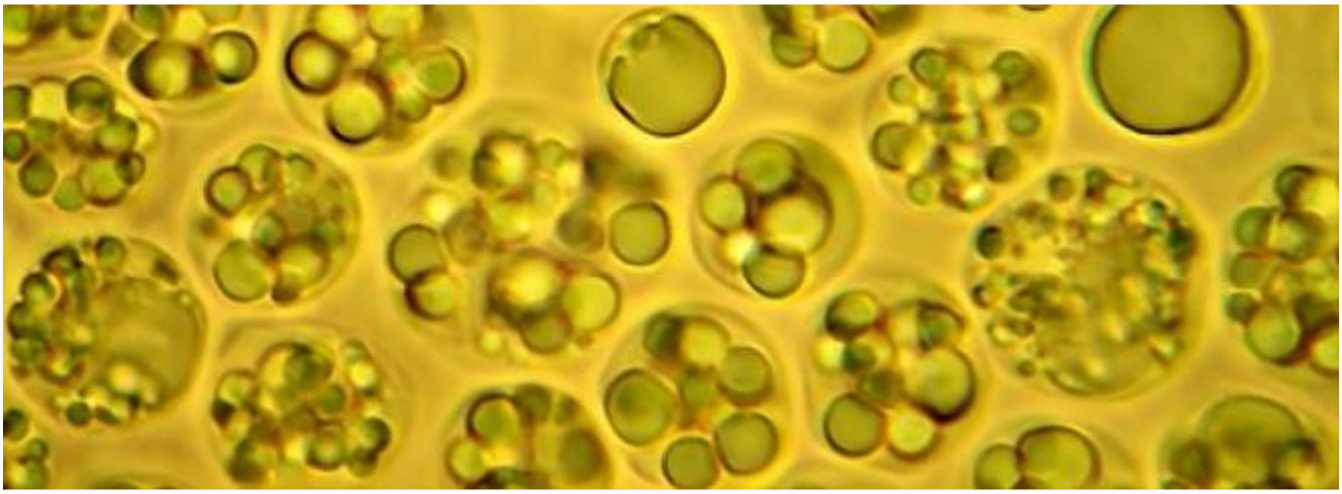

Fig. 1. Microscopic view of *Schizochytrium* sp. [9]

The ability of *Schizochytrium* sp. to produce valuable compounds such as omega-3 fatty acids, carotenoids, and polysaccharides further enhances its biotechnological importance. Current research trends focus on optimizing the cultivation conditions and genetic manipulation of *Schizochytrium* sp. to maximize the yield of these valuable compounds. Future prospects include the development of large-scale bioprocessing systems that leverage the robustness and metabolic versatility of *Schizochytrium* sp. for sustainable production of high-value bioproducts [10].

II. Production of Omega-3 Fatty Acids

One of the most significant biotechnological applications of *Schizochytrium* sp. lies in the production of omega-3 fatty acids, particularly docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) [1]. (Fig. 2). Represents that these long-chain polyunsaturated fatty acids (LC-PUFAs) are crucial for maintaining cardiovascular health, cognitive functions, and infant development [11]. *Schizochytrium* sp. employs the polyketide synthase pathway for DHA synthesis, offering a sustainable alternative to fish oil [12]. The scalability of *Schizochytrium* sp. cultivation, coupled with its high lipid content, positions it as a valuable and sustainable source of omega-3 fatty acids [13].

Omega-3 fatty acids, particularly DHA and EPA, synthesized by *Schizochytrium* sp. through the polyketide synthase pathway, are vital for cardiovascular health, cognitive functions, and infant development [11]. This sustainable alternative to fish oil addresses environmental concerns related to overfishing, thereby supporting global nutritional needs [14]

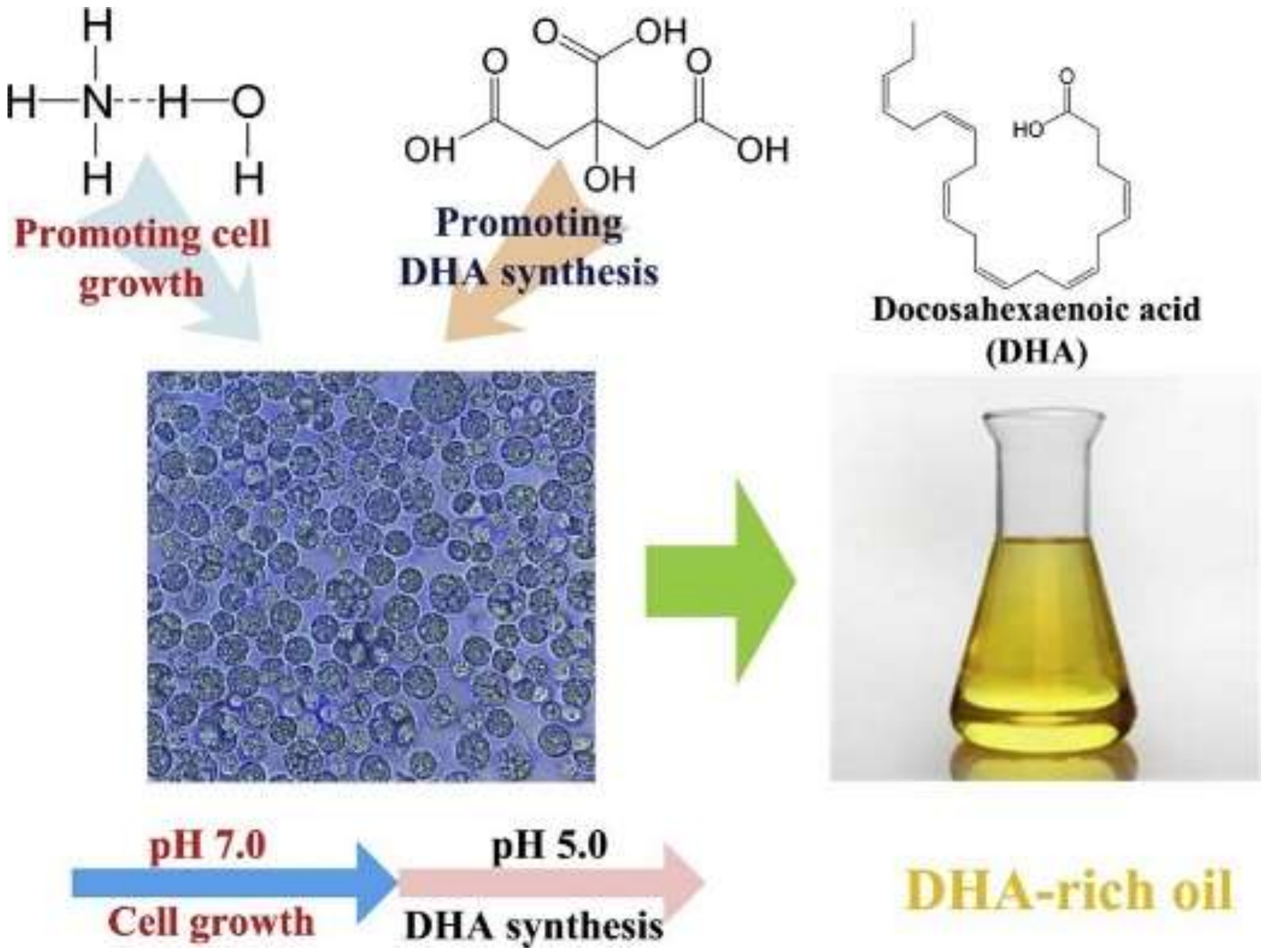

Fig. 2 Acidic conditions (pH 5.0) promote DHA synthesis, while pH increased to pH 7.0 enhance cell growth in *Schizochytrium* sp., with applications in food and pharmaceuticals [15]

Research indicates that DHA derived from *Schizochytrium* sp. can enhance cognitive functions and visual processing in animal models [16,17]. Furthermore, the production of these essential nutrients from *Schizochytrium* sp. holds promise for addressing global nutritional needs, particularly given the environmental concerns associated with overfishing and the sustainability of fish oil sources. Thus, the biotechnological exploitation of *Schizochytrium* sp. not only contributes to human health but also supports environmental sustainability [1].

In the study of lipid and DHA production in various strains of *Schizochytrium* sp., it was found that different environmental and fermentation conditions significantly impact productivity rates. Table 2 illustrates the fermentation conditions, lipid content in biomass, DHA content in lipids, lipid productivity, and DHA productivity in several strains of *Schizochytrium* sp., along with the respective references.

Table 1. DHA production in native strains of *Schizochytrium* (*Aurantiochytrium*) spp [9,13,15]

Microorganism	**Fermentation conditions**	**Lipid in biomass (%)**	**DHA in lipid (%)**	**Lipid productivity (mg L- 1 h- 1)**	**DHA productivity (mg L- 1 h- 1)**
Aurantiochytrium sp. TC 20	Fed-batch culture on glycerol, peptone and yeast extract (20 ◦C, 69 h)	>35	48	535	311
Aurantiochytrium limacinum SR21	Fed-batch culture on glucose, glycerol, yeast extract and monosodium glutamate (25 ◦C, 96 h)	84	~39	771	337
Schizochytrium sp. S31	Fed-batch culture on glycerol and yeast extract (28 ◦C, 96 h	50	~42	793	301
Aurantiochytrium sp. T66	Batch culture (nutrient limited) on glycerol and glutamate (28 ◦C, 150–180 h)	~63	39 to 52	~300	93
Schizochytrium sp. SH103	Fed-batch culture on glucose and yeast extract (28 ◦C, 48 h)	~46	~30	900–1000	317
Schizochytrium sp. HX- 308	Fed-batch culture on glucose and yeast extract (30 ◦C, 120 h) in 50 L stirred tank	~69	~43	~863	369
Schizochytrium sp. HX- 308	Fed-batch culture on glucose and yeast extract (30 ◦C, 120 h) in 7 m3 stirred tank	~58	~52	~623	~327
Schizochytrium sp. HX- 308	Fed-batch culture on glucose and yeast extract (apparently 30 ◦C, 128 h) in 1.5 m3 stirred tank	~50	~45	~275	119
Schizochytrium sp. HX- 3	Fed-batch culture on glucose and yeast extract (30 ◦C, 120 h) in 5 L stirred tank with pH controlled by ammonia and citric ac	~52	~52	~275	~273
Schizochytrium sp. HX- 308	Fed-batch (continuously fed) culture on glucose and yeast extract (30 ◦C, 120 h) in 50 L stirred tank	~57	~55	~275	320
Schizochytrium sp. LU310	Fed-batch culture (28 ◦C, 192 h) on glucose, corn steep solids and glutamate in baffled flasks	~59	~48	~275	242
Schizochytrium sp. HX- 308	Batch cultures (30 ◦C, 70 h) on glucose and yeast extract followed by nutrient limitation	~66	~38	~275	291
Schizochytrium sp. SR21	Batch culture (28 ◦C, up to 125 h) on glucose and corn steep liquor	~78	~36	~275	~138

III. Carotenoid Production

Algae have a wide range of biotechnical applications, from space research to the development of functional foods and urbanization [18–21]. *Schizochytrium* sp. produces a variety of carotenoids, including astaxanthin and β-carotene, which possess significant antioxidant properties and have applications in food, cosmetics, and pharmaceuticals [22]. Carotenoids are natural pigments with potent antioxidant activity and potential health benefits, such as reducing inflammation and boosting the immune system. *Schizochytrium* sp. offers a renewable and scalable source of these compounds, addressing the growing demand for natural colorants and nutraceutical ingredients. Furthermore, metabolic engineering can enhance carotenoid production in *Schizochytrium* sp., further increasing its commercial viability and application [23]. As mentioned in the (Table 2) , *Schizochytrium* sp. produces a variety of carotenoids, including astaxanthin and β-carotene, which possess significant antioxidant properties. These carotenoids are increasingly used in food, cosmetics, and pharmaceuticals due to their health benefits and natural pigment properties [22,24]. Metabolic engineering can further enhance the production of these valuable compounds [23].

Table 2**.** Carotenoid production in various strains of *Schizochytrium* sp. [9,13]

Microorganism	**Fermentation Conditions**	**Astaxanthin Content (mg/g)**	**β-Carotene Content (mg/g)**	**Applications**
Schizochytrium sp. TC 20	Fed-batch culture on glycerol, peptone, and yeast extract (20°C, 69 h)	2.5	1.2	Food, Cosmetics, Pharmaceuticals
Schizochytrium limacinum SR21	Fed-batch culture on glucose, glycerol, yeast extract, and monosodium glutamate (25°C, 96 h)	3.1	1.5	Food, Cosmetics, Pharmaceuticals
Schizochytrium sp. S31	Fed-batch culture on glycerol and yeast extract (28°C, 96 h)	2.8	1.4	Food, Cosmetics, Pharmaceuticals
Schizochytrium sp. HX-308	Fed-batch culture on glucose and yeast extract (30°C, 120 h)	3.0	1.6	Food, Cosmetics, Pharmaceuticals

IV. Polysaccharide Production

Schizochytrium sp. not only synthesizes carotenoids such as astaxanthin and β-carotene with significant antioxidant properties and diverse industrial applications in food, cosmetics, and pharmaceuticals [22,24], but also produces polysaccharides with varied structural and functional properties [25]. These polysaccharides hold promise in sectors ranging from food to pharmaceuticals and bioplastics, contributing to the development of novel biomaterials for drug delivery and tissue engineering [26]. Furthermore, the utilization of *Schizochytrium* sp. biomass for biofuels and biodegradable plastics offers a sustainable solution to environmental challenges posed by conventional petrochemical-based products [27]. Advances in fermentation technology have further enhanced the efficiency of polysaccharide extraction [28], underscoring its potential in industrial applications. Recent developments in genetic and metabolic engineering have enabled the enhancement of polysaccharide yield and quality, making *Schizochytrium* sp. a more viable option for large-scale industrial processes [29]. Additionally, ongoing research into optimizing cultivation conditions and bioreactor designs continues to improve the overall productivity and economic feasibility of polysaccharide production [1,30].

Polysaccharides produced by *Schizochytrium* sp. have diverse applications in the food industry, cosmetics, pharmaceuticals, and biodegradable plastics; advances in fermentation technology and genetic engineering have significantly improved the efficiency and yield of polysaccharide extraction [31].

The biosynthesis of polysaccharides in *Schizochytrium* sp. involves complex metabolic pathways that are crucial for its diverse applications. Recent research has elucidated key enzymes and regulatory mechanisms involved in the biosynthesis of various polysaccharides, including β-glucans and galactans [32], as illustrated in Fig. 3. Understanding these pathways has paved the way for metabolic engineering approaches aimed at optimizing the production of high-value polysaccharides. For instance, targeted genetic modifications have been employed to enhance the expression of enzymes responsible for polysaccharide synthesis, resulting in increased yields and improved functional properties of the polysaccharides produced [33]. This progress not only underscores the biotechnological potential of *Schizochytrium* sp. but also demonstrates its capability to meet the growing demand for sustainable and functional biomaterials in various industries.

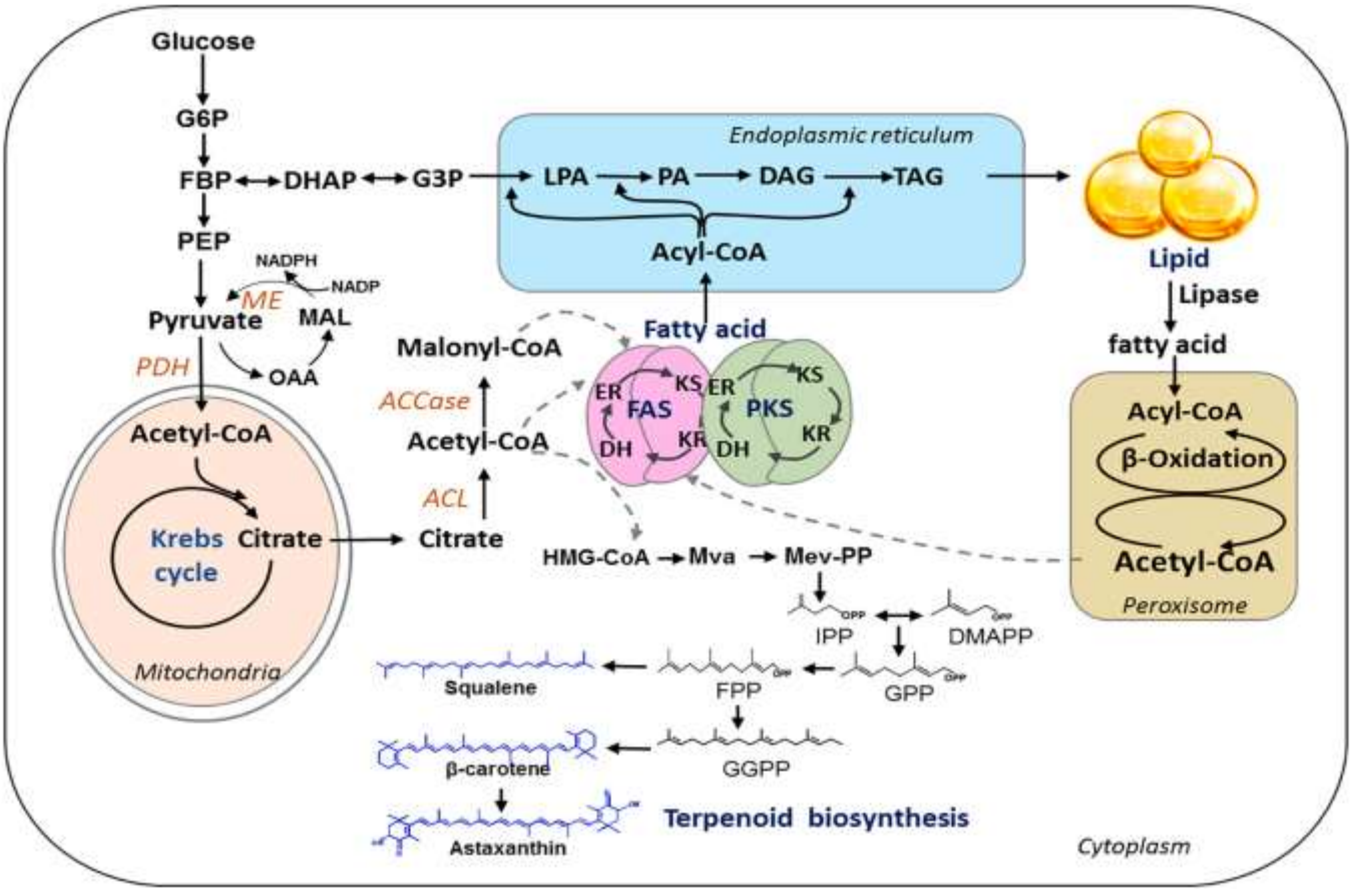

Fig.3. Overview of lipid and terpenoid synthesis metabolism in thraustochytrids [13]

Polysaccharides have become increasingly valuable in various industrial sectors due to their functional properties and potential for sustainable applications. In the food industry, polysaccharides are commonly used as food ingredients to enhance flavor, texture, and appearance, providing a natural way to improve product quality [34]. In the cosmetics and pharmaceutical industry, they are utilized for their diverse functional and biological properties, playing a crucial role in the formulation of skincare products and pharmaceuticals that offer both efficacy and safety [35]. Additionally, in the biodegradable plastics and biomaterials industry, polysaccharides contribute significantly to the development of biodegradable and renewable biomaterials, which are vital for promoting environmental sustainability and reducing dependency on conventional petrochemical products [36]. Moreover, emerging industries such as bioelectronics and sustainable packaging are exploring the use of polysaccharides for advanced applications, opening up new avenues for innovation and sustainable development [37]. (Table 3) provides a succinct summary of the applications and advantages of polysaccharides synthesized by *Schizochytrium* sp. in these diverse industrial sectors.

Table 3. Summary of the applications and advantages of polysaccharides synthesized by *Schizochytrium* sp. in diverse industrial sectors [9,12,13,15]

Industrial Sector	Applications and Benefits
Food Industry	Addition of polysaccharides as food ingredients, enhancing flavor and appearance of food products.
Cosmetics and Pharmaceutical Industry	Use of polysaccharides in developing skincare products and pharmaceuticals due to their diverse functional and biological properties.
Biodegradable Plastics and Biomaterials Industry	Contribution to developing biodegradable and renewable biomaterials, promoting environmental sustainability and reducing reliance on conventional petrochemical products
Emerging Industries like Bioelectronics and Sustainable Packaging	Utilization of polysaccharides in advanced applications such as bioelectronics and sustainable packaging, opening new avenues

Thraustochytrids are recognized for their exceptional ability to produce large quantities of lipids, with biomass yields reaching up to 165 g/L and lipid titers of 113 g/L without the need for genetic modification [13]. This efficiency surpasses that of other oleaginous microorganisms, such as *Chlorella vulgaris* and *Synechocystis* sp., which have lower photosynthetic growth rates and are less effective in lipid accumulation [38]. The high lipid production capability of thraustochytrids, along with their capacity to store fatty acids as triacylglycerols (TAGs), highlights their potential for biotechnological applications in producing sustainable lipid sources [39]. These properties make thraustochytrids a promising candidate for industrial lipid production, especially when considering the challenges faced by traditional photosynthetic organisms [40]. (Fig. 4) illustrates the fermentation process and the function of lipids in thraustochytrids [13].

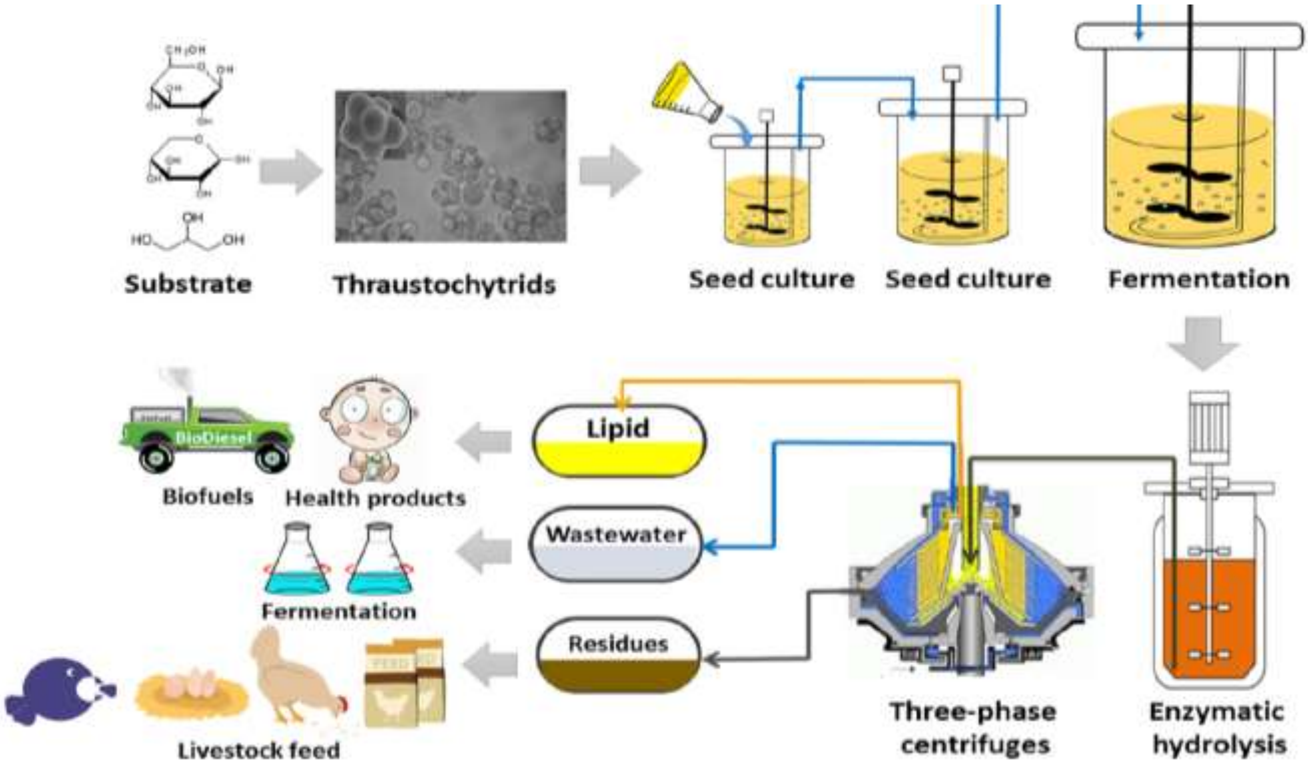

Fig. 4. The fermentation process and function of lipid in thraustochytrids [13]

V. CONCLUSION AND FUTURE PERSPECTIVES

The biotechnological importance of *Schizochytrium* sp. is evident from its diverse metabolic capabilities and potential applications across various industries. Continued research efforts aimed at optimizing cultivation strategies, metabolic engineering, and downstream processing will further enhance the commercial viability of *Schizochytrium*-based biotechnologies. Moreover, the exploration of untapped metabolic pathways and genetic resources within *Schizochytrium* sp. holds promise for the discovery of novel bioactive compounds and bioproducts. Overall, *Schizochytrium* sp. stands as a promising microorganism with significant implications for sustainable biotechnology and the bioeconomy. The ongoing research into optimizing cultivation strategies and metabolic engineering promises to unlock new bioproducts from *Schizochytrium* sp., enhancing its commercial viability and environmental sustainability [41]. This highlights the microorganism's potential to contribute significantly to the bioeconomy and sustainable biotechnology."

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