IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402, p- ISSN: 2319-2399.Volume 20, Issue 3 Ser. 1 (March 2026), PP 25-35
www.iosrjournals.org

Microalgae In Functional Food Development: Nutritional Value, Bioactivity, And Future Perspectives.

Akshaya Priya R, Iswarya Lakshmi A, Indumathi S.M, Jancy Mary E
Department Of Biotechnology, School Of Bio And Chemical Engineering, Sathyabama Institute Of Science And Technology, Chennai - 600119

Abstract
The study of microalgae has become an important source of raw materials for primary and secondary metabolites. These microalgae are found in freshwater, marine water resources and even in wastewater. These microalgae play an important role in food industries and in medical field where, microalgae like Spirulina and Chlorella, an unicellular green microalga, is considered as functional food due to its rich bioactive compounds like polyunsaturated fatty acids (PUFAs), polysaccharides, photosynthetic pigments, and phenolic compounds. These compounds contribute in widely in therapeutic effects which include antioxidant, anti-inflammatory, antimicrobial, antifungal, anticancer, anticoagulant, antiviral, and anti-enzymatic activities. This review comprehensively examines the chemical composition of Chlorella and its health benefits, ranging from managing hypertension to fibromyalgia. The increasing demand for healthier, organic and nutrient rich foods has stimulated interest in incorporating Chlorella into functional and sustainable food products, including fermented dairy foods such as yogurt, cheese and also in products like pasta, noodles, soups, ice creams and in readily available food items. This helps in the enrichment of animal-based dairy products with microalgae biomass that presents a promising strategy for developing and producing innovative hybrid foods that are rich in bioactive constituents. Furthermore, we discuss about the impacts of microalgal addition on physicochemical, antioxidant, sensory, and probiotic viability parameters in dairy products. Finally, this review governs the importance and use of microalgae in food products and in medical field by understanding the potential of Chlorella as a functional food ingredient to improve human health and its contribution to the sustainable food development.
Keywords: *Microalgae, Spirulina, Chlorella, polyunsaturated fatty acids (PUFAs), antioxidant, anti-inflammatory.*

Date of Submission: 08-03-2026 Date of Acceptance: 18-03-2026

I. Introduction

Microalgae is used as a Functional food in food industries nowadays. In recent years, microalgae have gained more attention as a raw material for the production of high-value bioactive compounds incorporated in food products. Their diverse metabolic pathways, in both primary and secondary metabolism, result in the synthesis of components such as lipids, proteins, carbohydrates, pigments, and phenolic compounds. Among these components, lipids play an important role in biodiesel production, establishing microalgae as potential contributors to sustainable biofuel alternatives [Singh & Gu, 2010; Safi et al., 2014]. The major advantage of using microalgae in industries is for their rapid growth rate and high biomass cultivation. They can complete their life cycle within few days and can be grown in diverse environments like freshwater, marine water, wastewater, and even in fermentation tanks [Blair et al., 2014; Chew et al., 2018]. Their adaptability and efficiency make them attractive for large-scale applications and production. Among these species, Chlorella vulgaris stands out for its high growth rate and metabolic activity under autotrophic, heterotrophic, mixotrophic, and phototrophic conditions. Studies show that maximum biomass production occurs in mixotrophic media or when cultured in photobioreactors [Liang et al., 2009; Dragone, 2022]. Chlorella sp., a unicellular green microalga of the division Chlorophyta, is one of the most cultivated microalgae worldwide due to its rich nutrition, Generally Recognized as Safe (GRAS) status, and wide range of industrial applications, including food, cosmetics, pharmaceuticals, and biofuels [Bito et al., 2020; Martínez-Ruiz et al., 2025].

This microalga is spherical in shape (2–10 μm in diameter) and possess thick cell wall composed of chitin and cellulose, offering mechanical and chemical protection; the cell wall also facilitates its resilience during downstream processing [Safi et al., 2014; Sharma & Sharma, 2019]. Nutritionally, Chlorella sp. is rich in proteins (51–58%), lipids (14–22%), carbohydrates (12–17%), nucleic acids (4–5%), and dietary fiber (0.4%). Approximately 60% of the total protein content in the species is made up of essential amino acids, making it an excellent plant-based protein source which could be easily absorbed by the human body. Moreover, it contains a high concentration of chlorophyll (1–4%), making it the richest known source of this green pigment. The vitamin profile includes provitamin A (β-carotene), vitamins E, B1 (thiamine), B2 (riboflavin), B3 (niacin), B6, B12, biotin, and folic acid, making it a potent dietary supplement [Safi et al., 2014; Rani et al., 2018; Bito et al., 2020]. Microalgae, such as Chlorella sp., are recognized for their capacity to produce a range of bioactive components with antioxidant, antibacterial, antiviral, anti-inflammatory, anticancer, and antihyperglycemic activities. These compounds are termed as nutraceuticals, which contribute positively to human health and increase interest in their use in functional foods.

Functional foods are defined as products providing health benefits beyond basic nutrition, including the prevention or reduction of risk of obesity, diabetes, cardiovascular disorders, and certain cancers [Ampofo & Abbey, 2022; Barghchi et al., 2023; Wali et al., 2021]. The nutritional profile of Chlorella sp. is further enhanced by its role in combating modern dietary challenges. Increased health concerns regarding excessive fat and sugar intake, microalgae-based ingredients offer a viable solution. Studies have explored the incorporation of natural bioactive-rich ingredients such as bee pollen, fruit powders, and algal biomass into baked food products like reduced-fat cookies, leading to improved nutritional value, increased dietary fiber, antioxidant capacity, and favorable physicochemical properties in final food products. This supports the integration of Chlorella in developing healthier food formulations [Ali et al., 2025; Çelekli et al., 2024; Dündar et al., 2023]. Historically, microalgae have served humanity since ancient times, when the Chinese consumed Nostoc species during times of famine. In modern times, Chlorella was the first cultured pure algae, isolated by M.J. Beijerinck in 1890. Later, Otto Warburg used Chlorella in plant physiology studies.

During the 1940s, when Chlorella was used as a dietary supplement for leprosy patients in Venezuela, showed observable health benefits. The Japanese further advanced their research into Chlorella during the 1950s, making it widespread as a nutrient supplement in Asia [Safi et al., 2014; Jibri et al., 2016]. From an environmental standpoint, microalgae play an important role in carbon fixation and oxygen generation. CO_2 bio-fixation by microalgae is recognized as a sustainable and eco-friendly method for reducing greenhouse gas emissions [Wang et al., 2016; Safi et al., 2014]. This highlights their benefits contributing to human health while supporting environmental sustainability. In today's developing world and growing population, the benefits of microalgae, particularly Chlorella sp., make them a valuable resource for the development of functional foods. Their rich nutritional profile, health-promoting bioactive compounds, adaptability, and eco-sustainability position microalgae as an innovative solution to modern challenges in health and food science [Martínez-Ruiz et al., 2025; Bito et al., 2020].

Overview of microalgae:

Microalgae, a diverse group of photosynthetic microorganisms, serve as nutrient source of primary and secondary metabolites with applications in food, feed, pharmaceuticals, and bioenergy sectors [Sathasivam et al., 2019; Udayan et al., 2017]. Adaptability of these microalgae allows them to thrive in various aquatic environments, including freshwater, marine water, and even wastewater ecosystems [Wang et al., 2016; Chew et al., 2018]. Understanding their taxonomy, cultivation, and processing is essential to utilize its full potential of these organisms as functional food ingredients [Safi et al., 2014; Coronado-Reyes et al., 2020]. These microalgae are helpful in biotechnological applications to enrich the nutrient value of products, including four main species: Spirulina (Arthrospira), Chlorella, Dunaliella salina, and Haematococcus pluvialis [Ampofo & Abbey, 2022; Yaakob et al., 2014].

Classification and Commonly Used Species

Microalgae are diverse organisms which can be broadly classified based on their pigments, morphology, and molecular phylogeny into several major groups across different kingdoms and phyla [Darienko et al., 2015]. Their classification is complex due to high morphological plasticity and cryptic species diversity; however, integrated taxonomy using both morphological and molecular tools such as DNA barcoding is increasingly employed in species identification and systematics [Darienko et al., 2015]. This integrative taxonomy allows more accurate species delimitation and has discovered a richer biodiversity than previously recognized species, in which over 50,000 species are documented globally [Darienko et al., 2015; Sharma & Sharma, 2019].

The microalgae utilized in functional foods primarily are from several major groups which include: Chlorophyta (Green algae): This includes Chlorella vulgaris and Scenedesmus species. These are rich in proteins, essential fatty acids and pigments like chlorophyll and carotenoids, and polysaccharides displaying various bioactivities [Safi et al., 2014; Bito et al., 2020]; Cyanobacteria (Blue-Green algae): This is represented by Spirulina platensis (Arthrospira) and is noticed for its phycobiliproteins such as phycocyanin and antioxidant properties [Kargın & Bilgüven, 2022; Jibri et al., 2016]; Diatoms (Bacillariophyta): Known for unique silica cell walls and production of valuable lipids including eicosapentaenoic acid (EPA) [Sathasivam et al., 2019]; and other major groups such as Dunaliella salina (high β-carotene producer) and Haematococcus pluvialis (source of astaxanthin), used mainly for nutraceutical pigment production [Gouveia et al., 2006; Martínez-Ruiz et al., 2025].

Many species remain undiscovered and are under evaluation through genome sequencing and molecular phylogenetics methods, which help in their identification and classification based on their functions [Darienko et al., 2015; Coronado-Reyes et al., 2020].

"Table:1 Differences Between Spirulina and Chlorella vulgaris"

Features	Spirulina (Arthrospira platensis)	Chlorella vulgaris
Classification	Cyanobacteria (blue-green algae)	Green algae (Chlorophyta)
Cell size & shape	Filamentous, spiral-shaped, ~3.5 billion years old	Unicellular, spherical, 2–10 µm diameter
Habitat	Fresh, alkaline water, tropical regions	Freshwater and saltwater in temperate zones
Protein content	~55-70% dry weight, slightly higher than Chlorella	~51-58% dry weight
Essential ammino acids	Rich in 18 amino acids, slightly lower total and essential AA than Chlorella	Contains all essential amino acids, slightly higher total and essential AA
Lipid content	5-8%, high in gamma-linolenic acid (GLA), linoleic acid	14-22%, higher in polyunsaturated fatty acids (PUFAs), omega-3s like EPA and DHA
Carbohydrate & fiber	~7%, low dietary fiber	12-17%, higher dietary fiber (~4.5%)
Proteins	Chlorophyll a and b, phycocyanin (blue pigment)	Chlorophyll (higher content), carotenoids (β-carotene, lutein)
Vitamins	Rich in B vitamins (B1, B2, B3, B5, B7), vitamin E, vitamin C	Rich in provitamin A (β-carotene), vitamins E, B1, B2, B6, B12, folate, and biotin
Minerals	High potassium, iron, copper, sodium, zinc	Higher magnesium, calcium, zinc, iron
Antioxidant properties	Strong antioxidant capacity, especially for phycocyanin and other bioactives	Higher total phenolic content, DPPH scavenging, potent antioxidant activity
Health benefits	Immune support, anti-inflammatory, antioxidant, antiviral, lipid-lowering	Antioxidant, anti-inflammatory, antimicrobial, antiviral, anticancer, detoxifying
Taste & sensory aspects	Earthy, marine flavor; blue-green color	Mild, vegetal flavor; bright green color
Cultivation	Prefers alkaline freshwater, easy to cultivate in open ponds	Thrives in freshwater, more suited for closed systems (photobioreactors)
Processing challenges	Cell wall is soft, easier to digest and process	Tough cell wall made of cellulose and chitin, requires disruption for digestibility
Applications	Dietary supplements, protein powders, additives in snacks, smoothies	Functional foods, dairy alternatives, beverages, supplements, natural colorants

Cultivation Methods

Effective cultivation of microalgae biomass is very essential for their commercial application [Safi et al., 2014; Coronado-Reyes et al., 2020]. Cultivation techniques of microalgae are designed to optimize biomass productivity and bioactive compound content according to necessity, while balancing economic and environmental sustainability [Dragone, 2022; Wang et al., 2016].

Some of the cultivation methods are as follows;

Open Pond Systems: This method of cultivation use shallow, raceway-type ponds that utilize natural sunlight and atmospheric carbon dioxide. They are cost-efficient and suitable for its tolerance to environmental fluctuations and modifications. However, contamination by unnecessary organisms, lower productivity, and seasonal variability limit their efficiency [Blair et al., 2014; Singh & Gu, 2010].

Photobioreactors (PBRs): Here, closed or semi-closed systems such as tubular, flat-panel, or column reactors are used for its controlled environments with optimized light, temperature, pH, and nutrient supply. Photobioreactors provide higher biomass yields, greater product consistency, and reduce the risk of contamination [Liang et al., 2009; Dragone, 2022].

Microalgae can be cultivated under autotrophic conditions using CO_2 and light, mixotrophic modes combining photosynthesis and organic carbon sources, or heterotrophic growth on organic substrates in the dark to boost the biomass yields and metabolite production [Liang et al., 2009; Candido & Lombardi, 2018]. Nutrients management, especially nitrogen and phosphorus availability and stress factors like light intensity and temperature, are applied to enhance the accumulation of desired compounds such as lipids or other pigments [Willette et al., 2022; Church et al., 2017].

Harvesting and Processing Techniques

Due to the size of microalgal cells and low biomass density in culture, harvesting is often a cost-intensive hurdle in microalgal production [Safi et al., 2014]. Some of the harvesting methods and processing techniques include: Centrifugation method - which is a highly effective method for biomass recovery but quite energy-intensive [Safi et al., 2014]; Filtration and Membrane Separation - which is suitable for larger cells cultivation but requires high maintenance to prevent membrane fouling [Mayhead et al., 2018]; Flocculation - in which usage of chemicals or bioflocculants aggregate cells to enhance sedimentation; natural flocculants like chitosan are preferred to avoid contamination [Hussein et al., 2017]; Drying - which helps in stabilization of biomass through spray-drying, freeze-drying, or drum drying, which aims to maintain the nutritional value and bioactive quality of the cells [Safi et al., 2014]; Extraction and Purification Techniques such as solvent extraction, CO_2 extraction, and enzymatic hydrolysis to isolate proteins, lipids, pigments, and polysaccharides while maintaining bioactivity of the cells and biomass for functional food applications [Gouveia et al., 2006; Tang et al., 2020].

Preserving the structural integrity and bioactivity of compounds of the cells during processing is crucial to maintain the functional and therapeutic benefits of microalgal ingredients [Bito et al., 2020; Martínez-Ruiz et al., 2025].

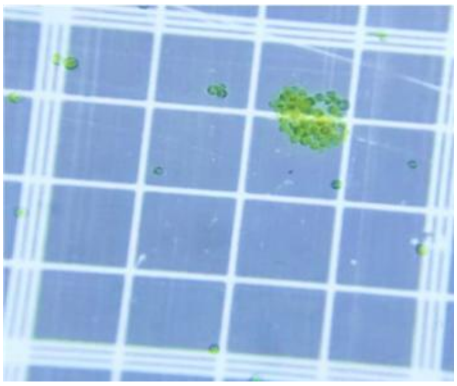

Fig:1 Chlorella vulgaris (Coronado-Reyes, J. A., Salazar-Torres, J. A., Juarez-Campos, B., & Gonzalez-Hernandez, J. C. (2020). Chlorella vulgaris, a microalgae important to be used in Biotechnology: a review. *Food Science and Technology*, *42*, e37320)

Nutritional composition of microalgae

These microalgae are recognized for their high nutritional value, providing macronutrients and micronutrients which are very essential for human and animal health [Ampofo & Abbey, 2022; Sathasivam et al., 2019]. The biochemical composition of the cells varies among species and cultivation conditions but in general it includes high-quality proteins, essential lipids, vitamins, minerals, carbohydrates, dietary fibers and pigments with functional properties [Safi et al., 2014; Bito et al., 2020].

Proteins and amino acids

Microalgae typically contain 40–70% of protein on dry weight condition, making them one of the richest plant-based protein sources compared to other traditional foods [Safi et al., 2014; Rani et al., 2018]. For example, Chlorella vulgaris contain protein contents exceeding 60%, with a well-balanced essential amino acid profile compared to animal proteins [Bito et al., 2020; Safi et al., 2014]. Spirulina (Arthrospira platensis) also provides high protein level which are rich in essential amino acids except methionine [Jibri et al., 2016; Kargın & Bilgüven, 2022]. Bioactive peptides released by enzymatic hydrolysis of microalgal proteins exhibit health-promoting effects such as antihypertensivity, antioxidant, and anti-inflammatory activities [Wali et al., 2021]. The digestibility of microalgal proteins is generally high but can be affected by cell wall composition whereas by the processing methods like cell disruption can enhance their bioavailability [Bito et al., 2020; Martínez-Ruiz et al., 2025].

Lipids and essential fatty acids

The total lipid content in microalgae vary from 5%- 20%, they contain significant proportions of polyunsaturated fatty acids (PUFAs), notable omega-3 fatty acids such as alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) [Safi et al., 2014; Kumaran et al., 2023]. This contributes to cardiovascular and neurological health and also exhibit anti-inflammatory effects [Barghchi et al., 2023]. Chlorella species contain a notable amount of saturated fatty acids but also some PUFAs, whereas spirulina tends to have higher monounsaturated and polyunsaturated profiles [Safi et al., 2014]. Incorporation of microalgae into animal feed show enrichment of milk and meat with beneficial omega-3 fatty acids, enhancing the product's nutritional value [Yaakob et al., 2014].

Vitamins and minerals

Microalgae are rich in various vitamins like B-complex (riboflavin, niacin, B12), vitamin C, A (as carotenoids), D, E, and K [Bito et al., 2020; Rani et al., 2018]. For example, Chlorella contains considerable amounts of niacin and riboflavin conducive to metabolic and antioxidant functions [Safi et al., 2014]. Minerals like iron, calcium, magnesium, potassium, zinc, manganese, and copper are present in more numberwhich contribute to dietary mineral intake [Bito et al., 2020]. Studies confirm that microalgae such as Chlorella and Aphanizomenon provide daily intakes of the above given micronutrients. However, variable heavy metal content must be monitored for food safety standards [Martínez-Ruiz et al., 2025].

Carbohydrates and dietary fiber

Carbohydrates in microalgae consists of large amount of polysaccharides, some of which are water-soluble and act as dietary fibers with prebiotic potential [Sathasivam et al., 2019]. The polysaccharides like sulfated polysaccharides in Chlorella can modify immune responses and exhibit anticoagulant and antiviral properties [Wali et al., 2021]. The carbohydrate content varies, around 10%–20% of dry weight, which provides energy as well as functional benefits that enhance gut microbiota [Safi et al., 2014].

Pigments

Microalgae are rich in different pigments with antioxidant and photoprotective properties which include: Chlorophylls (Predominantly chlorophyll a and b, which have antioxidant activities and potential detoxifying effects are preferred) [Bito et al., 2020; Gouveia et al., 2006], Carotenoids (Including β-carotene, lutein, zeaxanthin, and astaxanthin in various species. These pigments have high antioxidant activity and contribute to eye health and reduction of oxidative stress [Gouveia et al., 2006; Martínez-Ruiz et al., 2025], Phycobiliproteins are mainly found in cyanobacteria like spirulina, such as phycocyanin, which exhibit anti-inflammatory and antioxidant effects) [Kargın & Bilgüven, 2022]. Pigment contents can vary based on the species, growth conditions, and extraction methods [Safi et al., 2014; Gouveia et al., 2006].

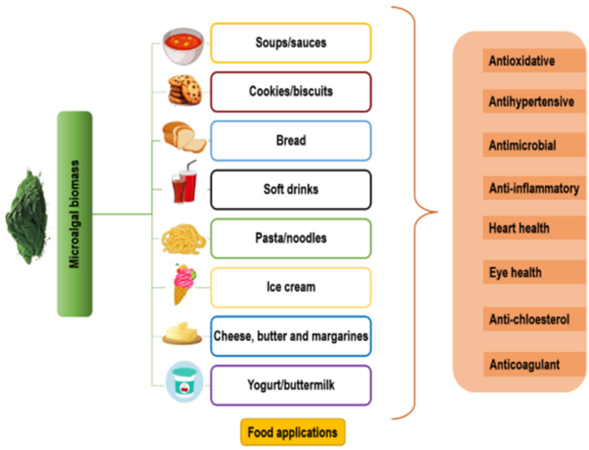

Fig: 2 Nutritional composition of Chlorella vulgaris (Martínez-Ruiz, F. E., Andrade-Bustamante, G., Holguín-Peña, R. J., Renganathan, P., Gaysina, L. A., Sukhanova, N. V., & Puente, E. O. R. (2025). Microalgae as Functional Food Ingredients: Nutritional Benefits, Challenges, and Regulatory Considerations for Safe Consumption. *Biomass*, *5*(2), 25.)

Bioactive compounds and health benefits

The bioactive compounds in microalgae exhibit their multifunctional therapeutic potentials, many of which have been validated in vitro and in vivo, eventhough human clinical trails and evidence are still developing.

Microalgae contains antioxidant molecules like carotenoids, chlorophylls, polyphenols, vitamins C and E, and bioactive peptides. These compounds combine with Reactive oxygen species (ROS), reducing oxidative stress implicated in aging, cancer, cardiovascular diseases, and neurodegeneration.

Spirulina and *Chlorella* extracts have demonstrated strong antioxidant activity in DPPH and ABTS radical combining assays. Antioxidant activities also protects host cells against oxidative damage and improve their immune functions.

Polysaccharides and lipids isolated, modify and regulate inflammatory pathways by downregulating pro-inflammatory cytokines [Wali et al., 2021; Sathasivam et al., 2019]. Animal trial studies show that microalgal supplementation reduces the markers of chronic inflammation and support its potential use in inflammatory disorders [Barghchi et al., 2023; Abdel-Aziem et al., 2018]. Phycobiliproteins and carotenoids contribute to anti-inflammatory effects, enhancing their potential in managing diseases linked with chronic inflammation [Kargın & Bilgüven, 2022; Gouveia et al., 2006].

Microalgal metabolites that include sulphated polysaccharides, phenolic compounds, and bioactive peptides inhibit pathogenic bacteria, fungi, and viruses [Hussein et al., 2018; Sathasivam et al., 2019]. For example, Chlorella sulphated polysaccharides show antiviral activity against enveloped viruses by interfering with viral entry and replication [Wali et al., 2021]. The antimicrobial properties support the microalgal applications as natural preservatives in food and as adjuncts in health promotion [Hussein et al., 2018; Çelekli et al., 2024].

"Table :2 Bioactive compounds and its functions"

Bioactive Compounds	Functions
Chlorophyll	Powerful antioxidant with detoxifying properties; supports liver function, wound healing, and immune health.
Carotenoids	Includes β-carotene, lutein, and zeaxanthin; protect cells from oxidative stress, support eye health, and reduce inflammation.
Polysaccharides	Exhibit immunomodulatory, antiviral, anticoagulant, and anti-inflammatory effects; support gut health through prebiotic activity.
Phenolic compounds	Act as antioxidants, scavenging free radicals and reducing oxidative damage and inflammation.
Polyunsaturated fatty acids (PUFA)	Contain omega-3 and omega-6 fatty acids that help reduce inflammation, support cardiovascular and neural health.
Proteins & peptides	High-quality proteins with essential amino acids; peptides exert antioxidant, antihypertensive, and anti-inflammatory effects.
Vitamins (A, B-complex C, E, K)	Support metabolic processes, antioxidant defense, immune function, and cellular health.
Minerals (iron, magnesium, calcium, zinc)	Aid enzymatic functions, bone health, oxygen transport, and immune regulation.

Applications in functional food formulation

Microalgae, particularly species like *Chlorella*, *Spirulina*, *Nannochloropsis*, and *Haematococcus*, have gained significant traction as functional food ingredients due to their rich nutritional profiles and bioactive compounds.

Microalgae in beverages, snacks, supplements, and dairy alternatives

Microalgae proteins, pigments, and polysaccharides are incorporated into different types of food cominations for nutritional fortification and functional enhancement [Qazi et al., 2021; Csatlos et al., 2023]. Some of these include; Beverages: Microalgal powders enrich smoothies, juices, and plant-based milk alternatives, improving protein content, antioxidant capacity, and food colour [Csatlos et al., 2023]; Snacks and Baked Goods: Microalgae improve nutritional value and provide natural colours and flavours [Ali et al., 2025; Gouveia et al., 2007]; Dietary Supplements: Concentrated form of microalgae like Chlorella and Spirulina tablets or capsules provide concentrated sources of vitamins, minerals, PUFAs, and bioactive peptides [Bito et al., 2020; Rani et al., 2018]; Dairy Alternatives: Microalgal proteins enhance plant-based yogurts, cheese, and ice creams, contributing to texture, emulsification, and nutritional value [Hernández et al., 2022; Muela et al., 2024]. Recent advances in protein extraction methods have improved the solubility and emulsifying properties of microalgal proteins, enabling their use in 3D-printed foods and novel formulations [Giura et al., 2024]. Microalgal biomass can also replace partial animal protein, aligning with sustainable and plant-forward consumer trends [Martínez-Ruiz et al., 2025].

Role in improving food shelf life and sensory properties

Microalgae derived antioxidants like carotenoids, phenolics help retard lipid oxidation and microbial spoilage, which extend the shelf life of foods [Gouveia et al., 2006; Çelekli et al., 2024]. Their antimicrobial properties contribute to natural food preservation [Hussein et al., 2018]. Sensory impacts of microalgae often include green coloration and marine/floral notes, requiring sensory optimization strategies. Formulation efforts of microalgae balance desirable nutritional and functional outcomes with consumer acceptance through flavour masking, appropriate dosing, and hybrid ingredient combinations [Dündar et al., 2023; Baune et al., 2024].

Microalgal polysaccharides serve as prebiotics, stimulating beneficial gut microbiota and enhancing probiotic viability in fermented foods [Sathasivam et al., 2019]. Such combinations amplify immune and gut health regulations [Wali et al., 2021]. Integration of microalgae in probiotic dairy products like yogurt improves probiotic survival and antioxidant activity, creating synergistic functional foods promising for gastrointestinal health [Csatlos et al., 2023]. Additionally, microalgal fibers and oligosaccharides in functional food products like beverages and snacks provide prebiotic dietary fiber, further improving gut microbiota diversity [Sathasivam et al., 2019].

Safety, regulatory aspects and consumer acceptance

Microalgae-based functional foods must be safe to consume, meaning they are free from harmful substances and do not cause any health issues. This safety standard is ensured through government rules and approvals, which regulate how these foods are produced, tested, labeled, and sold to protect consumers. Consumer acceptance of the product depends on people's willingness to try and regularly use microalgae infused foods, which is influenced by factors like taste, appearance, health benefits, price, and trust in the safety and quality guaranteed by regulations [Martínez-Ruiz et al., 2025; Çelekli et al., 2024].

GRAS Status and toxicological concerns

Several microalgal species, including Chlorella vulgaris and Spirulina platensis, hold Generally Recognized as Safe (GRAS) status by regulatory agencies such as the U.S. FDA and EFSA in Europe [Bito et al., 2020; Martínez-Ruiz et al., 2025]. Safety evaluations continue regarding contaminations of heavy metals, microcystins and endotoxins, which can accumulate depending on culture conditions [Martínez-Ruiz et al., 2025]. Toxicological studies indicate low allergenicity and safety at typical dietary exposure levels, but quality controls and standardized cultivation are important to ensure consumer safety [Bito et al., 2020].

Regulatory Frameworks which include: USA (FDA): Microalgal biomass and their specific extracts are regulated under food additive, dietary supplement, or novel food provisions. GRAS notifications have been granted for multiple species or products [Bito et al., 2020]; Europe (EFSA): Microalgae incorporated functional foods fall under Novel Food Regulations requiring pre-market safety assessments. EFSA has approved Chlorella vulgaris and Spirulina as novel foods after proper safety evaluations [Martínez-Ruiz et al., 2025]; India (FSSAI): Microalgal biomass and their extracts fall under nutraceutical and food additive regulations, with recent guidelines encouraging sustainable protein sources in the food sector [Rani et al., 2018]. Regulatory aspects and clarity regarding authorized species, health claims, labelling, and contamination factors remain evolving. Compliance with Good Manufacturing Practices (GMP) and risk assessments is vital for market access [Martínez-Ruiz et al., 2025]

Despite the health benefits, consumer acceptance is challenged by; Sensory Attributes: The distinct colour (often green) and flavour profiles sometimes perceived as off-putting (fishy or seaweed-like) [Dündar et al., 2023; Baune et al., 2024]; Novelty and Awareness: Limited consumer knowledge requires education and marketing to build trust and desirability [Çelekli et al., 2024]; Price and Availability: Production costs remain high compared to conventional ingredients, scalability and cost reduction remain as priorities [Dragone, 2022; Singh & Gu, 2010]. Industry trends reveal growing interest among health-conscious and environmentally aware consumers in plant-based, sustainable functional foods, presenting market opportunities. Innovative product formats combining microalgae with other familiar ingredients help improve acceptance [Giura et al., 2024].

Some of the further key challenges in safety and consumer acceptance of microalgae functional foods include: Species Diversity and Biomass Variability in which The widespread variety of microalgal species and variations in their biomass composition due to cultivation conditions create difficulties in standardizing products for safety and efficacy [Safi et al., 2014]; Safety Concerns Regarding Contaminants which can accumulate heavy metals, toxins and microbial contaminants depending on growth environment. There is need for safety evaluations including toxicology to ensure safe consumption levels [Martínez-Ruiz et al., 2025]; Lack of Comprehensive Bioavailability and Safety Data where bioactive compounds from microalgae show promising health benefits, conclusive human clinical evidence on bioavailability, efficacy and safety is often lacking [Bito et al., 2020]; Unpleasant Sensory Properties like "fishy" odour, green colour pigments, and strong flavours of microalgae biomass can be undesirable, negatively impacting product appearance and acceptance [Dündar et al., 2023]; Challenges in Processing and Extraction where inefficient or harsh processing techniques can alter functional structures of bioactive compounds, reducing their activity and safety profiles [Tang et al., 2020]; Regulatory Uncertainties for variabilities in regulatory approvals across countries, including Novel Food authorizations, and lack of harmonized guidelines for microalgal products can limit market entry and consumer trust [Martínez-Ruiz et al., 2025]; Consumer Awareness and Perception where limited knowledge on microalgae benefits and concerns about novel foods can hinder willingness to try or adopt microalgae-based products. Unusual sensory characteristics and price points pose barriers [Çelekli et al., 2024]; Cost and Scalability where high production and processing costs often make these products more expensive than conventional foods, affecting consumer adaptation [Dragone, 2022]. These challenges increase the nessecity of ongoing research, improved cultivation and processing technologies, safety testing, sensory optimization, clear regulations, and consumer education to facilitate wider acceptance and safe use of microalgae in functional foods [Martínez-Ruiz et al., 2025; Bito et al., 2020].

II. Future Perspective

Recent advances in the incorporation of microalgae in functional food development include genetic engineering to enhance nutrient content and bioactive production, improved cultivation and processing technologies for higher yields and quality, and integration with circular economy models to promote sustainability of the products [Tang et al., 2020; Dragone, 2022]. Future perspectives focus on personalized nutritional value, where microalgae-based products are engineered to individual health needs using omics and AI, and on their potential to contribute to global food security through sustainable production [Martínez-Ruiz et al., 2025]. Challenges remain the same in scaling up, regulatory approval, consumer acceptance, and ensuring long-term safety, but ongoing innovations in microalgae as a key ingredient for healthier, sustainable diets [Çelekli et al., 2024; Bito et al., 2020].

The recent breakthroughs in genetic engineering and synthetic biology enhance microalgae's nutritional and functional properties [Tang et al., 2020]. Scientists are using gene-editing tools such as CRISPR/Cas9 to precisely modify genes involved in the biosynthesis of valuable compounds like essential amino acids, omega-3 fatty acids (EPA and DHA), pigments and antioxidants [Kumaran et al., 2023]. Metabolic engineering facilitates the re-mapping of the biochemical pathways to increase the yield and concentration of these bioactives [Dragone, 2022]. This allows tailoring of microalgae to produce higher-quality biomass with improved flavour, digestibility, and health-promoting components. Some Engineered strains can grow faster and tolerate environmental stresses, increasing biomass productivity and reducing production costs [Coronado-Reyes et al., 2020]. Efforts also focus on minimizing undesirable compounds and toxins to improve safety. However, genetically modified microalgae face regulatory issues and public acceptance challenges that contains risk assessment and communication [Martínez-Ruiz et al., 2025].

Microalgae biomass cultivation aligns well with the principles of a circular economy, which seeks to minimize waste and optimize the resource use in food systems as microalgae can grow on non-arable land using brackish or wastewater, which reduces the use of freshwater and farmland [Wang et al., 2016; Chew et al., 2018]. Waste carbon dioxide from industries can be supplied to algal cultures, helping mitigate greenhouse gases and closing carbon loops [Wang et al., 2016]. Nutrients like nitrogen and phosphorus are the often pollutants in wastewater which can be recovered by algae, decreasing environmental contamination [Chew et al., 2018; Mayhead et al., 2018]. By combining microalgae production with other industries such as biofuel, agriculture and aquaculture integrate biorefineries by maximizing the use of biomass and byproducts [Singh & Gu, 2010; Wilkie et al., 2014]. Such sustainable systems contribute to the climate change mitigation, resource efficiency, and resilient food supply chains [Dragone, 2022].

Advances in nutritional science, genomics, and data analytics facilitates the emergence of personalized nutrition and dietary approaches to an individual's genetics, lifestyle, and health status [Martínez-Ruiz et al., 2025]. Microalgae-based ingredients can be customized to deliver specific nutrients or bio-actives that address the health goals such as cardiovascular support, cognitive enhancement and immune modulation [Barghchi et al., 2023]. Omics technologies such as genomics, metabolomics, proteomics are combined with artificial intelligence which enable detailed understanding of nutrient–gene interactions and metabolic responses [Bito et al., 2020]. Functional foods containing optimized microalgae strains or their extracts may be formulated to support the individual micronutrient deficiencies or particular chronic conditions. Personalized nutritional value in microalgae could improve diet adherence, efficacy of health interventions, and consumer engagement. Their challenges include establishing their clinical evidence, regulatory clarity, and scalable production of personalized products [Martínez-Ruiz et al., 2025].

III. Discussion

On further discussion Microalgae have emerged as a valuable and versatile resource in the development of functional foods due to their exceptional nutritional composition value and widespread spectrum of bioactive compounds [Safi et al., 2014; Ampofo & Abbey, 2022]. Predominantly, species like Chlorella and Spirulina have gained prominence because of their high protein content, balanced essential amino acids, and rich profiles of polyunsaturated fatty acids (especially omega-3 EPA and DHA), vitamins, minerals, and pigments such as chlorophyll and carotenoids [Bito et al., 2020; Safi et al., 2014]. These nutrients contribute to basic nutrition and also deliver significant health benefits, including antioxidant, anti-inflammatory, antimicrobial, antifungal, antiviral, and anticancer activities [Wali et al., 2021; Barghchi et al., 2023; Hussein et al., 2018].

The adaptability of microalgae to different methods of culture systems—from open ponds to advanced photobioreactors—combined with innovative harvesting and processing techniques, allows large-scale production with preserved bioactivity [Dragone, 2022; Safi et al., 2014]. Incorporation of microalgae into a variety of food products, including beverages, dairy alternatives, snacks, and baked goods, enriches their nutritional quality and functional properties without considerably compromising sensory attributes when properly formulated [Ali et al., 2025; Csatlos et al., 2023; Dündar et al., 2023]. Additionally, microalgae-derived compounds support food preservation by extending shelf life due to their antioxidative and antimicrobial potentials [Gouveia et al., 2006; Hussein et al., 2018].

Growing environmental concerns and need for sustainable food sources have directed attention to microalgae as eco-friendly options. Their ability to utilize non-arable land, freshwater-efficient cultivation, and capacity for waste CO2 and nutrient recycling fit well within circular economy models, emphasizing sustainability alongside nutrition [Wang et al., 2016; Chew et al., 2018].

Despite these promising attributes, challenges persist. The unique sensory profile of microalgae—characterized by their green color and marine-like flavor—poses limitations to consumer acceptance [Dündar et al., 2023; Baune et al., 2024]. Variability in biomass composition and potential contamination with heavy metals or toxins require stringent quality control and standardized regulatory frameworks [Martínez-Ruiz et al., 2025]. Moreover, the production costs remain high, influencing commercial availability and market penetration [Dragone, 2022; Singh & Gu, 2010].

Ongoing research continue to address these challenges, focusing on genetic and metabolic engineering to enhance nutrient yields and improve taste and digestibility [Tang et al., 2020]. Advances in personalized nutrition provide opportunities for microalgae to be tailored for specific health needs, supported by omics technologies and artificial intelligence [Martínez-Ruiz et al., 2025]. Regulatory bodies globally have begun establishing guidelines to ensure safety and consistency, but harmonization remains a work in progress [Bito et al., 2020].

Microalgae are gaining significant attention as transformative ingredient in functional foods due to their exceptional nutrient content and diverse bioactive compounds, which support overall health and help mitigate chronic diseases [Ampofo & Abbey, 2022; Barghchi et al., 2023]. They are rich sources of high-quality proteins, essential fatty acids such as omega-3, antioxidants, vitamins, and minerals, making them highly valuable for improving human nutrition [Safi et al., 2014; Bito et al., 2020]. Moreover, microalgae cultivation is sustainable, requiring minimal land and water resources. Their ability to grow in diverse environments and integrate within circular economy models reduces environmental impact and addresses urgent global challenges like food security and climate change [Wang et al., 2016; Dragone, 2022].

Looking ahead, the development of microalgae-based functional foods is driven by technological innovations such as genetic editing and metabolic engineering. These tools allow the creation of optimized microalgal strains with enhanced nutrient profiles, higher biomass yields, and improved taste and texture, which are critical for consumer acceptance [Tang et al., 2020; Coronado-Reyes et al., 2020]. Furthermore, the emerging field of personalized nutrition presents exciting opportunities for microalgae, enabling the design of tailored food products that meet individual health requirements by leveraging advances in genomics, metabolomics, and artificial intelligence [Martínez-Ruiz et al., 2025].

By investing in research, product innovation, sensory optimization, and consumer education, these barriers can be overcomed [Çelekli et al., 2024]. With these efforts, microalgae can become a core component of next-generation functional foods, contributing to healthier diets, more sustainable food systems, and improved global public health. Their multifunctional, natural, and sustainable characteristics offer immense potential to revolutionize food and nutrition, making them key players in the future of food security and health promotion worldwide [Bito et al., 2020; Martínez-Ruiz et al., 2025].

References

[1]. Abdel-Aziem, S. H., Abd El-Kader, H. A., Ibrahim, F. M., & Sharaf, H. A. Evaluation Of The Alleviative Role Of Chlorella Vulgaris And Spirulina Platensis Extract Against Ovarian Dysfunctions Induced By Monosodium Glutamate In Mice. Journal Of Genetic Engineering And Biotechnology, 16(2), 2018, 653-660.

[2]. Ali, R. F., El-Anany, A., Almujaydil, M. S., Algheshairy, R. M., Alhomaid, R. M., & Alharbi, H. F. Nutritional Characteristics And Sensory Aspects Of Pan Bread Fortified With Different Quantities Of Chlorella Vulgaris Powder. Food Chemistry Advances, 6, 2025, 100940.

[3]. Ampofo, J., & Abbey, L. Microalgae: Bioactive Composition, Health Benefits, Safety And Prospects As Potential High-Value Ingredients For The Functional Food Industry. Foods, 11(12), 2022, 1744.

[4]. Arsiya, F., Sayadi, M. H., & Sobhani, S. Green Synthesis Of Palladium Nanoparticles Using Chlorella Vulgaris. Materials Letters, 186, 2017, 113-115.

[5]. Barghchi, H., Dehnavi, Z., Nattagh-Eshtivani, E., Alwaily, E. R., Almulla, A. F., Kareem, A. K., ... & Pahlavani, N. The Effects Of Chlorella Vulgaris On Cardiovascular Risk Factors: A Comprehensive Review On Putative Molecular Mechanisms. Biomedicine & Pharmacotherapy, 162, 2023, 114624.

[6]. Baune, M. C., Lickert, T., Schilling, F., Bindrich, U., Tomasevic, I., Heinz, V., ... & Terjung, N. Impact Of Four Different Chlorella Vulgaris Strains On The Properties Of Durum Wheat Semolina Pasta. Applied Sciences, 14(19), 2024, 8760.

[7]. Bito, T., Okumura, E., Fujishima, M., & Watanabe, F. Potential Of Chlorella As A Dietary Supplement To Promote Human Health. Nutrients, 12(9), 2020, 2524.

[8]. Blair, M. F., Kokabian, B., & Gude, V. G. Light And Growth Medium Effect On Chlorella Vulgaris Biomass Production. Journal Of Environmental Chemical Engineering, 2(1), 2014, 665-674.

[9]. Boukid, F., Comaposada, J., Ribas-Agustí, A., & Castellari, M. Development Of High-Protein Vegetable Creams By Using Single-Cell Ingredients From Some Microalgae Species. Foods, 10(11), 2021, 2550.

[10]. Candido, C., & Lombardi, A. T. The Physiology Of Chlorella Vulgaris Grown In Conventional And Biodigested Treated Vinasses. Algal Research, 30, 2018, 79-85.

[11]. Çelekli, A., Özbal, B., & Bozkurt, H. Challenges In Functional Food Products With The Incorporation Of Some Microalgae. Foods, 13(5), 2024, 725.

[12]. Chew, K. W., Chia, S. R., Show, P. L., Ling, T. C., Arya, S. S., & Chang, J. S. Food Waste Compost As An Organic Nutrient Source For The Cultivation Of Chlorella Vulgaris. Bioresource Technology, 267, 2018, 356-362.

[13]. Church, J., Hwang, J. H., Kim, K. T., Mclean, R., Oh, Y. K., Nam, B., ... & Lee, W. H. Effect Of Salt Type And Concentration On The Growth And Lipid Content Of Chlorella Vulgaris In Synthetic Saline Wastewater For Biofuel Production. Bioresource Technology, 243, 2017, 147-153.

[14]. Coronado-Reyes, J. A., Salazar-Torres, J. A., Juarez-Campos, B., & Gonzalez-Hernandez, J. C. Chlorella Vulgaris, A Microalgae Important To Be Used In Biotechnology: A Review. Food Science And Technology, 42, 2020, E37320.

[15]. Csatlos, N. I., Simon, E., Teleky, B. E., Szabo, K., Diaconeasa, Z. M., Vodnar, D. C., ... & Pop, O. L. Development Of A Fermented Beverage With Chlorella Vulgaris Powder On Soybean-Based Fermented Beverage. Biomolecules, 13(2), 2023, 245.

[16]. Darienko, T., Gustavs, L., Eggert, A., Wolf, W., & Proeschold, T. Evaluating The Species Boundaries Of Green Microalgae (Coccomyxa, Trebouxiophyceae, Chlorophyta) Using Integrative Taxonomy And DNA Barcoding With Further Implications For The Species Identification In Environmental Samples. Plos One, 10(6), 2015, E0127838.

[17]. Dragone, G. Challenges And Opportunities To Increase Economic Feasibility And Sustainability Of Mixotrophic Cultivation Of Green Microalgae Of The Genus Chlorella. Renewable And Sustainable Energy Reviews, 160, 2022, 112284.

[18]. Dündar, A. N., Şahin, O. I., & Sarıcaoğlu, F. T. Low-Fat Cookies With Chlorella Vulgaris: Effects On Dough Rheology, Physical, Textural And Sensory Properties Of Cookies. Gıda, 48(3), 2023, 526-544.

[19]. Fradique, M., Batista, A. P., Nunes, M. C., Gouveia, L., Bandarra, N. M., & Raymundo, A. Incorporation Of Chlorella Vulgaris And Spirulina Maxima Biomass In Pasta Products. Part 1: Preparation And Evaluation. Journal Of The Science Of Food And Agriculture, 90(10), 2010, 1656-1664.

[20]. Gharib, F. A. E. L., Osama, K., Sattar, A. M. A. E., & Ahmed, E. Z. Impact Of Chlorella Vulgaris, Nannochloropsis Salina, And Arthrospira Platensis As Bio-Stimulants On Common Bean Plant Growth, Yield And Antioxidant Capacity. Scientific Reports, 14(1), 2024, 1398.

[21]. Giura, L., Urtasun, L., Ansorena, D., Astiasaran, I., & Raymundo, A. Printable Formulations Of Protein And Chlorella Vulgaris Enriched Vegetable Puree For Dysphagia Diet. Algal Research, 79, 2024, 103447.

[22]. Gouveia, L., Batista, A. P., Miranda, A., Empis, J., & Raymundo, A. Chlorella Vulgaris Biomass Used As Colouring Source In Traditional Butter Cookies. Innovative Food Science & Emerging Technologies, 8(3), 2007, 433-436.

[23]. Gouveia, L., Raymundo, A., Batista, A. P., Sousa, I., & Empis, J. Chlorella Vulgaris And Haematococcus Pluvialis Biomass As Colouring And Antioxidant In Food Emulsions. European Food Research And Technology, 222(3), 2006, 362-367

[24]. Hernández, H., Nunes, M. C., Prista, C., & Raymundo, A. Innovative And Healthier Dairy Products Through The Addition Of Microalgae: A Review. Foods, 11(5), 2022, 755.

[25]. Hussein, H. J., Naji, S. S., & Al-Khafaji, N. M. S. Antibacterial Properties Of The Chlorella Vulgaris Isolated From Polluted Water In Iraq. Journal Of Pharmaceutical Sciences And Research, 10(10), 2018, 2457-2460.

[26]. Hussein, M. H., Abdullah, A. M., Badr El-Din, N. I., & Mishaqa, E. S. I. Biosorption Potential Of The Microchlorophyte Chlorella Vulgaris For Some Pesticides. Journal Of Fertilizers & Pesticides, 8(1), 2017, 1000177.

[27]. Jibri, S. M., Jakada, B. H., Umar, H. Y., & Ahmad, T. A. Q. Importance Of Some Algal Species As A Source Of Food And Supplement. International Journal Of Current Microbiology And Applied Sciences, 5(5), 2016, 186-193.

[28]. Kargın, H., & Bilgüven, M. Microalgae—Macroalgae Based Nutraceuticals And Their Benefits. Current Trends In Natural Sciences, 11, 2022, 232-246.

[29]. Kumaran, M., Palanisamy, K. M., Bhuyar, P., Maniam, G. P., Rahim, M. H. A., & Govindan, N. Agriculture Of Microalgae Chlorella Vulgaris For Polyunsaturated Fatty Acids (Pufas) Production Employing Palm Oil Mill Effluents (POME) For Future Food, Wastewater, And Energy Nexus. Energy Nexus, 9, 2023, 100169.

[30]. Li, J., Wang, Y., Fan, Z., Tang, P., Wu, M., Xiao, H., & Zeng, Z. Toxicity Of Tetracycline And Metronidazole In Chlorella Pyrenoidosa. International Journal Of Environmental Research And Public Health, 20(4), 2023, 3623.

[31]. Liang, Y., Sarkany, N., & Cui, Y. Biomass And Lipid Productivities Of Chlorella Vulgaris Under Autotrophic, Heterotrophic And Mixotrophic Growth Conditions. Biotechnology Letters, 31(7), 2009, 1043-1049.

[32]. Martínez-Ruiz, F. E., Andrade-Bustamante, G., Holguín-Peña, R. J., Renganathan, P., Gaysina, L. A., Sukhanova, N. V., & Puente, E. O. R. Microalgae As Functional Food Ingredients: Nutritional Benefits, Challenges, And Regulatory Considerations For Safe Consumption. Biomass, 5(2), 2025, 25.

[33]. Mayhead, E., Silkina, A., Llewellyn, C. A., & Fuentes-Grünewald, C. Comparing Nutrient Removal From Membrane Filtered And Unfiltered Domestic Wastewater Using Chlorella Vulgaris. Biology, 7(1), 2018, 12.

[34]. Mendes, A. R., Spínola, M. P., Lordelo, M., & Prates, J. A. Chemical Compounds, Bioactivities, And Applications Of Chlorella Vulgaris In Food, Feed And Medicine. Applied Sciences, 14(23), 2024, 10810.

[35]. Muela, T., Abellán, A., Bande-De León, C., Gómez, P., & Gil, M. D. Effect Of Macro And Microalgae Addition On Nutritional, Physicochemical, Sensorial, And Functional Properties Of A Vegetable Cream. Foods, 13(11), 2024, 1651.

[36]. Qazi, W. M., Ballance, S., Kousoulaki, K., Uhlen, A. K., Kleinegris, D. M., Skjånes, K., & Rieder, A. Protein Enrichment Of Wheat Bread With Microalgae: Microchloropsis Gaditana, Tetraselmis Chui And Chlorella Vulgaris. Foods, 10(12), 2021, 3078.

[37]. Rani, K., Sandal, N., & Sahoo, P. K. A Comprehensive Review On Chlorella—Its Composition, Health Benefits, Market And Regulatory Scenario. The Pharma Innovation Journal, 7(7), 2018, 584-589.

[38]. Romero, N., Visentini, F. F., Márquez, V. E., Santiago, L. G., Castro, G. R., & Gagneten, A. M. Physiological And Morphological Responses Of Green Microalgae Chlorella Vulgaris To Silver Nanoparticles. Environmental Research, 189, 2020, 109857.

[39]. Safi, C., Zebib, B., Merah, O., Pontalier, P. Y., & Vaca-Garcia, C. Morphology, Composition, Production, Processing And Applications Of Chlorella Vulgaris: A Review. Renewable And Sustainable Energy Reviews, 35, 2014, 265-278.

[40]. Sathasivam, R., Radhakrishnan, R., Hashem, A., & Abd_Allah, E. F. Microalgae Metabolites: A Rich Source For Food And Medicine. Saudi Journal Of Biological Sciences, 26(4), 2019, 709-722.

[41]. Sharma, A., & Sharma, V. A Review On Chlorella Vulgaris: A Versatile Microalga. International Journal Of Chemical Studies, 7(3), 2019, 982-987.

[42]. Singh, A., Singh, D., & Chandra, R. Cost-Effective Production Of Biohydrogen From Paper Industry Wastewater Using A Green Alga, Chlorella Vulgaris MMM01. International Journal Of Hydrogen Energy, 39(14), 2014, 7660-7668.

[43]. Singh, J., & Gu, S. Commercialization Potential Of Microalgae For Biofuels Production. Renewable And Sustainable Energy Reviews, 14(9), 2010, 2596-2610.

[44]. Singh, S., Kate, B. N., & Banerjee, U. C. Bioactive Compounds From Cyanobacteria And Microalgae: An Overview. Critical Reviews In Biotechnology, 25(3), 2005, 73-95.

[45]. Tang, D. Y. Y., Khoo, K. S., Chew, K. W., Tao, Y., Ho, S. H., & Show, P. L. Potential Utilization Of Bioproducts From Microalgae For The Quality Enhancement Of Natural Products. Bioresource Technology, 304, 2020, 122997.

[46]. Udayan, A., Arumugam, M., & Pandey, A. Nutraceuticals From Algae And Cyanobacteria. In: Algal Green Chemistry. Elsevier, 2017, 65-89.

[47]. Wali, A. F., Al Dhaheri, Y., Pillai, J. R., Mushtaq, A., Rao, P. G., Rabbani, S. A., & Firdous, A. Chlorella Vulgaris: A Multipurpose Microalga With Medicinal Applications. Journal Of Food Biochemistry, 45(1), 2021, E13546.

[48]. Wang, Y., Ho, S. H., Cheng, C. L., Guo, W. Q., Nagarajan, D., Ren, N. Q., & Chang, J. S. Perspectives On The Feasibility Of Using Microalgae For Industrial Wastewater Treatment. Bioresource Technology, 222, 2016, 485-497.

[49]. Wilkie, A. C., Edmundson, S. J., & Duncan, J. G. Indigenous Microalgae Bloom To Harvest: Biofertilizer Production For Sustainable Nutrient Management. Biomass And Bioenergy, 68, 2014, 33-42.

[50]. Willette, S., Jones-Baumgardt, C., & Mackinnon, S. L. Effect Of Carbon Dioxide And Light On Biomass And Biocompound Production In Chlorella Vulgaris. Journal Of Applied Phycology, 34(3), 2022, 1227-1238.

[51]. Yaakob, Z., Ali, E., Zainal, A., Mohamad, M., & Takriff, M. S. An Overview: Biomolecules From Microalgae For Animal Feed And Aquaculture. Journal Of Biological Research-Thessaloniki, 21(1), 2014, 1-10.