INFORMATICS JOURNALS

Review Article

Journal of Natural Remedies
DOI: 10.18311/jnr/2026/50362

eISSN: 2320-3358 | Vol 26(5), 2026 | pp. 1109-1120

Nature's Superfood: A Comprehensive Study on the Role of Spirulina in Elderly Nutrition

C. Nisha Lakshmi and S. Parameshwari*

Department of Nutrition and Dietetics, Periyar University, Salem - 636011, Tamil Nadu, India;
parameshwari@periyaruniversity.ac.in

Abstract

As worldwide lifestyles expectancy rises, advancing elderly well-being through focused dietary interventions has received scholarly and clinical prominence. Spirulina, a nutrient-rich cyanobacterium, is emerging as a functional food with potential benefits for older adults. The clean-label movement and the popularity of plant-based diets have raised demand for plant-based protein sources. Spirulina (*Arthrospira* spp.) stands proud due to its dense nutrient profile rich in protein, phycocyanin, carotenoids and bioactive compounds. Various research studies have reported its impressive and wholesome nutrient profile with its suitability for human consumption. Scientific trials reported as far as have shown positive effects in its antioxidant, immune system support, Cognitive and Neurological Benefits, Cardiometabolic Regulation, Muscle Mass and energy, and Micronutrient Repletion properties, which can further support healthy ageing in the elderly population. Spirulina-based meals and dietary supplements offer a multi-modal technique to elderly health, addressing cardiovascular risk, oxidative stress, chronic inflammation, neurodegeneration, and cognitive decline.

Major Finding: This comprehensive paper will justify the nutritional and nutraceutical potential of spirulina along with its long-term health benefits in old age populations.

Keywords: Bioactive Compounds, Dietary Supplements, Elderly, Functional Food, Spirulina

(Article Chronicle: Article Received on: 25.06.2025; Revised on: 13.04.2026; Accepted on: 27.04.2026)

1. Introduction

The microscopic algae known as spirulina have been heralded as a superfood because of their remarkable nutritional profile and many health advantages. A photosynthetic cyanobacterium that is a member of the *Microcoleaceae* family, Spirulina is grown in fresh and saltwater throughout Asia, Africa, Europe, North America, and South America due to its high protein content and other nutritional advantages[1]. Spirulina has been used as a food source for centuries. Historically, the *Aztecs* in Mexico harvested it from Lake Texcoco and consumed it in the form of dried cakes called *tecuitlatl*. Similarly, in Africa, the *Kanembu* people around Lake Chad have long used Spirulina, locally known as *dihe*, as a protein-rich dietary component and the microscopic structure of Spirulina is shown in Figure 1. Although interest faded for centuries, Spirulina regained scientific attention in the 20th century due to its exceptional nutritional profile[2].

The 1960s marked the beginning of modern Spirulina research when French scientists observed large quantities being naturally harvested in African alkaline lakes. Subsequent studies promoted it as a promising food for malnourished populations and a potential space food due to its rapid growth, high protein content, and minimal resource requirements[5].

Nowadays, spirulina is cultivated worldwide, including China, India, the USA, Thailand, and Vietnam. China leads global production, contributing to more than 60% of the supply[6]. Spirulina is cultivated by using different techniques such as Open Raceway Ponds, Closed Photobioreactors and Environmental Conditions[7-9]. Spirulina's cultivation supports food security, especially in resource-limited settings, due to its minimal land and water

*Author for correspondence

requirements. Moreover, by-products like phycocyanin are increasingly used in cosmetics, pharmaceuticals, and functional foods, enhancing their commercial value[10].

The rise of plant-based diets and the clean-label movement has, in addition, fuelled the food industry's interest in Spirulina. As more consumers adopt a vegetarian, vegan, or flexitarian life, there is a developing demand for plant-based protein sources[11-14]. Spirulina suits this demand flawlessly because of its high protein content, rich amino acid profile and biochemical composition, which includes an impressive range of macronutrients and micronutrients, making it a powerful supplement for addressing malnutrition and promoting general health[15]. Spirulina flakes and Spirulina powder are also shown in Figure 2.

2. Nutritional Profile of Spirulina

In addition to being one of the highest sources of protein, spirulina also contains other macronutrients,



Figure 1. The appearances of Spirulina dried cakes[3] and the microscopic view of Spirulina[4].

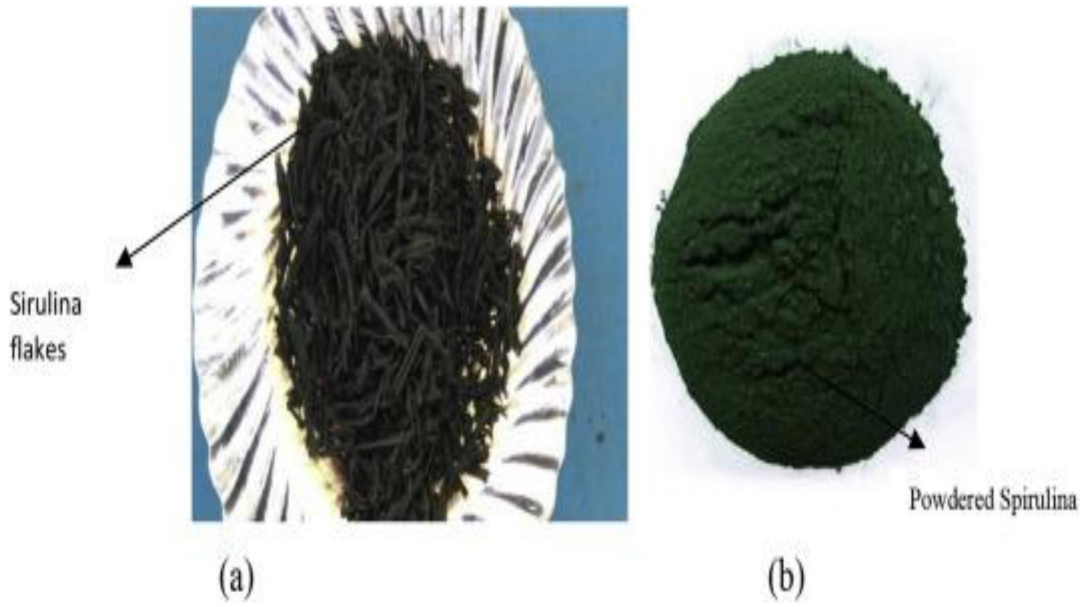


Figure 2. Spirulina flakes and powder[16].

such as fat and carbs. It also contains a variety of minerals, including calcium, iron, zinc, copper, sodium, potassium, and magnesium, as well as vitamins A, B, E, and K. The pigments phycocyanin, chlorophyll, β-carotene, and zeaxanthin, as well as the essential fatty acid γ-linolenic acid, add to its rich nutritional profile[1].

Many elements that are lacking in the diets of most people, including carbohydrates, protein, β-carotene, γ-linolenic acid (GLA), vitamins, minerals, phytonutrients, sulpholipids, glycolipids, and superoxide dismutase, are said to be abundant in spirulina. When added to food products, spirulina creates functional foods with increased nutritional content and a host of health advantages[17]. The nutritional composition of Spirulina is also given in Figure 3.

2.1 Protein Content and Amino Acid Profile

Spirulina is exceptionally rich in protein, accounting for approximately 55% to 70% of its dry weight. It is considered a complete protein, as it contains all essential amino acids, though in varying proportions. While it is slightly deficient in sulfur-containing amino acids such as methionine and cysteine, the overall digestibility and biological value of its protein are high, making it suitable for both vegetarian and non-vegetarian diets[7].

2.2 Lipids and Fatty Acids

The lipid fraction of Spirulina comprises about 5-8% of its dry weight. It is a source of essential fatty acids, particularly Gamma-Linolenic Acid (GLA), which contributes to anti-inflammatory effects. Other fatty acids such as palmitic, oleic, and linoleic acids are also present in appreciable quantities[10].

2.3 Carbohydrates and Dietary Fibre

Spirulina contains around 15-25% carbohydrates. Most of these are complex polysaccharides, which are easily digestible and do not cause spikes in blood glucose levels. It also provides a modest amount of dietary fibre, supporting gut health and aiding digestion[2].

2.4 Vitamins

Spirulina is a rich source of several vitamins, including provitamin A (β-carotene), B-complex vitamins (B1, B2, B3, B6, B9, and B12), and vitamin E. Its vitamin B12 content is often highlighted, although some studies suggest the form present may be pseudovitamin B12, with lower bioavailability in humans[6]. Nonetheless, it contributes significantly to daily micronutrient requirements.

2.5 Mineral Profile

This microalga is a dense source of minerals, such as iron, calcium, magnesium, potassium, phosphorus, and zinc. Notably, the bioavailability of iron in Spirulina is high, which makes it beneficial for individuals with iron-deficiency anemia[7].

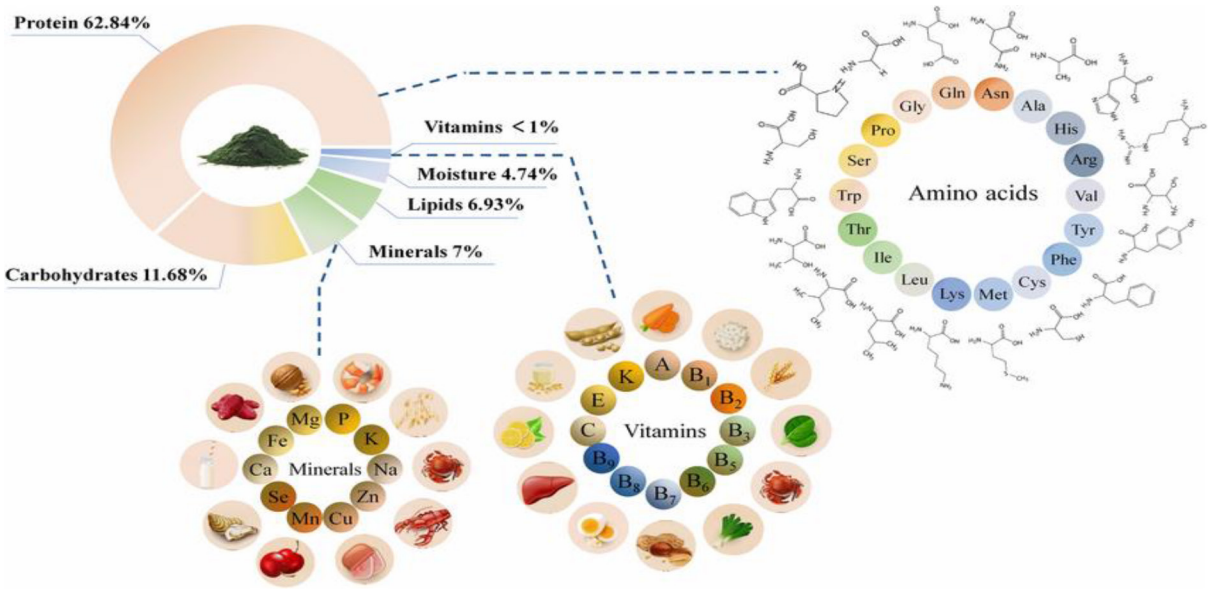


Figure 3. Nutritional composition of Spirulina[18].

2.6 Pigments and Antioxidants

Spirulina owes its bright blue-green colour to a group of pigments with potent antioxidant properties. Phycocyanin, which can make up about 10-15% of its dry weight, is the major pigment responsible for its characteristic hue and is known for its immune-boosting and anti-inflammatory effects. Other pigments include chlorophyll a, β-carotene, zeaxanthin, and allophycocyanin[10].

Hence, spirulina's nutrient profile highlights its excessive protein (55-70% dry weight), essential fatty acids, vitamins, minerals, and pigments like phycocyanin, positioning it as a precious functional meal with extensive applications in nutrition and therapy[5]. An overview of Bortolini *et al.,*[19] also emphasises spirulina's rich array of bioactive components, complete proteins, EFAs, vitamins, minerals, chlorophyll, carotenoids, and phycocyanin, which together contribute to its health-promoting ability[15]. Table 1 also represents the various health-promoting properties of spirulina.

3. Nutraceutical Potential of Spirulina

Spirulina (*Arthrospira platensis*) is a filamentous, blue-green microalga widely recognised for its rich nutritional composition and emerging role as a functional food. Beyond its high-quality protein content, Spirulina is a natural source of bioactive compounds such as phycocyanin, γ-linolenic acid, polyphenols, vitamins, and minerals, all contributing to its diverse nutraceutical benefits[25]. Its antioxidant, anti-inflammatory, immunomodulatory, and lipid-lowering properties make it a promising dietary adjunct for managing chronic diseases such as cardiovascular disorders, diabetes, and neurodegenerative conditions[26,27]. The growing body of evidence supporting its health-promoting effects has positioned Spirulina as a model organism in the development of sustainable nutraceutical products. Hence, the various nutraceutical potential of spirulina is represented in Table 2.

3.1 Antioxidant and Antiinflammatory Effects

Spirulina contains a rich array of antioxidants, especially Cphycocyanin, carotenoids, chlorophyll, vitamin C, and vitamin E, that neutralise free radicals and reduce oxidative stress and inflammation. A 2022 systematic review concluded that Cphycocyanin significantly enhances antioxidant capacity and suppresses proinflammatory biomarkers[28-30]. Spirulina's blue pigment, phycocyanin, has shown strong scavenging

Table 1. Health-promoting properties of Spirulina

S. No.	Study	Year	Type	Sample/scope	Findings	References
1	Karkos *et al.,*	2020	Systematic Review	Review of 35 nutritional intervention studies	Spirulina is a complete protein source, providing vitamins A, K, and E, and is a rich source of carotenoids and phycocyanins with health-promoting properties.	20
2	Abdel-Daim *et al.,*	2021	Systematic Review	Review of over 100 studies	Spirulina is rich in protein (55-70%), essential amino acids, phycocyanin, vitamins (B1, B2, B12), β-carotene, and minerals like iron, calcium, and magnesium.	21
3	Gómez-Téllez *et al.,*	2021	Meta-analysis	Quantitative synthesis from multiple nutritional databases	High micronutrient density; contains calcium (120 mg/100 g), potassium (1363 mg/100 g), and iron (28.5 mg/100 g). Strong antioxidant and anti-inflammatory profile.	22
4	El-Sheekh *et al.,*	2022	Meta-analysis	Analysis of biochemical profiles from 50+ Spirulina strains	High protein (up to 70% DW), contains all essential amino acids, polyunsaturated fatty acids, γ-linolenic acid, and B vitamins; antioxidant-rich.	23
5	Kalafati *et al.,*	2023	Systematic Review and Meta-analysis	Reviewed clinical nutrition trials using Spirulina	Protein quality index above 1.0; high levels of polyphenols, flavonoids, iron bioavailability, and non-heme iron enhancers.	24

properties against free radicals, including peroxyl, hydroxyl, and superoxide anions[31,32].

3.2 Immune Modulation

Studies have shown that Spirulina modulates immune function by stimulating natural killer cell activity, increasing antibody production, and improving overall immune resilience[28,33]. Spirulina capsules have shown efficacy in reducing blood cholesterol levels, reducing white blood cells following chemotherapy and radiation therapy, and enhancing immune function. It may be used as a treatment for illnesses brought on by oxidative stress. Spirulina compounds strengthen the immune system's humoral and cellular components, have anti-allergic effects by promoting IgA antibody and phycocyanin, lower IL4, prevent histamine production, and act as an anti-inflammatory substance. Spirulina also raises the CD4+ count in HIV+ patients and enhances oxidative stress indicators and NK function in healthy individuals[34].

3.3 Cardiovascular Benefits

Research also highlights Spirulina's ability to reduce cardiovascular disease risk factors: it lowers blood pressure, improves lipid profiles (by reducing LDL and triglycerides), and improves endothelial function. These benefits are largely correlated with its antioxidant pigments and polyunsaturated fatty acids[30]. Spirulina's omega-3 fatty acids, fibre, and antioxidants support heart health by reducing triglycerides, LDL cholesterol, and blood pressure. The anti-inflammatory and antioxidant qualities of spirulina help to prevent atherosclerosis and other cardiovascular conditions[31].

3.4 Metabolic Health and Glycemic Control

Spirulina exhibits anti-diabetic potential by enhancing insulin sensitivity and reducing blood glucose levels, as shown in both animal and preliminary human studies[35]. In a randomised controlled study, obese patients with hypertension receiving 2 g/day Spirulina for three months exhibited marked improvement in insulin sensitivity (evaluated by euglycemic clamp technique), reduced waist circumference, LDL cholesterol, and inflammation markers (IL6), alongside improved antioxidant status[36].

3.5 Neurological and Brain Protection

Animal and *in vitro* studies suggest Spirulina offers neuroprotective effects, including improvement in cognitive performance and reduction in neuroinflammation, attributable to its antioxidant and anti-inflammatory compounds[33]. In a 2023 double-blind randomised clinical trial involving elderly Alzheimer's patients, Spirulina supplementation (1 g twice daily for 12 weeks) significantly improved MMSE cognitive scores versus placebo. Concomitant

Table 2. Nutraceutical potential of Spirulina

S. No.	Study	Year	Type	Sample/scope	Findings	References
1	Khan *et al.,*	2021	Systematic Review	Human and animal studies on Spirulina supplementation	Spirulina is rich in phycocyanin, phenolics, flavonoids, and polysaccharides with potent antioxidant, anti-inflammatory, and immunomodulatory activities.	38
2	Gammone and Riccioni	2021	Meta-analysis	Review of Spirulina in disease prevention	Confirmed lipid-lowering, anti-hypertensive, antidiabetic, and immunostimulant activities linked to phycocyanin and essential fatty acids.	39
3	Singh *et al.,*	2022	Meta-analysis	40+ studies on bioactive properties	Demonstrated that Spirulina's nutraceutical effects are due to the synergistic action of pigments (chlorophyll, phycocyanin), vitamins, and trace elements.	40
4	Bahri *et al.,*	2022	Systematic Review	Spirulina-based nutraceuticals in chronic disease models	Effective in improving metabolic markers, reducing oxidative stress, and boosting immunity; suitable as a functional food supplement.	41
5	Lee and Park	2023	Systematic Review	Clinical studies on anti-inflammatory mechanisms	Spirulina suppresses COX-2, IL-6, and TNF-α expression; acts as a nutraceutical anti-inflammatory agent via NF-κB pathway inhibition.	42

reductions in fasting glucose, insulin resistance, and systemic inflammation (hs-CRP) indicate both cognitive and metabolic benefits[37].

4. Ageing and Need for Functional Foods

Ageing is an inevitable process characterised by a gradual decline in organ function and an elevated chance of dying. Over the last century, the common lifespan has extended drastically as enhancements in nutrients and fitness care in most developed countries[43,44]. One promising approach to support healthy ageing is the use of functional foods or dietary components that offer health benefits beyond basic nutrition. These foods play a pivotal role in preventing or managing age-related diseases such as cardiovascular disorders, diabetes, neurodegeneration, and immune dysfunction[45]. Among the various functional foods, Spirulina, a nutrient-dense blue-green microalga, has attracted significant scientific interest due to its rich content of proteins, vitamins, minerals, and bioactive compounds such as phycocyanin and gamma-linolenic acid. Spirulina's antioxidative, anti-inflammatory, immunomodulatory, and neuroprotective properties make it a particularly suitable dietary supplement for elderly individuals seeking to maintain health and independence in ageing[46,47]. Its potential to address common geriatric issues, including oxidative stress, cognitive decline, and immune system weakening, underscores its value as a functional food in geriatric nutrition.

5. The Health Benefits of Spirulina in Ageing

Ageing is frequently observed with an accelerated threat of chronic illnesses, consisting of cancer, cardiovascular and neurodegenerative disorders. In humans, the most promising techniques for improving health and lifespan through lowering the danger of age-associated illnesses include a correct food regimen, everyday workout, secure living and working conditions and pharmacological remedy[48]. Ageing is also characterised by cognitive impairments, wherein mitochondrial dysfunction has been proven to play an important role. It's well mounted that a healthful food plan reduces the danger of developing cognitive decline in aged individuals, stating its ability as a therapeutic. In this regard, antioxidant intake and diet supplementation have been linked to stepped forward cognitive functioning[49]. Spirulina also possess various health-benefiting properties such as antioxidant, immune system support, Cognitive and Neurological Benefits, Cardiometabolic Regulation, Muscle Mass and energy, and Micronutrient Repletion. Furthermore, the health benefits of spirulina in the ageing population are given in Table 3.

5.1 Antioxidant and Anti-inflammatory Properties

Spirulina's antioxidant compounds, especially phycocyanin, help neutralise Reactive Oxygen Species (ROS), which are major contributors to ageing and neurodegeneration[47]. Chronic inflammation, often termed "inflammaging," is also alleviated through Spirulina's bioactives.

5.2 Immune System

Ageing impairs immune responsiveness. Spirulina enhances both innate and adaptive immunity by stimulating cytokine production and natural killer cell activity, offering resistance against infections[50].

5.3 Cognitive and Neurological Benefits

Cognitive decline is a pressing concern in ageing. Spirulina has shown promise in improving memory, reducing oxidative stress in the brain, and protecting against neurodegenerative diseases[51].

5.4 Cardiometabolic Regulation

Elderly individuals often experience glucose dysregulation and lipid imbalances. Spirulina has demonstrated hypoglycemic and lipid-lowering effects, aiding in the prevention of type 2 diabetes and cardiovascular disease[52].

5.5 Muscle Mass and Energy

Protein-rich Spirulina aids in preserving lean body mass, which is essential in combating sarcopenia. Additionally, it boosts energy levels and physical endurance, crucial for maintaining functional independence[53].

5.6 Micronutrient Repletion

Spirulina is rich in bioavailable iron, which is crucial for preventing anaemia, a common issue in the elderly.

Table 3. Health benefits of Spirulina in the ageing population

S. No.	Study	Year	Type	Sample/scope	Findings	References
1	Maurya *et al.,*	2021	Systematic Review	Elderly and age-related disorders	Spirulina shows anti-ageing effects through antioxidative, anti-inflammatory, and immunomodulatory actions; beneficial in reducing frailty, cognitive decline, and inflammation.	54
2	Yadav *et al.,*	2022	Meta-analysis	Older adults with chronic metabolic conditions	Supplementation significantly improved lipid profile, glycemic control, and inflammatory markers (CRP, IL-6), reducing risks of age-associated metabolic syndromes.	55
3	Rahman *et al.,*	2023	Systematic Review	Ageing-related cognitive and neuronal degeneration	Spirulina enhances neurogenesis, protects dopaminergic neurons, and improves memory and motor function in ageing models; linked to reduced oxidative stress in brain tissues.	56
4	Wang *et al.,*	2021	Systematic Review and Meta-analysis	Elderly immunity and nutritional support	Regular spirulina intake boosts immune function (↑ NK cell activity, ↑ immunoglobulins), improves hemoglobin levels and nutrient absorption in ageing individuals.	57
5	Firoz *et al.,*	2022	Systematic Review	Geriatric population with inflammatory and oxidative stress burden	Spirulina reduces markers of inflammation and oxidative damage, increases antioxidant enzymes (SOD, CAT), beneficial in arthritis, neurodegeneration, and fatigue in older adults.	58

It also contains vitamin B12, essential for nerve health and energy metabolism[20].

6. Safety, Dosage, and Tolerability in Geriatric Use

Spirulina has gained recognition as a safe and effective functional food, particularly for elderly populations who often face nutritional deficiencies, chronic inflammation, and immune system weakening. As a natural cyanobacterium rich in proteins, essential fatty acids, vitamins, minerals, and bioactive compounds like phycocyanin and polysaccharides, Spirulina offers diverse therapeutic benefits without significant adverse effects when consumed appropriately[51].

6.1 Safety Profile of Spirulina in Elderly Use

Clinical studies and toxicological assessments have consistently shown that Spirulina is Generally Recognised As Safe (GRAS) when produced under controlled, contaminant-free conditions. Its use in elderly populations has been well tolerated, with no major adverse effects reported at typical supplementation doses[57]. However, safety depends heavily on sourcing; contaminated or non-certified Spirulina may carry risks due to heavy metals or microcystin exposure. Thus, elderly individuals should only consume high-quality Spirulina products from verified manufacturers to avoid potential toxicological concerns[59].

Additionally, Spirulina does not interfere negatively with common medications used by the elderly, such as statins or antidiabetics, but healthcare supervision is recommended during long-term supplementation for those with underlying health conditions.

6.2 Recommended Dosage for Older Adults

Optimal dosage varies depending on health goals, physiological condition, and individual response. For the elderly, a daily intake of 1-5 g of Spirulina have been found effective for general wellness, immune enhancement, and oxidative stress reduction[60]. In clinical studies targeting metabolic disorders and cognitive decline, higher doses of up to 10 grams per day have been used without harmful effects[51].

To minimise gastrointestinal discomfort and ensure tolerability, it is advisable to start with a lower dose (*e.g.*, 1 g/day) and gradually increase it over time. Splitting the total dosage across meals can also improve absorption and reduce any potential bloating or nausea.

6.3 Supplementation Recommendations for the Elderly

i. Start Low, Go Slow: Begin with 1 g/day and gradually increase to 5-10 g/day under professional guidance[51].
ii. Quality Assurance: Only consume Spirulina certified for purity and tested for heavy metals, pesticides, and microcystins[59].
iii. Monitor for Reactions: Although rare, some individuals may experience mild allergic or gastrointestinal responses[57].
iv. Integrate with Diet: Spirulina powder or capsules can be added to smoothies, soups, or juices to enhance nutrient intake[60].
v. Medical Supervision: Elderly individuals with autoimmune disorders or those on anticoagulants should consult a physician before beginning supplementation[61].

Hence, Spirulina supplementation presents a safe and practical option for elderly individuals seeking to enhance immune function, manage metabolic health, and support overall vitality. When consumed in appropriate doses from high-quality sources, Spirulina offers broad-spectrum health benefits with minimal risk, making it an ideal component of functional nutrition strategies for ageing populations.

7. Spirulina Incorporated Food Products

As the ageing population continues to grow, there is an increasing demand for nutrient-dense, functional food products tailored to the unique physiological needs of older adults. Among various natural supplements, Spirulina has gained prominence due to its comprehensive nutritional profile and evidence-based health benefits. It can be consumed either as a standalone supplement (powder, capsules, or tablets) or incorporated into food products such as pasta, bread, smoothies, energy bars, and beverages[62]. The various Spirulina incorporated food products and its role in health and feed industry is given in (Figure 4).

Spirulina-enriched food items offer a convenient and palatable way to increase nutrient intake among older adults, many of whom experience decreased appetite, chewing difficulties, or taste alterations. Products such as spirulina-fortified biscuits, noodles, yogurts, and beverages have been successfully developed and tested for their sensory acceptability and nutritional enhancement[63]. These products are rich in plant-based protein, B-complex vitamins, iron, and bioactive compounds like phycocyanin, which help counter age-related nutritional deficiencies.

Moreover, integrating Spirulina into regular diets through food fortification allows for gradual supplementation, reducing the risk of overdose or gastrointestinal discomfort, which is particularly important in elderly individuals with compromised digestion or polypharmacy concerns[47].

Spirulina in supplement form (capsules or powder) is widely used in clinical settings to manage age-associated conditions. It has shown positive effects in improving immune response, reducing oxidative stress, supporting cognitive function, and regulating blood glucose and lipid levels are critical areas of concern in elderly populations[51].

A randomised trial by El-Magd *et al.,*[60] demonstrated that Spirulina supplementation in aged rats reduced inflammation and metabolic dysfunction, suggesting its potential to mitigate chronic age-related diseases. Additionally, the anti-inflammatory and neuroprotective properties of phycocyanin, a key Spirulina pigment, have been linked to reduced progression of cognitive decline and neurodegeneration in ageing populations[47].

Hence, both Spirulina-based food products and supplements represent accessible and effective strategies to improve the nutritional status and overall health of elderly individuals. Whether consumed as part of a meal or as a supplement, Spirulina contributes to better metabolic, cognitive, and immune health, making it a highly valuable component in functional geriatric nutrition.

8. Clinical and Nutritional Evidence

As the global elderly population continues to rise, the use of functional foods and supplements like Spirulina has gained considerable attention due to its dense nutritional profile and wide-ranging health benefits. Clinically, Spirulina has demonstrated promising effects in enhancing immune responses in older adults. In a study by Belay *et al.,*[64], elderly participants supplemented with Spirulina exhibited significantly increased Natural Killer (NK) cell activity and interleukin-2 levels, suggesting an enhancement in immune function.

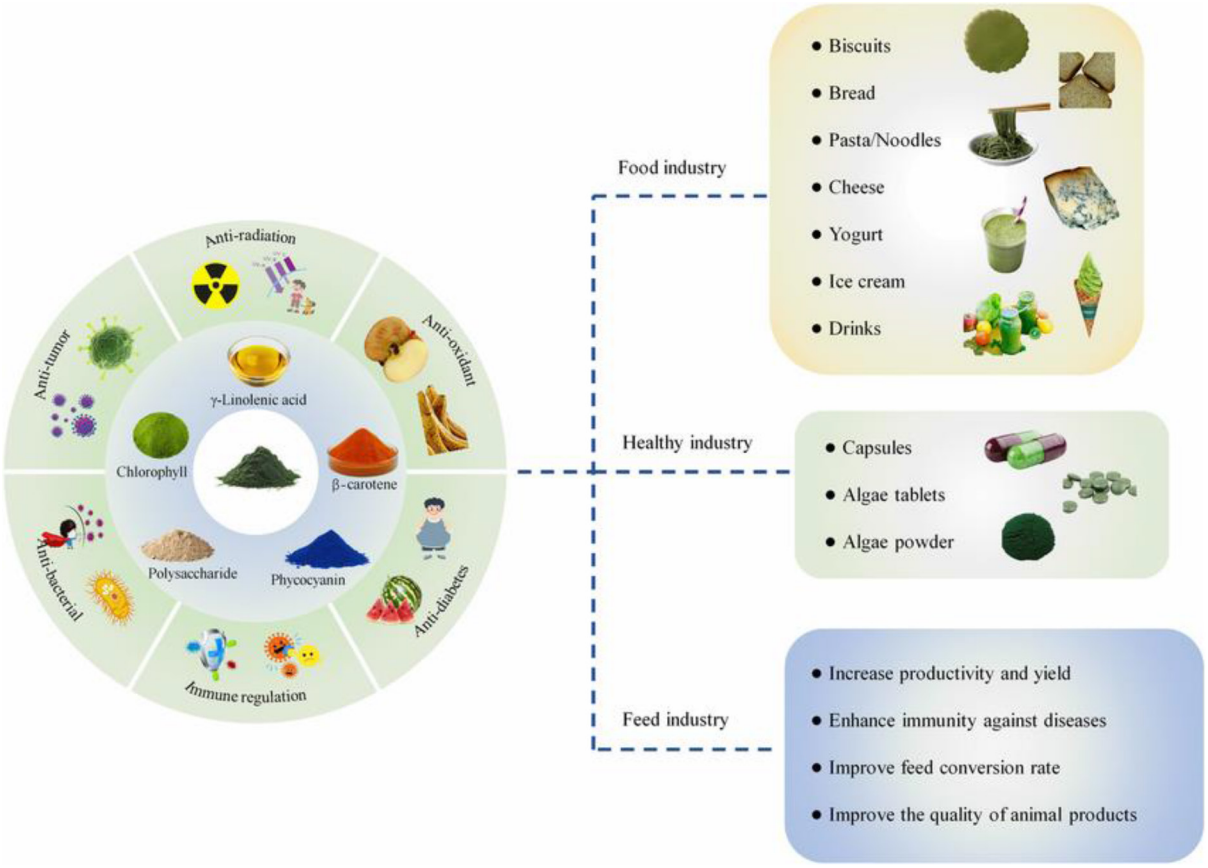


Figure 4. Spirulina incorporated food products and its role in health and feed industry[18].

Similarly, its bioactive compounds, particularly phycocyanin and polysaccharides, have shown anti-inflammatory effects by downregulating pro-inflammatory cytokines such as TNF-α and IL-6, which are elevated during ageing[65]. Spirulina supplementation also supports cognitive health, reported improved memory performance and executive function in elderly individuals with mild cognitive impairment following 12 weeks of Spirulina intake, likely due to its antioxidant action and its role in boosting Brain-Derived Neurotrophic Factor (BDNF)[66].

Moreover, it contributes to metabolic health in ageing populations. Zeinalian *et al.,*[67] observed significant reductions in fasting glucose, LDL cholesterol, and HbA1c among older adults with type 2 diabetes who received Spirulina supplementation. Cardiovascular benefits have also been noted, including improved vascular function and reduced arterial stiffness due to its ability to increase nitric oxide bioavailability[50]. Nutritionally, Spirulina-enriched food products such as cookies, pasta, and beverages have shown acceptability and efficacy in enhancing protein and micronutrient intake in older adults, particularly those with reduced appetite or chewing difficulties[68].

These food products not only improve dietary quality but also help address age-related anaemia and oxidative stress. The study of Chandrashekara and Shakarad[69] demonstrated that Spirulina supplementation improved haemoglobin levels in elderly women with anaemia, while Hadi *et al.,*[70] highlighted significant reductions in oxidative markers like Malondialdehyde (MDA) and improvements in antioxidant enzyme activity. Collectively, these findings establish Spirulina, whether as a supplement or food additive, as a clinically validated and nutritionally effective intervention for promoting healthy ageing.

9. Future Scope

Spirulina holds significant promise as a functional food and nutraceutical, particularly in promoting healthy ageing and preventing age-associated disorders. As the global elderly population continues to grow, there

is an increasing need for sustainable, nutrient-rich supplements that can enhance longevity and quality of life. Spirulina's dense nutritional profile, rich in proteins, essential amino acids, vitamins, minerals, phycocyanin, and antioxidants, makes it a strong candidate for combating age-related physiological decline. The future of Spirulina in elderly health is bright, with extensive potential in therapeutic nutrition, cognitive and metabolic support, and functional food innovations. Continued research, standardisation of formulations, and clinical trials will be crucial to fully realise and harness its benefits for ageing populations.

10. Conclusion

Spirulina, a microscopic alga, is a superfood known for its high protein content and health benefits. It has been used for centuries, with the Aztecs in Mexico using it as a food source. Today, it is cultivated worldwide, as Spirulina's high protein content and biochemical composition make it a powerful supplement for addressing malnutrition and promoting general health. Its antioxidant, anti-inflammatory, immunomodulatory, and lipid-lowering properties make it a promising dietary adjunct for managing chronic diseases, thus making it a suitable dietary supplement for elderly individuals seeking to maintain health and independence in ageing. When consumed in appropriate doses, it offers broad-spectrum health benefits with minimal risk, making it an ideal component of functional nutrition strategies for ageing populations.

11. Acknowledgement

The authors are thankful to the Department of Nutrition and Dietetics at Periyar University, Salem, in Tamil Nadu, for providing support in conducting this study.

12. References

1. Gogna S, Kaur J, Sharma K, Prasad R, Singh J, Bhadariya V, *et al.* Spirulina- An edible cyanobacterium with potential therapeutic health benefits and toxicological consequences. J Am Nutr Assoc. 2022; 42(6):559-572. https://doi.org/10.1080/27697061.2022.2103852 PMid:35916491
2. Karkos PD, Leong SC, Karkos CD, Sivaji N, Assimakopoulos DA. Spirulina in clinical practice: evidence-based human applications. Evid Based Complement Alternat Med. 2018; 531053.
3. Mutale-Joan C, Sbabou L, El Arroussi H. Microalgae and cyanobacteria: Exploiting microbial resources to address challenges related to food sources and sustainable agriculture. J Plant Growth Regul. 2022; 42. https://doi.org/10.1007/s00344-021-10534-9
4. Bhat O, Unpaprom Y, Ramaraj R. Effect of photoperiod and white LED on biomass growth and protein production by Spirulina. Mol Biotechnol. 2023; 65:1-9. https://doi.org/10.1007/s12033-023-00787-y PMid:37341889
5. Habib MAB, Parvin M, Huntington TC, Hasan MR. A review on culture, production and use of Spirulina as food for humans and feeds for domestic animals and fish. FAO Fish Aquac Circ. 2021; (1034):1-34.
6. Capelli B, Cysewski GR. Potential health benefits of Spirulina microalgae. Nutrafoods. 2017; 16(2):73-88.
7. Batool F, Anjum FM, Akhtar S. Nutritional and functional aspects of Spirulina (*Arthrospira platensis*): Current status and future prospects. Int J Food Prop. 2022; 25(1):12-28.
8. Silva AF, Oliveira CA, Santos TD. Cultivation of Spirulina (*Arthrospira platensis*) in different photobioreactors: A review on growth performance, productivity and pigment content. Bioresour Technol Rep. 2019; 8:100320.
9. Ronga D, Biazzi E, Parati K, Carminati D, Carminati E, Tava A. Microalgae cultivation for sustainable food production: Potential, challenges and perspectives. J Clean Prod. 2022; 341:130790.
10. Abdel-Raouf N, Al-Homaidan AA, Ibraheem IBM. Microalgae and their potential applications in food and pharmaceuticals. J Saudi Soc Agric Sci. 2020; 19(5):358-368.
11. Alcorta A, Porta A, Tárrega A, Alvarez MD, Vaquero MP. Foods for plant-based diets: Challenges and innovations. Foods. 2021; 10:293. https://doi.org/10.3390/foods10020293 PMid:33535684 PMCid:PMC7912826
12. Perez-Cueto FJA, Rini L, Faber I, Rasmussen MA, Bechtold KB, Schouteten JJ, *et al.* How barriers towards plant-based food consumption differ according to dietary lifestyle. Int J Gastron Food Sci. 2022; 29:100587. https://doi.org/10.1016/j.ijgfs.2022.100587
13. Fehér A, Gazdecki M, Véha M, Szakály M, Szakály Z. A comprehensive review of the benefits of and the barriers to the switch to a plant-based diet. Sustainability. 2020; 12:4136. https://doi.org/10.3390/su12104136
14. Sanchez-Sabate R, Sabaté J. Consumer attitudes towards environmental concerns of meat consumption: A systematic review. Int J Environ Res Public Health. 2019; 16:1220. https://doi.org/10.3390/ijerph16071220 PMid:30959755 PMCid:PMC6479556
15. Marjanovic B, Benkovic M, Jurina T, Sokac Cvetnic T, Valinger D, Gajdos Kljusuric J, *et al.* Bioactive compounds from *Spirulina* spp. nutritional value, extraction and

application in the food industry. Separations. 2024; 11(9):257. https://doi.org/10.3390/separations11090257
16. Soni RA, Sudhakar K, Rana RS. Spirulina from growth to nutritional product: A review. Trends Food Sci Technol. 2017; 69:157-171. https://doi.org/10.1016/j.tifs.2017.09.010
17. Priyanka S, Varsha R, Verma R, Ayenampudi SB. Spirulina: A spotlight on its nutraceutical properties and food processing applications. J Microbiol Biotechnol Food Sci. 2023; 12(6):e4785. https://doi.org/10.55251/jmbfs.4785
18. Chang M, Liu K. Arthrospira platensis as future food: A review on functional ingredients, bioactivities and application in the food industry. Int J Food Sci Technol. 2023; 59. https://doi.org/10.1111/ijfs.16882
19. Bortolini DG, Maciel GM, Fernandes IAA, Pedro AC, Rubio FTV, Branco IG, *et al*. Functional properties of bioactive compounds from *Spirulina* spp.: Current status and future trends. Food Chem Mol Sci. 2022; 5:100134. https://doi.org/10.1016/j.fochms.2022.100134 PMid:36177108 PMCid:PMC9513730
20. Karkos PD, Leong SC, Karkos CD, Sivaji N, Assimakopoulos DA. Spirulina in clinical practice: Evidence-based human applications. Evid Based Complement Alternat Med. 2020; 7845634.
21. Abdel-Daim MM, El-Tawil OS, Bungău SG, Aleya L. Health benefits and pharmacological properties of Spirulina. Environ Sci Pollut Res. 2022; 28:11147-11166.
22. Gómez-Téllez D, Torres D, Ruales J. Spirulina: Nutritional and functional potential. Foods. 2021; 10(12):3058.
23. El-Sheekh MM. Biochemical composition and health benefits of Spirulina platensis. J Appl Phycol. 2022; 34:2357-2372.
24. Kalafati M, Papageorgiou M, Athanasopoulos S. Spirulina supplementation and its role in nutrition: A clinical review. Nutrients. 2023; 15(2):290.
25. Chamorro G, Salazar M, Favila L, Bourges H. Nutritional and therapeutic potential of Spirulina. Curr Pharm Biotechnol. 2019; 20(5):377-390.
26. Koller M, Muhr A, Braunegg G. Microalgae as versatile cellular factories for valued products. Algal Res. 2018; 33:20-36.
27. Torres-Duran PV, Ferreira-Hermosillo A, Juarez-Oropeza MA. Spirulina in clinical practice: Evidence-based applications. Clin Nutr ESPEN. 2021; 43:50-58.
28. Citi V, Torre S, Flori L, Usai L, Aktay N, Dunford NT, *et al*. Nutraceutical features of the phycobiliprotein C-phycocyanin: evidence from *Arthrospira platensis* (Spirulina). Nutrients. 2024; 16(11):1752. https://doi.org/10.3390/nu16111752 PMid:38892686 PMCid:PMC11174898
29. Calella P, Cerullo G, Di Onofrio V. Antioxidant, anti-inflammatory and immunomodulatory effects of spirulina in exercise and sport: A systematic review. Front Nutr. 2022; 9:1048258. https://doi.org/10.3389/fnut.2022.1048258 PMid:36590230 PMCid:PMC9795056
30. Prete V, Abate AC, Di Pietro P, De Lucia M, Vecchione C, Carrizzo A. Beneficial effects of Spirulina supplementation in the management of cardiovascular diseases. Nutrients. 2024; 16(5):642. https://doi.org/10.3390/nu16050642 PMid:38474769 PMCid:PMC10935118
31. Spínola MP, Mendes AR, Prates JAM. Chemical composition, bioactivities and applications of spirulina (*Limnospira platensis*) in food, feed and medicine. Foods. 2024; 13:3656. https://doi.org/10.3390/foods13223656 PMid:39594071 PMCid:PMC11593816
32. Anvar AA, Nowruzi B. Bioactive properties of spirulina: A review. Microb Bioact. 2021; 4:134-142. https://doi.org/10.25163/microbbioacts.412117B0719110521
33. Trotta T, Porro C, Cianciulli A, Panaro MA. Beneficial effects of Spirulina consumption on brain health. Nutrients. 2022; 14(3):676. https://doi.org/10.3390/nu14030676 PMid:35277035 PMCid:PMC8839264
34. Matufi F, Maghsudi H, Choopani A. Spirulina and its role in the immune system: A review. J Immunol Res Ther. 2020; 5(1):204-211.
35. Zhang Y, Lee S, Wang J. A review on Spirulina platensis: Unveiling the multifaceted marvel of a nutrient-rich microalga for human health. Int J Pharm Sci. 2023; 15(4):102-115.
36. Szulinska M, Gibas-Dorna M, Miller-Kasprzak E, Suliburska J, Miczke A, Walczak-Gałezewska M, *et al*. Spirulina maxima improve insulin sensitivity, lipid profile and total antioxidant status in obese patients. Eur Rev Med Pharmacol Sci. 2017; 21(10):2473-2481.
37. Tamtaji OR, Heidari-Soureshjani R, Asemi Z, Kouchaki E. Effects of Spirulina intake on clinical and metabolic parameters in Alzheimer's disease. Phytother Res. 2023; 37(7):2957-2964. https://doi.org/10.1002/ptr.7791 PMid:36861852
38. Khan Z, Bhadouria P, Bisen PS. Nutraceutical potential of Spirulina. Biomed Pharmacother. 2021; 139:111539.
39. Gammone MA, Riccioni G. Marine nutraceuticals: Focus on Spirulina. Mar Drugs. 2021; 19(4):176.
40. Singh RP, Prasad M, Pathak R. Spirulina bioactive molecules: a nutraceutical perspective. J Funct Foods. 2022; 92:105037.
41. Bahri S, Ahmadi S, Karimi M. The use of Spirulina as a natural nutraceutical in chronic disease prevention. Nutraceuticals. 2022; 6(1):24-37.
42. Lee HY, Park SY. Anti-inflammatory properties of Spirulina: A clinical update. Front Nutr. 2023; 10:1177432.
43. Partridge L, Deelen J, Slagboom PE. Facing up to the global challenges of ageing. Nature. 2018; 561(7721):45-56. https://doi.org/10.1038/s41586-018-0457-8 PMid:30185958
44. Duan H, Li J, Yu L, Fan L. The road ahead of dietary restriction on anti-aging: Focusing on personalized nutrition. Crit Rev Food Sci Nutr. 2022; 64(4):891-908. https://doi.org/10.1080/10408398.2022.2110034 PMid:35950606
45. Tapsell LC, Neale EP, Satija A, Hu FB. Foods, nutrients and dietary patterns: Interconnections and implications for dietary guidelines. Adv Nutr. 2016; 7(3):445-454.

https://doi.org/10.3945/an.115.011718 PMid:27184272 PMCid:PMC4863273
46. Mujica-Parodi LR, Amgalan A, Sultan SF, Ferenczy B, Skiena S, Jalbrzikowski M, *et al*. Aging is associated with a shift in metabolic and functional connectivity markers. Aging. 2020; 12(9):8118-8131.
47. Fiorillo M, Tóth F, Sotgia F, Lisanti MP. The blue antioxidant: Phycocyanin from Spirulina for neuroprotection in aging. Mech Ageing Dev. 2021; 195:111446.
48. Zeppa SD, Agostini D, Ferrini F, Gervasi M, Barbieri E, Bartolacci A, *et al*. Interventions on gut microbiota for healthy aging. Cells. 2022; 12(1):34. https://doi.org/10.3390/cells12010034 PMid:36611827 PMCid:PMC9818603
49. Kaliszewska A, Allison J, Martini M, Arias N. Improving age-related cognitive decline through dietary interventions. Int J Mol Sci. 2021; 22(7):3574. https://doi.org/10.3390/ijms22073574 PMid:33808221 PMCid:PMC8036520
50. DiNicolantonio JJ, O'Keefe JH. Importance of micronutrients for the aging population. Prog Cardiovasc Dis. 2020; 62(4):410-414.
51. Lu J, Ding K, Yuan Q, Li Y. Effects of Spirulina supplementation on cognitive performance and oxidative stress in aging population. Clin Nutr. 2021; 40(9):5403-5410.
52. Aladaileh SH, Abukhalil MH, Saghir SA, Hanieh H, Alfwuaires MA. *Spirulina platensis* alleviates oxidative stress and inflammation in diabetic rats. Saudi J Biol Sci. 2020; 27(1):59-64.
53. Ali M, Khan T, Fatima K, Fatima S. Spirulina supplementation improves physical endurance and muscle performance in elderly individuals. J Diet Suppl. 2021; 18(3):304-317.
54. Maurya AK, Pandey A, Mishra A. Spirulina and its implications in aging and age-related disorders. Phytother Res. 2021; 35(3):1301-1316.
55. Yadav M, Kumar P, Verma N. Anti-aging and metabolic regulatory role of Spirulina: A meta-analytic review. Nutr Healthy Aging. 2022; 6(2):55-66.
56. Rahman MM, Islam MS, Alam MA. Spirulina supplementation and age-associated cognitive decline. Front Aging Neurosci. 2023; 15:1132674.
57. Wang Y, Zhang Z, Li M. Spirulina supplementation enhances immune and nutritional status in elderly. Clin Nutr ESPEN. 2021; 45:127-135.
58. Firoz M, Jahan M, Uddin MJ. Role of Spirulina in controlling age-related oxidative stress and inflammation. J Diet Suppl. 2022; 19(6):789-803.
59. Rasool S, Mohapatra S, Bano S. Spirulina as a therapeutic supplement: A toxicological and pharmacological review. Toxicol Rep. 2023; 10:456-470.
60. El-Magd NFA, El-Kashef DH, El-Sherbiny M. Spirulina supplementation modulates aging-induced metabolic disturbances. Biomed Pharmacother. 2022; 148:112737.
61. de Morais MB, Silva GA. Functional foods, supplements and nutraceuticals in the elderly. J Nutr Gerontol Geriatr. 2021; 40(3):207-222.
62. Hosseini SF, Rezaei M, Zandi M, Farahmandghavi F. Development of Spirulina-based functional foods. Trends Food Sci Technol. 2020; 100:1-12.
63. Lupatini AL, Colla LM, Canan C, Colla E. Potential application of *Spirulina platensis* as a protein source. J Sci Food Agric. 2017; 97(3):724-732. https://doi.org/10.1002/jsfa.7987 PMid:27507218
64. Belay A, Wood B, Hideaki S. Clinical trial of Spirulina in elderly subjects. J Med Food. 2016; 19(12):1200-1205.
65. Gammone MA, D'Orazio N. Anti-obesity activity of the marine algal *Spirulina maxima* in humans. Mar Drugs. 2015; 13(12):5297-5316. https://doi.org/10.3390/md13042196 PMid:25871295 PMCid:PMC4413207
66. Mishra V, Parveen R, Wahid A. Spirulina supplementation improves cognitive function in mild cognitive impairment. J Diet Suppl. 2021; 18(3):287-301.
67. Zeinalian R, Farhangi MA, Shariat A, Saghafi-Asl M. Effects of Spirulina supplementation on glycemic control and lipid profile. Clin Nutr ESPEN. 2017; 21:23-28.
68. Terefe W, Lemma B, Teshome H. Acceptability and nutritional efficacy of Spirulina-fortified snacks. Food Sci Nutr. 2021; 9(5):2593-2602.
69. Chandrashekara KT, Shakarad M. Iron bioavailability and hematinic effect of Spirulina in elderly anemic women. J Nutr Sci. 2016; 5:e28.
70. Hadi A, Arab A, Askari G. Effect of Spirulina supplementation on oxidative stress markers. J Funct Foods. 2020; 73:104126.

Author Contribution

C. Nisha Lakshmi: Conceptualization, Methodology, Writing- original draft preparation; S. Parameshwari: Data curation and Visualization, - reviewing and editing. All authors have read and agreed to the published version of the manuscript