

## A bibliometric analysis of the growing market of *Spirulina*-based algal products and emerging trends

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### Abstract

*Spirulina platensis* is a photosynthetic filamentous cyanobacterium that is considered a “superfood” due to its high protein content and other valuable metabolites. There is a huge research gap in the field of *Spirulina* in Pakistan. This is the first paper focused on the analysis of the worldwide research and market trends of *Spirulina*-based bioproducts. The research trend analysis was carried out by using the Elsevier Scopus database to analyze the worldwide research trends in *Spirulina*-based bioproducts from 2000 to 2021. The number of publications, publications type, countries/territories, journals, and *Spirulina* research areas worldwide were focused to determine the evolution and latest tendencies in this field. The data showed that there is an emerging trend in different fields with a continuous increase in scientific articles. During the last twenty years, the highest number of publications came out of India followed by China and the United States. The most relevant journals publishing *Spirulina* research are Bioresource Technology, Journal of Applied Phycology, Aquaculture, and Algal research. Bibliometric analyses showed that the field of Agricultural and Biological Sciences has been the leading area followed by Biochemistry, Genetics, and Molecular Biology in terms of the highest number of articles published. Further, the industrial and market trend analyses showed that the *Spirulina*-based dietary supplement market is one of the most leading markets, it is predicted that by 2031 the market value would be USD 254 billion with 9.4% Compound Annual Growth Rate (CAGR). Therefore, in future the expectations are high for the production and commercialization of *Spirulina*-based bioproducts in Pakistan.

**Keywords:** Elsevier Scopus database; Research trends; Food supplement; Market value; Compound Annual Growth Rate (CAGR)

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### 1. Introduction

*Spirulina* is an autotrophic, filamentous

cyanobacterium that exhibits spiral morphology and can grow in high saline, alkaline, and brackish

water (Chen et al., 2021). It is rich in high value-added compounds such as proteins (65%), carbohydrates (20%), fats (5%), and others (10%), which include pigments, vitamins (particularly Vitamin B12 and provitamin  $\beta$ -carotene), minerals, essential fatty acids, essential amino acids, phycobiliproteins, etc. (Seghiri et al., 2019). The valuable compounds of *Spirulina* have antioxidant, anti-inflammatory, anti-viral, anti-microbial, and immune-protectant activities (Arslan et al., 2021, Stanic-Vucinic et al., 2018). Because of its composition and health benefits, *Spirulina* has shown the potential to be used as food or as an important ingredient in developing functional foods (dietary supplements and feed supplements) (Manirafasha et al., 2018). For the last decades, *Spirulina* has been the top trend in the food industry, produced and consumed as a nutritional supplement and promoted as a “superfood” (Koru, 2012). In 1974, the United Nations World Food Conference declared *Spirulina* as the “Best Food for Future” due to its high value pigments and proteins. *Spirulina* has potential beneficial market applications such as nutraceuticals, pharmaceuticals, antioxidants, animal feed, human food, and beverages (Guldaz et al., 2020, Han et al., 2021). Over the last couple of decades, the production of food products enriched with *Spirulina* has increasingly gained attention by consumer due to its high nutritious composition and health related benefits. *Spirulina* was used in reforming multiple traditional food products such as *Spirulina* enriched cookies (Şahin, 2020), pasta (Grahl et al., 2020), ice-cream (Tiepo et al., 2021), and blend with juices (El-Beltagi et al., 2020) like mixing with pomegranate juice.

The *Spirulina* market is continuously flourishing, a market value of \$348 million was achieved in 2018 and expected to reach by \$779 million in 2026 with at least 10.5% Compound Annual Growth Rate (CAGR) (Silva et al., 2020). Several prominent companies such as Earthrise Nutritional, California (USA), Cyanotech Corporation, Hawaii (USA), Spira Veg (Canada), SUKIN SKINCARE (Australia), Blue Biotech (Germany), Chr. Hansen A/S (Denmark), C.B.N. Bio-engineering Co., Ltd (China) etc. (Barsanti and Gualtieri, 2018, Soni et al., 2021) are focusing on the cultivation and commercialization of *Spirulina* based products like *Spirulina* powder, capsules, tablets and phycocyanin.

The present study was aimed at the comprehensive analysis of the worldwide research trends focused on *Spirulina* published from 2000 to 2021, using the data, retrieved from the Elsevier Scopus database ([www.scopus.com](http://www.scopus.com)), to highlight the new perspectives in this research area. A bibliometric study was also used for this purpose, which is consisted of analyzing and evaluating the results of the literature published on a specific topic. The data help to identify the main publishing countries worldwide, the total number of publications in recent years, top journals publishing, type of the publications, and the research areas in which most of the publications are published. This study also provided a basis for the comprehensive understanding of recent industrial and market trends in the *Spirulina*-based market and provided guidelines for the future trends.

## 2. Methodology

In this study, a complete information about the recent trends in the *Spirulina* research was extracted from the Elsevier Scopus database by using the [TITLE-ABS-KEY (*Spirulina*)] as the search query. The search resulted in 5,290 documents being obtained after limiting the search within [Article title, Abstract, Keywords] and the research period from 2000 to 2021, and the resulted data were selected for further analysis. It was observed that the results vary in different search parameters were used. It should be noted that this method has some gaps due to the introduction of keywords that do not fit the subject area of the articles by the author. The industry and market trend analysis were performed by the freely available information on the internet, mainly, ‘webpages of companies’, ‘project webpages’ and ‘market reports’ related to *Spirulina*. The applications of *Spirulina* were analyzed by the information taken from the ‘market reports’, ‘project webpages and research articles from the Google scholar.

## 3. Results and discussion

### 3.1. Global publications by year

The progress in global scientific publications from 2000 to 2021. It was observed that the number of publications before 2000 were low, while in 2021 which is the last year of the data survey, the highest number of papers were published (Fig 1). The

results showed that there is a poor publication trend from 2000 to 2010, while the trend rose dramatically from 2011 to 2021. It was also found that *Spirulina*-based studies continued to grow with 73 publications in 2000 to 507 publications in 2021, which indicated the growing global research interest into *Spirulina* over the previous two decades.

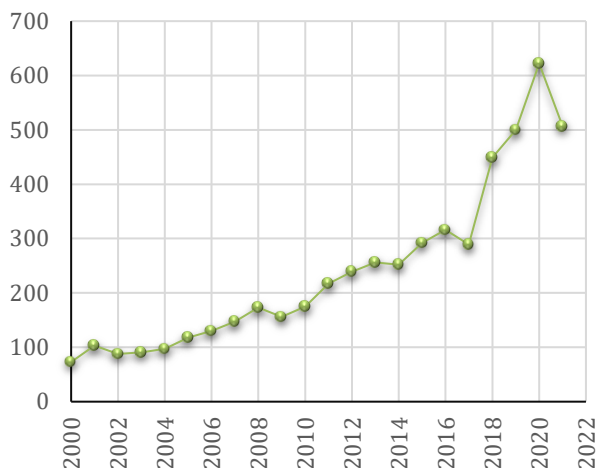


Fig. 1. Trends in the number of publications from 2000 to 2021

### 3.2. Global publications by country/territory

The top 15 countries/territories, indicating the major contributors (4,476 publications) focused on

*Spirulina* research are shown in (Fig 2). The top five publishing countries were India, China, United States, Brazil, and Egypt, with 780, 779, 464, 409, and 296 publications, respectively. Among these top 15 countries, 6 were Asian (India, China, Japan, Indonesia, Iran, South Korea), 3 American (United States, Mexico, Brazil), 3 European (Italy, France, Germany), and 3 transcontinental countries (Turkey, Egypt, Spain). The results showed that the maximum number of publications were produced by the Asian countries.

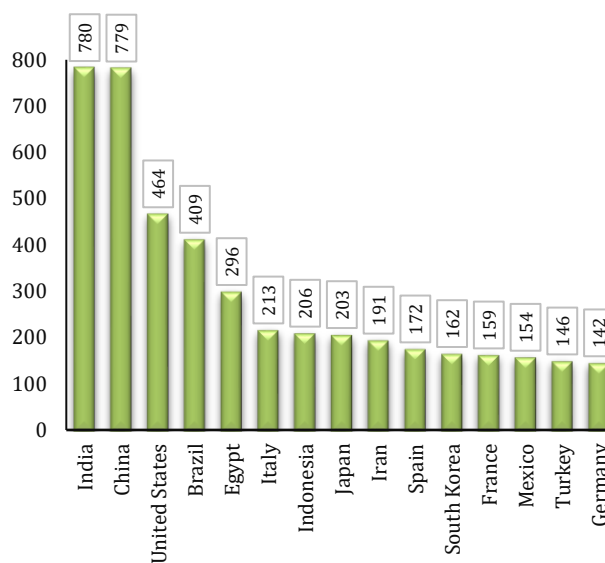


Fig. 2. Trends in the number of publications from 2000 to 2021 by countries/territories

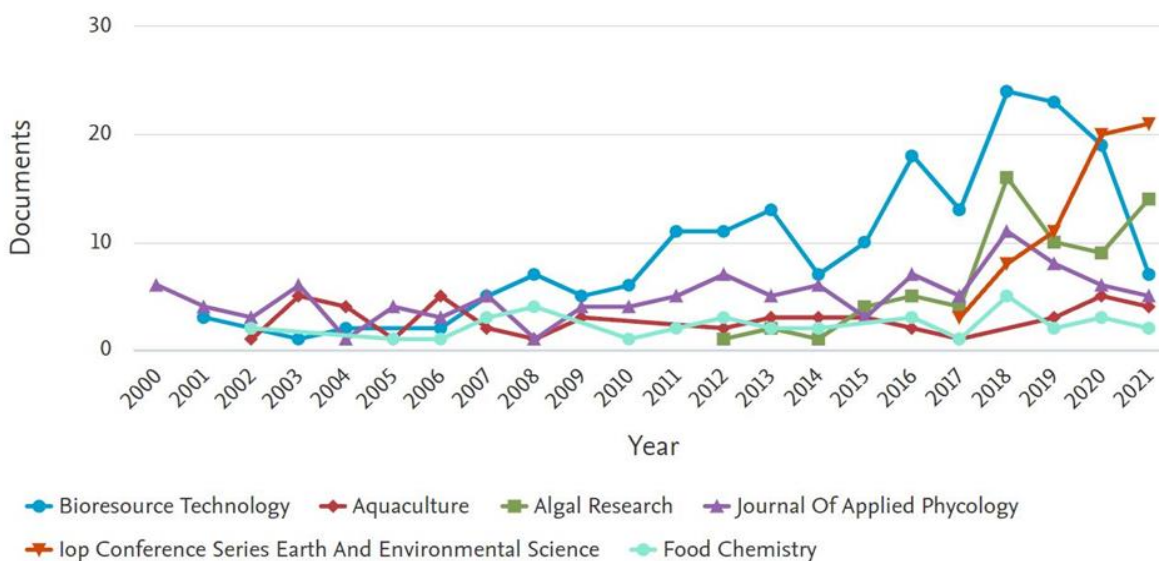


Fig. 3. Trends in the publications by different journals per year from 2000 to 2021





and Environmental Science (1,028). Other included, Chemical engineering (857), Medicine (804), Chemistry (697), Pharmacology, Toxicology and Pharmaceuticals (552), Energy (531), Immunology and Microbiology (512), Engineering (485), Materials Science (248), Physics and Astronomy (244), Nursing (224), Earth and Planetary Sciences (175), and Veterinary (130).

#### 4. Industry and market trend analysis

Worldwide annual production of *Spirulina* is around 10,000 tons/year (Bhattacharya and Goswami, 2020). It was observed that European Commission funded the most *Spirulina*-based projects during previous decades. Many *Spirulina*-based biorefineries are working on these projects to produce a wide range of useful bioproducts. A biorefinery is mainly a refinery that coalesce biomass conversion processes and results into multiple bioproducts and energy production (Costa et al., 2019). Aiming at *Spirulina* biorefinery recently there is an ongoing project entitled as Spiral G Project: The first demonstrator of *Spirulina* biorefinery ([www.spiralg.eu](http://www.spiralg.eu)). It is related to accessing the sustainability and profitability of each *Spirulina* biomass component.

The other projects are *Spirulina* Farming Project of India ([www.agrifarming.in/Spirulina-farming-project-report-extraction-process](http://www.agrifarming.in/Spirulina-farming-project-report-extraction-process)), *Spirulina* Project of India ([www.skorganicfarms.com/pages/Spirulina-project](http://www.skorganicfarms.com/pages/Spirulina-project)), *Spirulina* Farms Project of Jordan funded by European Union ([www.enpicbmed.eu/content/Spirulina-farms](http://www.enpicbmed.eu/content/Spirulina-farms)), *Spirulina* Farming Project of Mexico ([plus.enactus.org/s/global-search/Spirulina%20Farm](http://plus.enactus.org/s/global-search/Spirulina%20Farm)), Etika *Spirulina* Project of France ([plus.enactus.org/s/global-search/Etika%20Spirulina](http://plus.enactus.org/s/global-search/Etika%20Spirulina)), *Spirulina* Production Project of Senegal ([www.afci.de/projects/feasibility-study-Spirulina-production-project-central-senegal](http://www.afci.de/projects/feasibility-study-Spirulina-production-project-central-senegal)), and ROYAL *SPIRULINA* Project of USA ([web.facebook.com/RoyalSpirulinaUsa](https://web.facebook.com/RoyalSpirulinaUsa)) except *Spirulina* Production Project of Senegal, all other projects are ongoing.

The *Spirulina* Farming Project of India is associated with *Spirulina* cultivation and extraction processes, and they also provide training for *Spirulina* cultivation. The *Spirulina* Project of India was

launched to provide training related to *Spirulina* plant setup. The main objective of *Spirulina* Farms Project of Jordan is to establish a low-cost *Spirulina* farm integrated with high purity products. The purpose of *Spirulina* Farming Project of Mexico is to develop circular economy and the Etika *Spirulina* Project of France is originated to cope with worldwide issues of hunger and malnutrition. The *Spirulina* Production Project of Senegal was completed in 2020-12-31 and it was associated with the feasibility study of *Spirulina*. The objective of ROYAL *SPIRULINA* Project of USA is to popularize the new *Spirulina* brand “ROYAL *SPIRULINA*” in the USA by developing attractive packaging, websites, brochures etc.

There are multiple companies working on the excessive production of *Spirulina* biomass at pilot scale. North America, and Europe are the top commercial producers of *Spirulina*. Cyanotech, Earthrise, Cellana, BlueBioTech are the top companies associated with cultivation and marketing of *Spirulina*. According to Allied Market Research ([www.alliedmarketresearch.com/spirulina-market](http://www.alliedmarketresearch.com/spirulina-market)), global *Spirulina* market was USD 393.6 million and expected to reach USD 897.61 million by 2027, growing at a Compound Annual Growth Rate (CAGR) of 10.5% from 2020-2027 and same trend was observed in the case of application and formulation of *Spirulina*. In 2019, *Arthospira platensis* had a dominant position in Global *Spirulina* market and would be expected to maintain the highest position than other *Spirulina* species.

According to *Spirulina* Future Market Insight Report ([www.futuremarketinsights.com](http://www.futuremarketinsights.com)), in 2019 *Spirulina* powder market was USD 358 with 6% CAGR

([www.futuremarketinsights.com/reports/spirulina-powder-market](http://www.futuremarketinsights.com/reports/spirulina-powder-market)) and it is forecasted that in 2029 the food and beverages industry growth would be 73%. The global dietary supplement market in 2022 is expected to be USD 163.12 billion with 8% CAGR growth for 2022-2032. Due to high protein content of *Spirulina*, protein-based dietary supplement market is USD 22.3s billion in 2022 and predicted CAGR is 8.5% from 2022-2032 ([www.futuremarketinsights.com/reports/dietary-supplements-market](http://www.futuremarketinsights.com/reports/dietary-supplements-market)). The *Spirulina* market in U.S was expected to be USD 55.7 million in 2031 and sales of *Spirulina* in Japan are projected to grow at

a CAGR of 15.1% by 2031 (www.futuremarketinsights.com/reports/spirulina-extracts-market).

In 2019, North America had the leading position as a *Spirulina* supplier and expected to maintain its dominance with 11.2% Compound Annual Growth

Rate (CAGR), and Asia Pacific region is the biggest market of *Spirulina* which could be the profitable market for suppliers (Silva et al., 2020). The **Table 1** provides the detailed data related to *Spirulina* market.

**Table 1.** Worldwide market of *Spirulina*-based products

Country	Company	Products	Retail price	Annual sale 2020	URL	References
USA	Earthrise Nutritionals., California	<i>Spirulina</i> Natural Capsules 300C, <i>Spirulina</i> Natural Tablets 90T, 180T	\$100-\$244	N.A.	<a href="http://www.earthrise.com">www.earthrise.com</a>	(Al-Dhabi, 2013, Barsanti and
	Cyanotech Corporation., Hawaii	<i>Spirulina</i> powder and 500mg cold pressed tablets, Hawaiian <i>Spirulina</i>	27.99\$-224.99\$ (Hawaiian <i>Spirulina</i> )	31,899T\$	<a href="http://www.cyanotech.com">www.cyanotech.com</a>	Gualtieri, 2018, Costa et al., 2019, Shimamatsu, 2004,
	<i>Spirulina</i> Mater©	<i>Spirulina</i> Mater 100% tablets, <i>Spirulina</i> with vitamin C capsules, <i>Spirulina</i> with Lecithin	\$16.75-\$56.98	N.A.	<a href="http://Spirulinamater.com">Spirulinamater.com</a>	Soni et al., 2021)
	DDW-The Color House	Blue and green color for ice cream and confections	N.A.	N.A.	<a href="http://ddwcolor.com">ddwcolor.com</a>	
Canada	Sensient Technologies Corporation	In food coloring such as candies and ice cream	N.A.	1,332 M\$	<a href="http://www.sensient.com">www.sensient.com</a>	
	SpiraVeg	Raw fresh <i>Spirulina</i> , Freeze Dried powder & Frozen <i>Spirulina</i>	\$40-\$480	N.A.	<a href="http://spiraveg.com">spiraveg.com</a>	(Gómez Seeber, 2020)
Italy	Santè Naturels®	<i>Spirulina</i> Hawaii in Polvere Frullati e Preparazioni Culinarie, <i>Spirulina</i> Hawaii L'integratore più complete. 200 compresse da 500mg, <i>Spirulina</i> delle Hawaii 3×200 compresse da 500mg.	22,00€-116,38€	N.A.	<a href="http://www.sante-naturels.it">www.sante-naturels.it</a>	(Barsanti and Gualtieri, 2018)
Australia	Australian <i>Spirulina</i>	<i>Spirulina</i> tablets & powder	\$22-\$280	N.A.	<a href="http://www.australianSpirulina.com.au/Spirulina/order.htm">www.australianSpirulina.com.au/Spirulina/order.htm</a>	(Barsanti and Gualtieri, 2018, Soni et al., 2021)

	Sukin Skincare	Detoxifying Sheet Masque, Natural Facial Recovery Serum, Natural Cleansing Oil, Detoxifying Facial Scrub, Body Contouring Crème, Nutrient Rich Facial Moisturiser, Detoxifying Clay Mask	\$8.95-\$19.95	N.A.	<a href="http://sukinnatural.com.au/">sukinnatural.com.au/</a>	
<b>France</b>	Naturex SA	As coloring agent in food and beverages	N.A.	N.A.	<a href="http://www.naturex.com/BUSINESS-UNITS/Food-Beverage/Spirulina-By-Naturex">www.naturex.com/BUSINESS-UNITS/Food-Beverage/Spirulina-By-Naturex</a>	(Barsanti and Gualtieri, 2018, Soni et al., 2021)
	Institut Esthederm®	INTENSIVE <i>SPIRULINA</i> CREAM and SERUM	£62-£64	N.A.	<a href="http://www.esthederm.com">www.esthederm.com</a>	
	ELLA BACHÈ Nutridermologie	<i>Spirulina</i> smoothing mask, Green lift ( <i>Spirulina</i> Wrinkle Lifting Cream, <i>Spirulina</i> Wrinkle Lifting Light Cream, <i>Spirulina</i> Lifting Eye Cream, <i>Spirulina</i> Wrinkle Lifting Rich Cream)	\$38-\$113	N.A.	<a href="http://en.ellabache.com/">en.ellabache.com/</a>	
<b>Germany</b>	Blue Biotech	<i>Spirulina</i> 360, <i>Spirulina</i> 270, <i>Spirulina</i> 1200, <i>Spirulina</i> Chrom 550	11,99€-59,99€	N.A.	<a href="http://www.bluebiotech.de">www.bluebiotech.de</a>	(Barsanti and Gualtieri, 2018)
<b>Denmark</b>	Chr. Hansen A/S	Colors from <i>Spirulina</i> for cookies, ice cream, and snacks, Fruit Max® blue(Candy)	N.A.	283.3 M€	<a href="http://www.chr-hansen.com">www.chr-hansen.com</a>	(Barsanti and Gualtieri, 2018)
<b>Japan</b>	DIC Corporation	New <i>Spirulina</i> Ex Family, <i>Spirulina</i> Extract Gold, Premium <i>Spirulina</i> Extract.	Tablets (1058¥-8500¥) Powder (815¥-1574¥)	701,223M ¥	<a href="http://www.dlt-spl.co.jp/en/Spirulina/features.html">www.dlt-spl.co.jp/en/Spirulina/features.html</a>	(Al-Dhabi, 2013, Barsanti and Gualtieri, 2018, Costa et al., 2019)
	Japan Algae Co., Ltd., Tokyo	<i>Spirulina</i> · CoQ10, <i>Spirulina</i> 100% series <i>Spirulina</i> , Deep Ocean Water <i>Spirulina</i> Blend.	Powder (JPY1000-JPY1,960) Tablets (JPY1300-	N.A.	<a href="http://www.sp10.com">www.sp10.com</a>	

		Spi-Blue D, Spi-Blue Df, Spi-Blue D 180	JPY8000 base price)			
UK	Biovea, London	<i>Spirulina</i> capsules & tablets.	£8.99-£14.49	N.A.	<a href="http://www.biovea.net/uk">www.biovea.net/uk</a>	(Al-Dhabi, 2013)
	Zelens	YOUTH INTELLIGENCE, PEPTIDE COMPLEX, 3T COMPLEX	\$139-\$179	N.A.	<a href="http://us.zelens.com">us.zelens.com</a>	
	HELENA RUBINSTEIN	Powercell Skinmunity Emulsion	£101.63-£136.17	N.A.	<a href="http://www.helenarubinstein.co.uk">www.helenarubinstein.co.uk</a>	
New Zealand	New Zealand Green Health Lifestream International Ltd	<i>Spirulina</i> tablets	NZ\$37.95	N.A.	<a href="http://nzgreenhealth.com">nzgreenhealth.com</a>	(Al-Dhabi, 2013)
		Green Super Blend, Vital Nutrients Pack, Multi Vitamin+	\$21.90-\$79.00	1.66 M\$ (Annual revenue)	<a href="http://lifestream.co.nz">lifestream.co.nz</a>	
China	Bluetech	<i>Spirulina</i> Blue, <i>Spirulina</i> Extract, <i>Spirulina</i> tablets, phycocyanin, powder, and soft gel.	N.A.	N.A.	<a href="http://www.bestphycocyanin.com">www.bestphycocyanin.com</a>	(Costa et al., 2019)
	C.B.N. Bio-engineering Co., Ltd	<i>Spirulina</i> powder and tablets, Organic <i>Spirulina</i> powder and tablets, Phycocyanin	N.A.	N.A.	<a href="http://www.chinaSpirulina.com">www.chinaSpirulina.com</a>	
	Fuqing King Dnarmsa <i>Spirulina</i> Co., Ltd	<i>Spirulina</i> tablets, powder & phycocyanin.	N.A.	More than 1600 tons ( <i>Spirulina</i> production)	<a href="http://en.kingdnarmsa.cn">en.kingdnarmsa.cn</a>	
	Dongtai City <i>Spirulina</i> Bio-engineering Co., Ltd	<i>Spirulina</i> powder, tablets and phycocyanin	Dietary supplement <i>Spirulina</i> powder (\$9.9-\$15.5/Kg), Natural <i>Spirulina</i> (\$4.8-\$6.5/Piece), <i>Spirulina</i> powder (\$2.64-\$8.8), <i>Spirulina</i> tablets 250mg (\$1.1-\$1.56/Unit)	N.A.	1M\$-2.5M\$ (Annual turnover)	<a href="http://chinaSpirulina.en.china.cn">chinaSpirulina.en.china.cn</a>
	Xi'an Saiyang Bio-technology	<i>Spirulina</i> Extract, <i>Spirulina</i> Protein Powder, 100% Pure	N.A.	N.A.	<a href="http://www.syextract.com">www.syextract.com</a>	



	Co., Ltd	Organic Blue <i>Spirulina</i> Powder, 100% Natural <i>Spirulina</i> Extract Phycocyanin, E 18 <i>Spirulina</i> Extract Phycocyanin Powder, GMP Food Grade Phycocyanin Powder <i>Spirulina</i>				
<b>India</b>	Parry's Nutraceuticals	<i>Spirulina</i> tablets & powders.	N.A.	N.A.	<a href="http://www.parrynutraceuticals.com">www.parrynutraceuticals.com</a>	(Al-Dhabi, 2013, Barsanti and Gualtieri, 2018, Costa et al., 2019, Shimamatsu, 2004, Soni et al., 2021)
	Hydrolina Biotech	Spiruvita C, Dr. <i>Spirulina</i> , Diavita C, <i>Spirulina</i> herbal facepack, Vitalinaa <i>Spirulina</i> (tablets, powder and capsules)	N.A.	Up to 50 Lakh(annual turnover)	<a href="http://www.indiamart.com/hydrolina-biotech/">www.indiamart.com/hydrolina-biotech/</a>	
	Algene Biotech	<i>Spirulina</i> capsules, powder and tablets	Rs150-800	50Lakh-1Crore(Annual turnover)	<a href="http://www.indiamart.com/algene-biotech-surat/">www.indiamart.com/algene-biotech-surat/</a>	
<b>Taiwan</b>	Algae Energy	<i>Spirulina</i> tablets, <i>Spirulina</i> powder, Chlorella+CGF+ <i>Spirulina</i> tablets	N.A.	N.A.	<a href="http://www.wilson-groups.com">www.wilson-groups.com</a>	(Barsanti and Gualtieri, 2018)

#### 4.1. Applications of *Spirulina*-based products

*Spirulina* is rich in protein content and other valuable metabolites and based on its chemical composition *Spirulina* has multiple applications. Whole biomass (raw biomass) is used as human food, aquaculture, and animal feed. *Spirulina*'s valuable metabolites mainly pigment such as photosynthetic pigments like chlorophyll, and accessory pigments like phycocyanin and

carotenoids have anti-oxidant, anti-cancer and anti-diabetic abilities. Phycocyanin has multiple industrial applications such as nutraceutical, pharmaceutical, and in cosmetics industry as anti-aging agents etc. Out of multiple *Spirulina* applications, in 2019 nutraceutical application got lead and forecasted to maintain its lead in next multiple years. The worldwide *Spirulina* applications are shown in (Table 2)

**Table 2.** Applications of *Spirulina* on the basis of its bioactive compounds

Applications	Bioactive Compounds	Utility	References
Nutraceuticals	Phycocyanin	Improvement of immune system and type 2 diabetes, modulation of allergic rhinitis and prevention of skeletal muscle damage	(Han et al., 2021)
Cosmetics	PCL nanofibers, C-phycocyanin, Carotenoids, Ethanol and water extract	Anti-aging, antioxidant, anti-acne, moisturizing, brightening, and wound healing abilities	(Ragusa et al., 2021)

Human Food and beverages	Phycocyanin, Protein, Carbohydrates, Omega-3 fatty acids, Chlorophyll, minerals, vitamins, Astaxanthin	Improvement in the texture and viscosity of yogurt and cheese, production of alcohol-free beverages with improved color and taste, improvement in color and stability of desserts and in production of cookies, bread and biscuits	(Mehariya et al., 2021)
Animal Feed	Biomass additive with normal feed	Improvement in reproductive performance and immune response	(Alagawany et al., 2021)
Antioxidant and Pharmaceutical	Phycocyanin, Polyunsaturated fatty acids (PUFAs), Polysaccharide (PS), phenolic compounds, vitamins, carotenoids, minerals, and trace elements.	Anti-inflammatory, and anti-cancerous ability, protective effect on CVD, neuro-protective effect, involve in protection of liver, kidney and lungs and in reduction of cataract	(Han et al., 2021)

## 5. Research gap and future recommendations

Nowadays, the market of microalgae-based products is continuously flourishing. But still there are many bottlenecks in their cultivation, harvesting, and commercialization. Environmental conditions are one of crucial factors which play a pivotal role in the production of valuable metabolites and to obtain robust growth. So, optimization of environmental conditions (Doan et al., 2021) in terms of temperature, pH, nutrients, and light is cardinal and it lend a helping hand to decide specific conditions best suited to produce desired metabolites such as high and low temperature conditions promote the accumulation of saturated FA and unsaturated FA, respectively (Alishah Aratboni et al., 2019). After optimization of cultivation conditions, the next step is optimization of harvesting method.

Although, *Spirulina* has easy harvesting due to its floatation on the surface, but a large amount of biomass loss during harvesting. Currently, centrifugation, filtration, and floatation methods are used for *Spirulina*'s harvesting. Centrifugation method has the lowest biomass loss but not a suitable method at industrial scale due to high energy usage and in comparison, to centrifugation, filtration and floatation methods are cost-effective but too much biomass loss occurs during harvesting. So, there is need to develop an efficient method with lowest biomass loss. The hitch of biomass loss during filtration could be resolved by two ways either recycling of media or use as

inoculum for further cultivation. The next very important step is the commercialization of *Spirulina*-based products. However, the market of *Spirulina*-based products is continuously flourishing but still the products have high cost mainly in Pakistan (all the products are imported from abroad). Therefore, there is need to develop *Spirulina*-based industrial setup in Pakistan to cope with problems of food shortage.

## 6. Conclusion

A great evolution of *Spirulina* research is reflected on the basic analysis of 5,290 publications, from 2000 to 2021. This outstanding research is consistent with the increase in market demand for *Spirulina*-based products and advances in cultivation strategies. In addition to the trend regarding the number of publications in the world, other aspects under study were the number of publications by country/territory, publications by source, publications by type, publications by subject area, industry and market trend analysis, and applications of *Spirulina*. The countries which published the most on *Spirulina* included India (780 publications), China (779 publications), and the United States (464 publications). Most of the publications were published in two well-reputed journals namely, Bioresource Technology (187 publications) and the Journal of Applied Phycology (109 publications). This study also provided a basic information about the research direction of *Spirulina*. It is observed that most of the

publications are achieved in the field of Agricultural and Biological Sciences (1,732). It was shown that *Spirulina* market had a promising future, as the number of companies are continuously increasing.

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## Conflict of Interest

It is declared that authors have no conflict of interest.

## References

- Al-Dhabi NA, 2013. Heavy metal analysis in commercial *Spirulina* products for human consumption. *Saudi Journal of Biological Sciences*, 20: 383-388.
- Alagawany M, Taha AE, Noreldin A, El-Tarabily KA, & Abd El-Hack ME, 2021. Nutritional applications of species of *Spirulina* and *Chlorella* in farmed fish: A review. *Aquaculture*, 542: 736841.
- Alishah Aratboni H, Rafiei N, Garcia-Granados R, Alemzadeh A, & Morones-Ramírez JR, 2019. Biomass and lipid induction strategies in microalgae for biofuel production and other applications. *Microbial Cell Factories*, 18: 178.
- Arslan R, Eroglu EC, & Aksay S, 2021. Determination of bioactive properties of protein and pigments obtained from *Spirulina platensis*. *Journal of Food Processing and Preservation*, 45: e15150.
- Barsanti L, & Gualtieri P, 2018. Is exploitation of microalgae economically and energetically sustainable? *Algal Research*, 31: 107-115.
- Bhattacharya M, & Goswami S, 2020. Microalgae – A green multi-product biorefinery for future industrial prospects. *Biocatalysis and Agricultural Biotechnology*, 25: 101580.
- Chen Z, Li T, Yang B, Jin X, Wu H, Wu J, & Xiang W, 2021. Isolation of a novel strain of *Cyanobacterium* sp. with good adaptation to extreme alkalinity and high polysaccharide yield. *Journal of Oceanology and Limnology*, 39: 1131-1142.
- Costa JAV, Freitas BCB, Rosa GM, Moraes L, Morais MG, & Mitchell BG, 2019. Operational and economic aspects of *Spirulina*-based biorefinery. *Bioresource Technology*, 292: 121946.
- Doan YT-T, Ho M-T, Nguyen H-K, & Han H-D, 2021. Optimization of *Spirulina* sp. cultivation using reinforcement learning with state prediction based on LSTM neural network. *Journal of Applied Phycology*, 33: 2733-2744.
- El-Beltagi HS, Dhawi F, Ashoush IS, & Ramadan K, 2020. Antioxidant, anti-cancer and ameliorative activities of *Spirulina platensis* and pomegranate juice against hepatic damage induced by CCl<sub>4</sub>. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 48: 1941.
- Gómez Seeber P, 2020. Plan de negocios: Inteal.
- Grahl S, Strack M, Mensching A, & Mörlein D, 2020. Alternative protein sources in Western diets: Food product development and consumer acceptance of spirulina-filled pasta. *Food Quality and Preference*, 84: 103933.
- Guldass M, Ziyank-Demirtas S, Sahan Y, Yildiz E, & Gurbuz O, 2020. Antioxidant and anti-diabetic properties of *Spirulina platensis* produced in Turkey. *Food Science and Technology*, 41: 615-625.
- Han P, Li J, Zhong H, Xie J, Zhang P, Lu Q, & Zhou W, 2021. Anti-oxidation properties and therapeutic potentials of spirulina. *Algal Research*, 55: 102240.
- Koru E, 2012. Earth food *Spirulina* (*Arthrospira*): Production and quality standards. *Food additive*: 191-202.
- Manirafasha E, Murwanashyaka T, Ndikubwimana T, Rashid Ahmed N, Liu J, Lu Y, & Jing K, 2018. Enhancement of cell growth and phycocyanin production in *Arthrospira* (*Spirulina*) *platensis* by metabolic stress and nitrate fed-batch. *Bioresource Technology*, 255: 293-301.
- Mehariya S, Goswami RK, Karthikeyan OP, & Verma P, 2021. Microalgae for high-value products: A way towards green nutraceutical and pharmaceutical compounds. *Chemosphere*, 280: 130553.
- Ragusa I, Nardone GN, Zanatta S, Bertin W, & Amadio E, 2021. *Spirulina* for Skin Care: A Bright Blue Future. *Cosmetics*, 8: 7.
- Şahin OI, 2020. Functional and sensorial properties of cookies enriched with SPIRULINA and DUNALIELLA biomass. *Journal of Food Science and Technology*, 57: 3639-3646.
- Seghiri R, Kharbach M, & Essamri A, 2019. Functional Composition, Nutritional Properties, and Biological Activities of Moroccan *Spirulina* Microalga. *Journal of Food Quality*, 2019: 3707219.
- Shimamatsu H, 2004. Mass production of *Spirulina*, an edible microalga. *Hydrobiologia*, 512: 39-44.

- Silva SC, Ferreira ICFR, Dias MM, & Barreiro MF, 2020. Microalgae-Derived Pigments: A 10-Year Bibliometric Review and Industry and Market Trend Analysis. *Molecules*, 25: 3406.
- Soni RA, Sudhakar K, Rana R, & Baredar P, 2021. Food Supplements Formulated with *Spirulina*. *Algae*. Springer.
- Stanic-Vucinic D, Minic S, Nikolic MR, & Velickovic TC, 2018. Spirulina phycobiliproteins as food components and complements. *Microalgal biotechnology*: 129-149.
- Tiepo CBV, Gottardo FM, Mortari LM, Bertol CD, Reinehr CO, & Colla LM, 2021. Addition of *Spirulina platensis* in handmade ice cream: Physicochemical and sensory effects Adição de *Spirulina platensis* em sorvete caseiro: Efeitos físico-químicos e sensoriais. *Brazilian Journal of Development*, 7: 88106-88123.