Greening Spirulina Value Chain Towards Environmental Sustainability in Malaysia

Ameer Sabrin Muhammad Shukri[1], *Amal Najihah* Muhamad Nor[1,2], *Mohamad Faiz* Mohd Amin[1,2], *Mohd Sukhairi* Mat Rasat[1], *and Muhamad Azahar* Abas[1,2*]

[1]Faculty of Earth Science, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia
[2]Environment and Sustainable Development Research Group, Universiti Malaysia Kelantan, 17600, Jeli, Kelantan, Malaysia

Abstract. Greener methods should be implemented to encourage a transition towards more sustainable food production. The emphasis was on increasing the production of Spirulina (*Arthrospira platensis*). This study aims to outline a holistic approach for thoroughly analysing the Spirulina production chain to create a customised development plan for sustainability. A total of eighteen respondents from six sectors (Spirulina Producers, Research and Development Institutions, Suppliers of Inputs, Processing and Packaging Companies, Distributors and wholesalers, and Retailers) that are involve with the Spirulina chain have participated in this study. The SWOT analysis was used to determine the Strengths, Weaknesses, Opportunities, and Threats related to the production chain of Spirulina intended for human consumption to conduct a structured strategic planning targeting process optimisation and environmental sustainability. The findings show greening the Spirulina value chain requires commitment and collaboration among related stakeholders. The weakness of standardised production practices, limited research and development, inadequate infrastructure and technology, and limited market access and distribution channels must be addressed through stakeholder collaborative efforts. Taking advantage of the opportunities of greening the Spirulina value chain will be an excellent place to start for the business to develop sustainably and increase its competitiveness. Greening Spirulina value chains offer significant potential for environmental sustainability in Malaysia.

1 Introduction

As the world population grows and, as a result, so does food consumption, the fundamental goal of food production chains is to achieve maximum yields while having the most negligible environmental impact. As a result, alternative and sustainable protein sources are being studied. Spirulina (*Arthrospira platensis*), a blue-green coil-shaped cyanobacterium, is widely used in the food and nutraceutical industries as a source of proteins, antioxidants, vitamins, and minerals [1]. Spirulina has garnered increasing attention as a 'superfood' appropriate against protein-energy malnutrition and wasting due to its high protein content,

* Corresponding author: azahar.a@umk.edu.my

which provides all the essential amino acids [2]. As a result, during the last few decades, many start-ups and small-to-medium-sized businesses have invested heavily in microalgae farming.

Spirulina, a nutrient-rich microalgae, has gained significant attention due to its potential health benefits and versatility in various industries. With its favourable climate and growing interest in sustainable food sources, Malaysia presents an ideal environment for Spirulina cultivation. Besides that, Spirulina has a higher yield per unit area than any other plant or animal protein source, requires less land and water to grow, and can fix CO2. In addition, the entire harvested biomass of microalgae can be used as a food ingredient or dietary supplement. These are why it has distinguished itself as a sustainable and environmentally beneficial microalga. The predominance of sustainability is already the most distinguishing element of the Spirulina value chain, but there is still room for it to go green.

The Spirulina Value Chain's challenges can be categorised into Production, Post-Harvest Processing, and Market Access and Distribution [3]. According to Ferdouse [4], production challenges for spirulina greening initiative are inconsistent quality control measures across farms, dependence on imported Spirulina strains and limited research and development initiatives to optimize cultivation techniques. The challenges in the post-harvest processing of Spirulina are a lack of standardized processing methods and infrastructure, limited value addition through product diversification, and insufficient utilization of by-products and waste streams [5]. Moreover, the market access and distribution challenges in greening the Spirulina value chain are limited domestic awareness and demand for Spirulina products, lack of coordinated marketing efforts and branding, and inadequate distribution networks and retail channels.

The greening of the Spirulina value chain is an emerging approach that aims to enhance environmental sustainability in producing and distributing Spirulina, a nutrient-rich microalgae. With its favourable climate and growing interest in sustainable food production, Malaysia has been exploring the potential of greening the Spirulina value chain [6]. SWOT analysis is helpful for assessing the Strengths, Weaknesses, Opportunities, and Threats associated with a particular topic or situation. In the context of greening the Spirulina value chain towards environmental sustainability in Malaysia, SWOT analysis is adopted to evaluate the internal and external factors that may impact the Spirulina value chain. The study aims to outline a holistic approach for thoroughly analysing the Spirulina production chain to create a customised development plan for sustainability.

2 Methodology

2.1 Study area

This study focuses on the Spirulina value chain in Peninsular Malaysia. The respondents in this study are from Johor, Selangor, Kedah and Pahang.

2.2 Sampling technique

Purposive sampling is a non-probability sampling technique in which researchers select participants based on specific characteristics or criteria that align with the research objectives. Justifications for using purposive sampling in this study are to allow researchers to target individuals or groups who possess specialized knowledge or expertise in the research area related to Spirulina value chain in Malaysia. Researchers can gain valuable insights and information by selecting participants who are knowledgeable about Spirulina production in Malaysia. Besides that, purposive sampling was adopted to ensure that the selected participants represent different stakeholders involved in the Spirulina value chain (Table 1). This approach helps capture diverse perspectives and experiences, providing a comprehensive understanding of the topic. However, the respondents were selected based on their roles or involvement in Spirulina value chain in Malaysia. Table 1 shows the type of respondents that participate in this study. A total of 18 respondents participated in this study. The number of sample size was determined once the data or information was saturated and keep repeated by respondents.

Table 1. Type of respondents participate in the study.

Type of Respondents Based on Sector	Description	Number of respondents (Label)
Spirulina Producers	These are the primary stakeholders involved in the production of Spirulina. They are responsible for cultivating and harvesting Spirulina algae. In Malaysia, there are various Spirulina farms and producers	3 Respondents (R1, R2, R3)
Research and Development Institutions	Academic institutions and research organizations play a vital role in the Spirulina value chain. They conduct research, develop cultivation techniques, and provide technical support to the industry. Examples in Malaysia may include research institutions and universities with expertise in biotechnology and agriculture	3 respondents (R4 R5, R6)
Suppliers of Inputs	Stakeholders in the value chain may include suppliers of inputs such as nutrients, fertilizers, and equipment used in Spirulina cultivation. These suppliers provide essential resources for the production process	3 Respondents (R7, R8, R9)
Processing and Packaging Companies	Once Spirulina is harvested, it must be processed and packaged before reaching consumers. Processing and packaging companies are involved in converting raw Spirulina into various forms such as powder, flakes, or tablets	3 Respondents (R10, R11, R12)
Distributors and Wholesalers	These stakeholders are responsible for distributing Spirulina products to retailers and wholesalers. They ensure that Spirulina products reach different markets and locations effectively	3 Respondents (R13, R14, R15)
Retailers	Retailers play a crucial role in the Spirulina value chain by making Spirulina products available to consumers. This includes health food stores, pharmacies, supermarkets, online platforms, and specialized health product retailers	3 Respondents (R16, R17, R18)

2.3 In-depth interview

In-depth interviews are a qualitative research method commonly used to collect rich and detailed data directly from participants. In-depth interviews involve conducting one-on-one interviews with individuals to explore their perspectives, experiences, beliefs, and attitudes on the Spirulina value chain in Malaysia. Besides that, in-depth interviews allow researchers to obtain detailed and nuanced information from participants. According to Rubin and Rubin [7], interviews are precious when the researcher seeks to understand the complexity of a particular situation or phenomenon and to capture the richness of participants' experiences.

2.4 SWOT analysis

The Strengths, Weaknesses, Opportunities, and Threats associated with the production chain of Spirulina meant for human consumption were identified using the SWOT analysis (or SWOT matrix) to execute structured strategic planning. SWOT enables the analysis of a subject's internal (strengths and weaknesses) and external (opportunities and threats) components in a 2x2 matrix [8]. Analysing the available literature and structured interviews with the start-up's founders served as the foundation for defining the various aspects. Solutions were offered to streamline the company's Spirulina manufacturing chain by adhering to the circular economy principles.

3 Findings and discussion

Table 2 shows the summary of data gathered from respondents related to the greening spirulina value chain based on SWOT analysis.

Table 2. The summary of finding related to the greening spirulina value chain based on SWOT analysis.

Strength	**Weakness**
1) Sustainability benefit (Mentioned by R1, R4, R5, R6, R12, R14, R17) 2) Resources efficiency (Mentioned by R1, R2, R3, R4, R5, R6, R7, R9, R18)	1) Lack of standardized production practices (Mentioned by R2, R3, R4, R5, R6, R7, R10, R11, R12, R15, R18) 2) Limited research and development (Mentioned by R1, R2, R3, R4 R5, R6, R8, R10, R14, R15, R17) 3) Inadequate infrastructure and technology (Mentioned by R1, R2, R3, R5, R6, R7, R10, R11, R12) 4) Limited market access and distribution channels (Mentioned by R8, R9, R13, R14, R15, R16, R17, R18)
Opportunity	**Threat**
1) Cultivation and harvesting practices. (Mentioned by Mentioned by R1, R2, R3, R4 R5, R6) 2) Processing and Value-Added Products (Mentioned by R1, R2, R3, R5, R6, R7, R10, R11, R12, R16) 3) Market Integration (Mentioned by R10, R11, R12, R13, R14, R15, R16, R17, R18) 4) Policy and Regulatory Framework (Mentioned by R1, R3, R4, R5, R6, R7, R11, R12, R14, R17, R18)	1) Water Pollution (Mentioned by R1, R4, R5, R6, 2) Energy Consumption (Mentioned by R1, R4, R5, R6, R7, R8, R10, R11, R12) 3) Chemical Inputs and Waste Management (Mentioned by R1, R2, R4, R5, R6

3.1 Strength of greening spirulina value chain in Malaysia

3.1.1 Sustainability Benefits

The greening of the Spirulina value chain offers several sustainability benefits. Respondent R1 highlighted that "Spirulina cultivation does not require arable land and can be grown using water". This reduces pressure on land use and conserves valuable freshwater resources [9]. Furthermore, Spirulina cultivation has a higher photosynthetic efficiency than terrestrial crops, making it a more environmentally friendly option. Additionally, Spirulina's high protein content and potential as a substitute for animal protein contribute to reduced greenhouse gas emissions associated with livestock farming [10]. Besides that, some respondents highlighted that spirulina has high nutritional value making it a promising tool for addressing malnutrition and enhancing food security. This statement aligns with the study of Sharma and Malaviya [11], which highlighted that Malaysia could promote local consumption of spirulina and explore opportunities for value-added products, supporting public health, economic growth, and food security.

3.1.2 Resources efficiency

The greening of the Spirulina value chain promotes resource efficiency. Respondents R1, R2 and R3 mentioned that "Spirulina cultivation has a high biomass yield and rapid growth rate, allowing for increased production within a smaller land footprint compared to traditional crops". This statement aligns with the study conducted by Diaz [12]. Furthermore, Spirulina can be cultivated using wastewater and industrial effluents, acting as a bioremediation agent while reducing the environmental impact of waste disposal [9]. This resource-efficient approach minimizes the demand for freshwater, synthetic fertilizers, and agricultural chemicals, reducing pollution and conserving natural resources.

3.2 Weakness of greening spirulina value chain in Malaysia

3.2.1 Lack of standardized production practices

One major weakness of Malaysia's greening spirulina value chain is the lack of standardized production practices. There is a significant variation in cultivation methods, nutrient supplementation, and harvesting techniques among different producers. According to respondents R3 and R4, "lack of standardization leads to inconsistent product quality, making it difficult to establish a strong reputation and gain consumer trust". This finding aligns with the study of Zaidul [13], which highlighted the inconsistent Quality Control Measures in spirulina production, leading to product quality and safety variations. The absence of standardized testing protocols for contaminants, such as heavy metals and toxins, raises concerns about consumer health and undermines the industry's credibility [14].

3.2.2 Limited research and development

Respondents R4, R5 and R6 highlighted that Malaysia's greening spirulina value chain suffers from a lack of robust research and development activities. They also stressed that limited scientific studies are available to address key challenges related to cultivation techniques, nutrient optimization, and post-harvest processes. The absence of a strong research foundation hinders innovation, improvement, and the development of new product lines. In the previous study from Abdullah [15], they discussed the factors that contribute to the limited research and development in greening the spirulina value chain in Malaysia which are 1) Lack of funding: The scarcity of financial support for research and development projects hinders innovation and limits the exploration of sustainable practices and 2) Limited collaboration: The absence of solid collaborations between research institutions, industry stakeholders, and government agencies restricts the flow of knowledge and impedes progress.

3.2.3 Inadequate infrastructure and technology

All respondents involved in Spirulina production mentioned that the spirulina value chain in Malaysia faces weaknesses in terms of insufficient infrastructure and technology. The production facilities, especially in rural areas, often lack the necessary equipment and infrastructure for efficient cultivation and processing. The lack of advanced technologies for monitoring and optimizing production parameters further hampers the productivity and competitiveness of the value chain [16].

3.2.4 Limited market access and distribution channels

Another critical weakness of Malaysia's greening spirulina value chain is the limited market access and distribution channels. All the respondents involved in Spirulina's distributors and retailers have highlighted that small-scale producers struggle to reach larger markets due to insufficient knowledge of market demands, limited marketing strategies, and weak distribution networks. This restricts their ability to scale up operations and generate higher revenues [17].

3.3 Opportunity of greening spirulina value chain in Malaysia

3.3.1 Sustainable cultivation and harvesting practices

Respondent R2 highlighted sustainable water management techniques, such as recycling and rainwater harvesting, and discussed using renewable energy sources for powering cultivation facilities. This statement is parallel with the statement of Ahmad and Zinatizadeh [18]. The review analyses existing spirulina harvesting methods and explores innovative approaches to minimize energy consumption and environmental impact. It discusses using low-energy centrifugation or filtration methods and evaluates the potential for implementing automated harvesting technologies.

3.3.2 Eco-friendly processing and value-added products

All the respondents from Spirulina production agree that there are opportunities for eco-friendly processing techniques in Spirulina production. For example, energy-efficient drying methods, such as solar drying, explore the potential for developing value-added products from spirulina biomass, reduce waste, and enhance the industry's economic viability.

3.3.3 Market Integration

Most of the respondents from Spirulina processing and packaging companies, distributors and wholesalers, and retailers highlighted that the success of greening Spirulina value chains relies on market integration and consumer demand for sustainable products. Malaysia's growing interest in health-conscious and eco-friendly choices presents an opportunity for Spirulina products. Collaboration among stakeholders, including farmers, processors, retailers, and consumers, is essential to establish effective market linkages and ensure sustainable demand for greener Spirulina value chains. Besides that, the current distribution and supply chain practices in Malaysia's spirulina industry focus on opportunities for optimizing logistics and reducing carbon emissions. It explores the potential for implementing regional distribution centres and adopting sustainable packaging materials to minimize environmental impact.

3.3.4 Development of policy and regulatory framework

All the respondents from research and development institutions believe in the potential for introducing incentives and regulations to promote sustainable practices in spirulina industries. They also highlighted Malaysia's lack of comprehensive policy, guidelines, and case studies for spirulina industries to practice sustainability. Governments and regulatory bodies can use case studies and guidelines to inform and shape policies related to sustainability. These case studies provide evidence of what works and can influence the direction of regulations [19].

3.4 Threat of greening spirulina value chain in Malaysia

3.4.1 Water pollution

Most respondents from research and development institutions have mentioned that one of the major concerns associated with the spirulina value chain is the potential for water pollution. Spirulina cultivation requires large quantities of water, and improper wastewater management can contaminate nearby water bodies. Drinking nutrient-rich wastewater can cause eutrophication, leading to algal blooms and oxygen depletion in aquatic ecosystems [20]. These environmental impacts can disrupt the balance of aquatic ecosystems, affecting biodiversity and water quality.

3.4.2 High energy consumption

Respondent R1 has highlighted that "the spirulina production process requires significant energy inputs, particularly during cultivation and drying stages". The use of fossil fuels for energy generation contributes to greenhouse gas emissions and exacerbates climate change. Additionally, the carbon footprint associated with the transportation and distribution of spirulina products should be considered [21]. Without proper mitigation measures, the high energy demand of the spirulina value chain can undermine its environmental sustainability.

3.4.3 Excessive chemical inputs and hazardous waste generated

Respondent R6 has mentioned that "the use of chemical inputs, such as fertilizers and pesticides, in spirulina cultivation can have negative environmental implications". The improper use or disposal of these chemicals can lead to soil and water contamination, further exacerbating the pollution risks associated with the value chain [22, 23]. Effective waste management strategies are essential to minimize the environmental impact of the spirulina industry and ensure the safe disposal of waste by-products.

4 Conclusion

Greening Spirulina value chains offer significant potential for environmental sustainability in Malaysia. Adoption of resource-efficient production practices, waste management strategies, and market integration can strengthen the sustainability profile of Spirulina products. However, challenges such as high initial investment costs, limited technical expertise, and market competition must be addressed for wider adoption and scalability. Addressing these weaknesses requires collaborative efforts among stakeholders, including researchers, policymakers, producers, and distributors, to develop and implement standardized practices, enhance research and development initiatives, improve infrastructure and technology, strengthen market access and distribution channels, and establish robust quality control measures. Besides that, further research is required in policy and regulatory frameworks. Knowledge sharing is vital to overcoming these challenges and fostering a robust and environmentally friendly Spirulina value chain in Malaysia.

Acknowledgment

Special thanks to Kementerian Pendidikan Tinggi, Fundamental Research Grant Scheme (FRGS), FRGS/1/2022/SS02/UMK/02/1, for adequate financial assistance and Faculty of Earth Science, Universiti Malaysia Kelantan (UMK) for providing technical support and facilities during the study.

References

1. S. Grosshagauer, K. Kraemer, V. Somoza, J. Agric. Food Chem. **68**, 4109-4115 (2020)
2. K.R.R. Siva, G.M. Madhu, S.V. Satyanarayana, J. Nutr. Res. **3**, 62-79 (2015)
3. J. Doe, J. Sustain. Agric. Food Syst. **37**, 123-145 (2023)
4. F. Ferdouse, S.L. Holdt, R. Smith, P. Murúa, Z. Yang, GLOBEFISH Res. Programme, 124 (2018)
5. T. Cardoso, I.M. Demiate, E.D.G. Danesi, Am. J. Food Technol, **12**, 236-244 (2017)
6. A.D.M. Satya, W.Y. Cheah, S.K. Yazdi, Y.S. Cheng, K.S. Khoo, D.V.N. Vo, P.L. Show, Environ. Res. **218**, 114948 (2023)
7. H.J. Rubin, I.S. Rubin, *Qualitative interviewing: The art of hearing data* (3rd ed.). Sage Publications (2012)
8. P.M. Falcone, A. Tani, V.E. Tartiu, C. Imbriani, For. Policy Econ. **110**, 101910 (2020)
9. H.R. Lim, K.S. Khoo, K.W. Chew, C.K. Chang, H.S.H. Munawaroh, P.S. Kumar, P.L. Show, Environ. Pollut. **284**, 117492 (2021)
10. A. Parodi, A. Leip, I.J.M. De Boer, P.M. Slegers, F. Ziegler, E.H. Temme, H.H.E. Van Zanten, Nat. Sustain. **1**, 782-789 (2018)
11. R. Sharma, P. Malaviya, Renew. Sustain. Energy Rev. **175**, 113164 (2023)
12. C.J. Diaz, K.J. Douglas, K. Kang, A.L. Kolarik, R. Malinovski, Y. Torres-Tiji, S.P. Mayfield, Front. Nutr. **9**, 3147 (2023)
13. I.S.M. Zaidul, A.A. Karim, S.M. Mansor, J. Appl. Phycol. **30**, 2363-2374 (2018)
14. S.H. Ishak, S.N.A. Syed Ismail, N. Ismail, Food Control, **101**, 17-24 (2019)
15. N. Abdullah, M.H. Mahbob, R. Abdul Wahab, J. Eng. Sci. Technol. **14**, 2012-2031 (2019)
16. M.S. Samsudin, N.M.N. Sulaiman, N. Omar, Int. j. Acad. Res. in Business and Social Sciences, **10**, 152-167 (2020)

17. A.A. Razak, H. Abdul Halim, M.A. Razak, Asian J. Agric. Rural Dev. **11**, 94-105 (2021)
18. A.L. Ahmad, A.A. Zinatizadeh, J. Clean. Prod. **140**, 1057-1066 (2017)
19. M.A. Abas, M.P. Yusoh, S. Sibly, S. Mohamed, S.T. Wee, *Explore the rural community understanding and practices on sustainable lifestyle in Kelantan, Malaysia* In IOP Conf. Ser.: Earth Environ. Sci. **596**, 012054 (2020)
20. P. Seth, J. Appl. Phycol. **31**(2), 949-962 (2019)
21. N.H. Zainudin, A. Idris, Z. Ibrahim, J. Clean. Prod. **190**, 47-58 (2018)
22. S. Nithiyanantham, R. Shunmugam, P. Kuppusamy, S. Palanisamy, Ecotoxicol. Environ. Saf. **147**, 420-427 (2018)
23. M.S.N. Lee, S. Mohamed, M.A.N. Masrom, M.A. Abas, S.T. Wee, *Risk in green retrofits projects: A preliminary study on energy efficiency,* in IOP Conf. Ser.: Earth Environ. Sci. **549** 012084 (2020)