e-ISSN 2581-0405
Asian Journal of Applied Research for Community Development and Empowerment

Journal home page: http://ajarcde-safe-network.org ISSN 2581-0405

Comparative Study on the Extraction of Crude Fucoidan from Brown Seaweed Using Conventional, Microwave and Ultrasound-Assisted Methods

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ARTICLE INFO

Article History:
Received: 01 November 2024
Final Revision: 27 December 2024
Accepted: 09 January 2025
Online Publication: 10 January 2025

KEYWORDS

Algae, Extraction yield, Food product, Polysaccharide, Sargassum sp

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ABSTRACT

Brown seaweeds are rich in fucoidan, a sulfated polysaccharide with antimicrobial, immunomodulatory, antioxidant, and anticancer properties. The brown algae *Sargassum sp.* has not been thoroughly investigated for fucoidan extraction using various techniques and evaluations of their effects on extraction yield and its structural properties. The purpose of this study was to compare the structural characteristics and extraction yield of fucoidan from *Sargassum sp.* using conventional, microwave, and ultrasonic-assisted extraction methods. The results showed that a slightly higher yield was obtained by using the ultrasonic-assisted extraction method (2.772%) followed by the microwave-assisted extraction method (2.494%) and conventional extraction method (2.399%). However, the IC_{50} values for antioxidants were found to be lower (less value is preferable) for crude fucoidan obtained by microwave-assisted extraction method (175 µg/ml) than for conventional (195 µg/ml) and ultrasound-assisted extraction methods (230 µg/ml). The crude fucoidan obtained from the three different extraction methods showed moderate antioxidant strength

Contribution to Sustainable Development Goals (SDGs)
SDG 3: Good Health and Well-being
SDG 9: Industry, Innovation, and Infrastructure
SDG 12: Responsible Consumption and Production
DG 14: Life Below Water

1. INTRODUCTION

1.1. *Research Background*

Brown seaweed's cell walls contain a complex sulfated polysaccharide called fucoidan. Usually, hot water or acid is used as an extractant to extract this compound. However, important factors that can significantly affect the yield of fucoidan include the solid-to-solvent ratio, extraction duration, pH, and temperature [1]. Conventional extraction methods have several drawbacks, including longer operating durations, higher solvent and power consumptions, lower yields, and lower selectivity. Eco-friendly substitutes that employ high pressure, ultrasound, microwave, and enzymes to extract fucoidan from different algal sources have been developed to overcome these problems [2].

1.2. *Literature Review*

Based on the color of their pigments, seaweeds are divided into three taxonomic groups, namely green (*Chlorophyceae*), red (*Rhodophyceae*), and brown (*Phaeophyceae*) [1]. Fucoidan, an anionic water-soluble sulfated polysaccharide especially prevalent in L-fucose, is found in brown seaweed [3]. Numerous beneficial biological qualities are known to be exhibited by this compound, which was isolated from different species of Sargassum. For instance, research has demonstrated that fucoidan has antibacterial, anticancer, antilipogenic, antithrombin, antiangiogenic, antioxidant, and antidiabetic properties that are associated with its chemical structure [1]. Furthermore, because of its emulsifying properties, fucoidan is considered as valuable ingredient in the food industry [4].

Research on fucoidan extraction from *Sargassum siliquosum*, *Sargassum mcclurei*, *Sargassum wightii*, and *Sargassum muticum* has demonstrated the potential of ultrasound-assisted extraction as a faster and more effective substitute for other methods [5-8]. These investigations showed that fucoidan yield can be considerably increased by ultrasound-assisted extraction, while extraction time can be decreased. On the other hand, another study on fucoidan extraction from *Ascophyllum nodosum* [9] and *Fucus vesiculosus* [10] found that when compared to the conventional extraction method, microwave-assisted extraction method resulted in a significantly shorter amount of extraction time.

1.3. Research Objective

The aim of this research is to compare the effect of different extraction methods namely conventional, microwave, and ultrasound-assisted methods on the yield of extraction of fucoidan from brown seaweed *Sargassum sp.* The chemical structure of crude fucoidan extract and its antioxidant activities were also investigated.

2. MATERIALS AND METHODS

2.1. Materials

The dried brown seaweed *Sargassum sp* was obtained from Sepanjang Beach, Gunung Kidul, Special Region of Yogyakarta, Indonesia. All chemicals used in extraction such as ethanol, calcium chloride, and demineralized water were purchased from a local chemical store in Yogyakarta.

2.2. Depigmentation of brown seaweed

The dried brown seaweed was grinded using a grinder to obtain fine powders. The powdered materials were passed through a 30-mesh sieve, which allows particles smaller than 500 µm to pass through. Dried *Sargassum sp* was depigmented to remove the pigments from the seaweed sample. The procedure involved treating 100 g of seaweed powder with 1 liter of ethanol for 24 hours at room temperature. The depigmented seaweed residue was filtered through a paper filter, dried, and then stored in airtight containers at 25ºC until further use.

2.3. Conventional extraction method

Depigmented seaweed powder was mixed with deionized water at a ratio of 1:20 and heated to 65°C, for 60 minutes at 130 rpm using a water bath shaker (B-One SWB-30 Shaker Water Bath). Following extraction, the resulting mixture was filtered using filter paper to separate the residue from the supernatant. The residue was then allowed to dry in the shade. To precipitate the calcium alginate, the supernatant was treated with 1% calcium chloride and then kept in cold storage overnight. Centrifugation was used for 15 minutes at 5,000 rpm to remove the resultant precipitate. Crude fucoidan was precipitated by mixing the remaining supernatant with twice as much ethanol and incubated in a cold environment. The precipitated fucoidan could be separated from the supernatant by the centrifugation process that followed. The dried fucoidan's weight was calculated after freeze dried at -55 ºC using Freeze Dryer (VirTis Benchtop K).

2.4. Microwave assisted extraction method

Fucoidan was extracted from depigmented seaweed powder using a microwave reactor with power of 300 watts for 15 minutes at 30°C and a solid solvent ratio of 1:20. Following filtration, the seaweed residue was removed from the extracts. The process of gradually removing alginate and recovering fucoidan was performed as outlined in Section 2.3.

2.5. Ultrasound-assisted extraction method

Fucoidan was extracted from depigmented seaweed powder by using an ultrasonic processor (Ultrasonic Processor FS-300N) with a frequency of 40 kHz and a power of 300 W, for 15 minutes and a solid solvent ratio of 1:20. Following filtration, the seaweed residue was removed from the extracts. Alginate was gradually removed, and fucoidan was then eventually recovered following the procedure as outlined in Section 2.3.

2.6. Fucoidan yield

The fucoidan yield % was determined using the following formula [1].

$$\text{Fucoidan yield \% (w/w)} = \frac{\text{Weight of dried fucoidan (g)}}{\text{Weight of depipgmented algal powder (g)}} \times 100$$

2.7. Fucoidan characterization

To identify the extracted fucoidan's functional groups, Fourier transform infrared (FTIR) spectroscopy was carried out using a PerkinElmer FTIR. The range of the FTIR spectral scans was 4000 cm^{-1} to 400 cm^{-1}.

2.8. Analysis of antioxidant activity

Antioxidant activity was assessed using the 2,2-Diphenyl-1-picrylhydrazyl (DPPH) free radical inhibition assay. Several concentrations of fucoidan (0, 60, 120, 180, 240, and 300 µg/mL) were prepared for the sample solution. The absorbance was measured at a wavelength of 517 nm. The following formula was used to determine the inhibition percentage.

$$\%\text{inhibition} = \frac{(A_{\text{blank}} - A_{\text{sample}})}{A_{\text{blank}}} \times 100\%$$

and then the linear plot of %inhibition versus concentration was analyzed using the following equation.

$$y = a + bx$$

where x is the concentration of the measured substance and y is the % inhibition. Meanwhile, the IC_{50} value was determined as the x value of this equation when y was equal to 50%.

3. RESULT AND DISCUSSION

3.1. Fucoidan yield

The cell wall of brown seaweed is primarily commposed of sulfated polysaccharides containing fucose and polyanionic polysaccharides called alginates [11]. About 25–30% of the dry weight of brown seaweeds is made up of fucoidan, a sulfated polysaccharide [1].

https://doi.org/10.29165/ajarcde.v9i1.570

The yields of fucoidan extracted using conventional, microwave, and ultrasound-assisted extraction methods are presented in Table 1. The results from Table 1 showed that using microwave and ultrasound could increase the yield of fucoidan. The highest yield in this case was obtained by using ultrasound-assisted method. A similar finding was also obtained by Hanjabam et al. [7] for the extraction of crude fucoidan from *Sargassum wightii* using conventional and ultra-sonication extraction methods. They concluded that the ultra-sonication extraction method gave higher yield than the hot water extraction method. Similar conclusion was also reported by Antonisamy et al. [1] for the extraction of fucoidan from *Sargassum ilicifolium*. They reported that the ultrasonic bath method produced a 2.5-fold higher yield of fucoidan than the conventional method. This is because ultrasonic waves have a cavitation effect that improves cell wall lysis and solvent penetration by reducing mass transfer resistance and increasing polysaccharide release [1].

Ref. [12] reported the published data of fucoidan content from brown macroalgae of 102 different algae species. The crude fucoidan content from *Sargassum* genera from [12] with some additional data is summarized in Table 2. From Table 2, it can be concluded that the yield of fucoidan was varied depended on the algae species and the method of extraction. The result of the current study was similar to that of Sinurat, E. and Kusumawati, R. [42] for the extraction of fucoidan from brown seaweed *Sargassum binderi* Sonder using conventional method by extraction with calcium chloride at 85 °C for 4 hours. At higher temperature and longer extraction duration, the yield of fucoidan was 2.57% [42], whereas in the current study, the yield of 2.494 – 2.772% could be obtained for the extraction duration of only 15 minutes with the assistance of microwave and ultrasound. Thus, it is clear that extraction by adding microwave as well as ultrasound could produce fucoidan with higher yield at a much shorter extraction duration. To obtain a higher yield of fucoidan, more studies should be conducted for the extraction with the assistance of microwave and ultrasound but at higher temperatures (i.e. 85 °C) and longer duration (i.e. up to 1 hour).

Table 1. Fucoidan extraction yields obtained using the conventional, microwave and ultrasound-assisted extraction methods

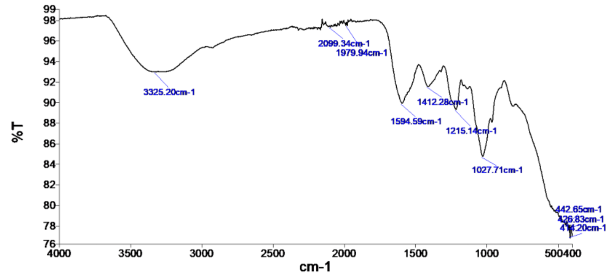
Parameter	Conventional	Microwave	Ultrasound
Extraction yield (%)	2.399±0.248	2.494±0.004	2.772±0.154

3.2. Functional group analysis

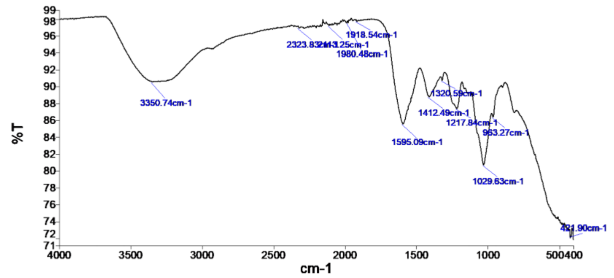
The FTIR analysis for all the samples is shown in Fig. 1. The broad bands at 3350–3325 cm^{-1} for all the samples is explained by O-H stretching vibrations, which are present in all polysaccharides [1]. The bands at 1029–1027 cm^{-1} show the S=O stretching, O-H bending (1412 cm^{-1}), and the C=C stretching (1595–1594 cm^{-1}). The spectra at 1412 cm^{-1} and 1595–1594 cm^{-1}, are ascribed to symmetric and asymmetric stretching vibrations of carboxylate groups, respectively, which may indicate the presence of uronic acid [46]. The area of polysaccharides of about 1029–1027 cm^{-1} shows the glucose and galactose that are typical of a pyranose ring [46]. The characteristic of fucoidan seen from the FTIR spectra is proven by the presence of absorption at 1217–1215 cm^{-1} which indicates sulfated polysaccharides [42].

Table 2. Summary of crude fucoidan content reported for several algal species from *Sargassum* genera

Species	Location	Crude content (%DW)	Ref.
Sargassum binderi	Malaysia	6.2	[13]
Sargassum duplicatum	Vietnam	0.32	[14]
Sargassum feldmannii	Vietnam	0.46	[14]
Sargassum filipendula	Indonesia	4.5 – 6.1	[15]
Sargassum fusiforme	China	3.94–11.24	[16]
Sargassum glaucescens	China	4.20	[17]
Sargassum hemiphyllum	China	2.72 ± 0.18	[18]
Sargassum hemiphyllum	China	4.69 ± 1.05	[5]
Sargassum henslowianum	China	6.25	[19]
Sargassum horneri	China	4.80	[17]
Sargassum mcclurei	Vietnam	2.7	[20]
Sargassum pallidum	Japan	1.86 – 6.31	[21]
Sargassum polycystum	China	3.41 ± 0.77	[5]
Sargassum ringgoldianum	China	0.95 ± 0.02	[22]
Sargassum siliquosum	China	5.08 ± 1.17	[5]
Sargassum stenophyllum	Brazil	0.4	[23]
Sargassum tenerrimum	India	3.1	[24]
Sargassum vachellianum	China	5.5 ± 0.25	[25]
Sargassum ilicifolium	India	2.68 – 6.74	[1]
Sargassum sp	Egypt	5.99–36.79	[4]
Sargassum wightii	India	10.59-14.61	[7]
Sargassum cinereum	Egypt	21.79±4.99	[26]
Sargassum thunbergii	China	2.85 ± 0.08	[27]
Sargassum polycystum	Bangladesh	4.1 – 6.1	[28]
Sargassum horneri	China	2.91±0.17	[29]
Sargassum Zhangii	China	2.85±0.35	[30]
Sargassum hemiphyllum	Taiwan	4.02 ± 0.27	[31]
Sargassum fusiforme	China	1.56	[32]
Sargassum polycystum	Malaysia	1.16 ± 0.07	[33]
Sargassum wightii	India	0.7–1	[34]
Sargassum cinereum	India	9.4 ± 1.9	[35]
Sargassum fluitans Borgesen	Mexico	0.84	[36]
Sargassum swartzii	India	5.96	[37]
Sargassum fusiforme	China	7.3	[38]
Sargassum polycystum	India	4.51±0.24	[39]
Sargassum fusiforme	China	6.02	[40]
Sargassum latifolium	Egypt	10.1±0.2	[41]
Sargassum binderi Sonder	Indonesia	2.57 – 6.00	[42]
Sargassum sp	Indonesia	1.04 – 4.1	[43]
Sargassum binderi Sonder	Indonesia	4.02±0.27	[44]
Sargassum filipendula	Indonesia	5.8 – 8.3	[45]



(a)



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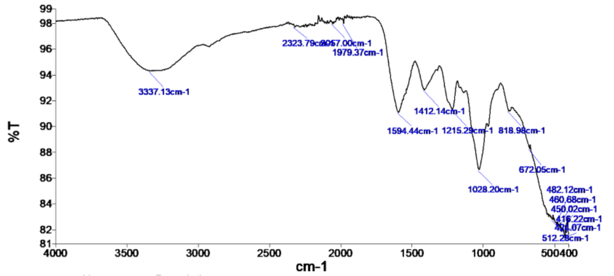

(c)

Fig. 1. FTIR spectra of fucoidan extracted from *Sargassum sp* using extraction method: (a) conventional, (b) microwave, (c) ultrasound

3.3. Antioxidant activity

DPPH test (2,2-diphenyl-1-picrylhydrazyl) method was used to obtain the antioxidant activity. IC_{50} (μg/ml) is a measure of antioxidant capacity that is used to determine antioxidant activity. The amount of test compound concentration that can inhibit free radicals by up to 50% is known as the IC_{50} value. The free radical reduction activity increases with a smaller IC_{50} value. The IC_{50} value category is very strong if the IC_{50} value <50 μg/ml, strong if the IC_{50} value is between 50 and 100 μg/ml, moderate if the IC_{50} value is between 100 and 250 μg/ml, and weak if the IC_{50} value is between 250 and 500 μg/ml [47].

The IC_{50} values for crude fucoidan obtained from the current study are presented in Table 3. It can be seen from Table 3 that the level of antioxidant strength for all samples were moderate. Among the three extraction methods used, fucoidan extracted using microwave assissted method resulted in the highest antioxidant activity (the lowest value is preferable). Other studies reported the lower values of IC_{50} suggesting the strong antioxidant acitivity for fucoidan extracted from different seaweed such as *Sargassum cinereum* with IC_{50} value of 75 μg/ml [35], and 69 – 99 μg/ml for *Sargassum fusiforme* [16].

Table 3. Average IC_{50} values of fucoidan obtained using the conventional, microwave, and ultrasound-assisted extraction methods

Parameter	Conventional	Microwave	Ultrasound
Average IC_{50} values (μg/ml)	195.58±5.40 (moderate)	175.62±2.80 (moderate)	230.21±21.29 (moderate)

4. CONCLUSION

This study offers a comparative assessment of the effects of conventional, ultrasound, and microwave-assisted extraction methods on the yield and functional characteristics of the crude fucoidan that was extracted from brown seaweed *Sargassum sp*. The yield of fucoidan extracted using an ultrasonic probe was slightly higher than those of conventional and microwave-assisted extracted fucoidan. The results also showed that the fucoidan obtained by all three methods exhibited moderate antioxidant activity. The IC_{50} values of fucoidan for all samples were between 175–230 μg/ml. The results of this investigation indicate that crude fucoidan derived from *Sargassum sp.* may prove to be a useful resource for the food industry as well as for medicinal purposes.

ACKNOWLEDGMENT

The authors gratefully acknowledged the Ministry of Education, Culture, Research, and Technology in Indonesia for the financial assistance.

REFERENCE

[1]. Arul Jayanthi Antonisamy, Karthikeyan Rajendran, Comparative study on the extraction methods, characterization, and bioactivity of crude fucoidan, a polysaccharide derived from *Sargassum ilicifolium*, Biochemical Engineering Journal, Volume 209, 2024, 109398, ISSN 1369-703X.

[2]. Dobrinčić A, Balbino S, Zorić Z, Pedisić S, Bursać Kovačević D, Elez Garofulić I, Dragović-Uzelac V. Advanced Technologies for the Extraction of Marine Brown Algal Polysaccharides, Marine Drugs, Volume 18, 2020, 168.

[3]. Wang Y, Xing M, Cao Q, Ji A, Liang H, Song S. Biological Activities of Fucoidan and the Factors Mediating Its Therapeutic Effects: A Review of Recent Studies. Marine Drugs, Volume 17, 2019, 183.

[4]. Awatief F. Hifney, Mustafa A. Fawzy, Khayria M. Abdel-Gawad, Mohamed Gomaa, Industrial optimization of fucoidan extraction from *Sargassum* sp. and its potential antioxidant and emulsifying activities, Food Hydrocolloids, Volume 54, Part A, 2016, Pages 77-88.

[5]. Shao-Hua Wang, Chih-Yu Huang, Chun-Yen Chen, Chia-Che Chang, Chun-Yung Huang, Cheng-Di Dong, Jo-Shu Chang, Isolation and purification of brown algae fucoidan from *Sargassum siliquosum* and the analysis of anti-lipogenesis activity, Biochemical Engineering Journal, Volume 165, 2021, 107798.

[6]. P.Le Thao My, V.Van Sung, T.Do Dat, H.M. Nam, M.T. Phong, N.H. Hieu, Ultrasound-Assisted Extraction of Fucoidan from Vietnamese Brown Seaweed *Sargassum mcclurei* and Testing Bioactivities of the Extract, ChemistrySelect 5 (2020) 4371-4380.

 https://doi.org/10.29165/ajarcde.v9i1.570

[7]. Mandakini Devi Hanjabam, Anuj Kumar, C.S. Tejpal, Elavarasan Krishnamoorthy, Pankaj Kishore, K. Ashok Kumar, Isolation of crude fucoidan from *Sargassum wightii* using conventional and ultra-sonication extraction methods, Bioactive Carbohydrates and Dietary Fibre, Volume 20, 2019, 100200.

[8]. Flórez-Fernández, N., López-García, M., González-Muñoz, M.J. et al. Ultrasound-assisted extraction of fucoidan from *Sargassum muticum*, Journal of Applied Phycology Volume 29, 2017, 1553-1561.

[9]. Yuan Yuan, Duncan Macquarrie, Microwave assisted extraction of sulfated polysaccharides (fucoidan) from *Ascophyllum nodosum* and its antioxidant activity, Carbohydrate Polymers, Volume 129, 2015, Pages 101-107.

[10]. Rosa M. Rodriguez-Jasso, Solange I. Mussatto, Lorenzo Pastrana, Cristóbal N. Aguilar, José A. Teixeira, Microwave-assisted extraction of sulfated polysaccharides (fucoidan) from brown seaweed, Carbohydrate Polymers, Volume 86, Issue 3, 2011, Pages 1137-1144.

[11]. Salmeán, A.A., Duffieux, D., Harholt, J. et al. Insoluble $(1 \rightarrow 3)$, $(1 \rightarrow 4)$-β-D-glucan is a component of cell walls in brown algae (Phaeophyceae) and is masked by alginates in tissues, Scientific Reports, Volume 7, 2017, Page 2880.

[12]. Wei Li, Jichen Chen, Yuan Feng, Xu Li, Guang Gao, Production and ecological function of fucoidans from marine algae in a changing ocean, International Journal of Biological Macromolecules, Volume 283, Part 4, 2024, 137944.

[13]. Seng Joe Lim, Wan Mustapha Wan Aida, Mohamad Yusof Maskat, Said Mamot, Jokiman Ropien, Diah Mazita Mohd, Isolation and antioxidant capacity of fucoidan from selected Malaysian seaweeds, Food Hydrocolloids, Volume 42, Part 2, 2014, Pages 280-288.

[14]. Shevchenko, N.Mseng., Usol′tseva (Men′shova), R.V., Ishina, I.A. et al., Structural Characteristics and in vitro Antitumor Activity of Water-Soluble Polysaccharides from Brown Algae of the Russian Far East and Vietnam, Chemistry of Natural Compounds, Volume 53, 2017, Pages 1–5.

[15]. R. Laeliocattleya, A. Suloi, P. Gayatri, N. Putri, Y. Anggraeni, Fucoidan content from brown seaweed (*Sargassum filipendula*) and its potential as radical scavenger, Journal of Physics: Conference Series, IOP Publishing, 2020, Pages 012023.

[16]. Jian Liu, Si-Ya Wu, Ling Chen, Qiao-Juan Li, Yi-Zhe Shen, Li Jin, Xu Zhang, Pei-Chao Chen, Ming-Jiang Wu, Jong-il Choi, Hai-Bin Tong, Different extraction methods bring about distinct physicochemical properties and antioxidant activities of *Sargassum fusiforme* fucoidans, International Journal of Biological Macromolecules, Volume 155, 2020, Pages 1385-1392.

[17]. Wang, Chun-Ying and Chen, Yean-Chang, Extraction and Characterization of Fucoidan from Six Brown Macroalgae, Journal of Marine Science and Technology, Volume 24, 2016, Pages 319-328.

[18]. Li R, Zhou Q-L, Chen S-T, Tai M-R, Cai H-Y, Ding R, Liu X-F, Chen J-P, Luo L-X, Zhong S-Y., Chemical Characterization and Immunomodulatory Activity of Fucoidan from *Sargassum hemiphyllum*, Marine Drugs, Volume 21, 2023, Pages 18.

[19]. Lin P, Chen S, Liao M, Wang W, Physicochemical Characterization of Fucoidans from *Sargassum henslowianum* C.Agardh and Their Antithrombotic Activity In Vitro, Marine Drugs, Volume 20, 2022, Pages 300.

[20]. Thinh PD, Menshova RV, Ermakova SP, Anastyuk SD, Ly BM, Zvyagintseva TN, Structural characteristics and anticancer activity of fucoidan from the brown alga *Sargassum mcclurei*, Marine Drugs, Volume 11, 2013 Pages 1456-76.

[21]. Skriptsova, A.V., Seasonal variations in the fucoidan content of brown algae from Peter the Great Bay, Sea of Japan, Russian Journal of Marine Biology, Volume 42, 2016, Pages 351–356.

[22]. Guo-Ying Li, Zhang-Cai Luo, Fang Yuan, Xiao-bin Yu, Combined process of high-pressure homogenization and hydrothermal extraction for the extraction of fucoidan with good antioxidant properties from *Nemacystus decipients*, Food and Bioproducts Processing, Volume 106, 2017, Pages 35-42.

[23]. Maria E.R Duarte, Marc A Cardoso, Miguel D Noseda, Alberto S Cerezo, Structural studies on fucoidans from the brown seaweed *Sargassum stenophyllum*, Carbohydrate Research, Volume 333, Issue 4, 2001, Pages 281-293.

[24]. Sharmistha Sinha, Akram Astani, Tuhin Ghosh, Paul Schnitzler, Bimalendu Ray, Polysaccharides from *Sargassum tenerrimum*: Structural features, chemical modification and anti-viral activity, Phytochemistry, Volume 71, Issues 2–3, 2010, Pages 235-242.

[25]. Jesumani V, Du H, Pei P, Aslam M, Huang N., Comparative study on skin protection activity of polyphenol-rich extract and polysaccharide-rich extract from *Sargassum vachellianum*, PLoS One, Volume 15, 2020, Pages e0227308.

[26]. Mostafa El-Sheekh, Eman A. Alwaleed, Wafaa M.A. Kassem, Hani Saber, Optimizing the fucoidan extraction using Box-Behnken Design and its potential bioactivity, International Journal of Biological Macromolecules, Volume 277, Part 3, 2024, 134490.

[27]. Hailan Wang, Fu Gu, Xiulian Ren, Qifeng Wei, Extraction of fucoidan and alginate from *Sargassum thunbergii* using dimethylamine solution: Insights into the process and mechanism, Journal of Industrial and Engineering Chemistry, 2024.

[28]. Dipak Roy, Mohammad Khairul Alam Sobuj, Md. Shoebul Islam, Md. Mozammel Haque, Md. Ariful Islam, Md. Mohidul Islam, Md. Zulfikar Ali, S.M. Rafiquzzaman, Compositional, structural, and functional characterization of fucoidan extracted from *Sargassum polycystum* collected from Saint Martin's Island, Bangladesh, Algal Research, Volume 80, 2024, 103542.

[29]. Shengyu Fan, Ying Xu, Lei Wang, Xin Gao, Soon-Mi Shim, Xiaoting Fu, *Sargassum horneri* fucoidan oligosaccharide: Purification, characterization, and antioxidant effects targeting the MAPK and KEAP1-NRF2 signaling pathways, Algal Research, Volume 84, 2024, 103756.

[30]. Rui Li, Qing-Ling Zhou, Rui-Yu Yang, Shu-Tong Chen, Rui Ding, Xiao-Fei Liu, Lian-Xiang Luo, Qiu-Yu Xia, Sai-Yi Zhong, Yi Qi, Richard J. Williams, Determining the potent immunostimulation potential arising from the heteropolysaccharide structure of a novel fucoidan, derived from *Sargassum Zhangii*, Food Chemistry: X, Volume 18, 2023, 100712.

[31]. Chun-Ju Sung, Hsiao-Hsien Wang, Kuang-Hui Sun, Chii-Cheng Hsieh, Roger Huang, Guang-Huan Sun, Shye-Jye Tang, Fucoidan from *Sargassum hemiphyllum* inhibits the stemness of cancer stem cells and epithelial-mesenchymal transitions in bladder cancer cells, International Journal of Biological Macromolecules, Volume 221, 2022, Pages 623-633.

[32]. Xue Liu, Xin Liu, Mikhail I. Kusaykin, Miansong Zhang, Xinfeng Bai, Tingting Cui, Yaping Shi, Changheng Liu, Airong Jia, Structural characterization of a P-selectin and EGFR dual-targeting fucoidan from *Sargassum fusiforme*, International Journal of Biological Macromolecules, Volume 199, 2022, Pages 86-95.

[33]. Nur Afifah Mohd Fauziee, Lee Sin Chang, Wan Aida Wan Mustapha, Adibi Rahiman Md Nor, Seng Joe Lim, Functional polysaccharides of fucoidan, laminaran and alginate from Malaysian brown seaweeds (*Sargassum polycystum*, *Turbinaria ornata* and *Padina boryana*), International Journal of Biological Macromolecules, Volume 167, 2021, Pages 1135-1145.

[34]. Sathiya Ramu, Anita Murali, Geetha Narasimhaiah, Anbu Jayaraman, Toxicological evaluation of *Sargassum Wightii* greville derived fucoidan in wistar rats: Haematological, biochemical and histopathological evidences, Toxicology Reports, Volume 7, 2020, Pages 874-882.

[35]. Sivasankara Narayani Somasundaram, Saravanan Shanmugam, Bharathiraja Subramanian, Ravindran Jaganathan, Cytotoxic effect of fucoidan extracted from *Sargassum cinereum* on colon cancer cell line HCT-15, International Journal of Biological Macromolecules, Volume 91, 2016, Pages 1215-1223.

[36]. Juan Chale-Dzul, Rebeca Pérez-Cabeza de Vaca, Carlos Quintal-Novelo, Leticia Olivera-Castillo, Rosa Moo-Puc, Hepatoprotective effect of a fucoidan extract from *Sargassum fluitans* Borgesen against CCl_4-induced toxicity in rats, International Journal of Biological Macromolecules, Volume 145, 2020, Pages 500-509.

[37]. Subramaniam Dinesh, Thangam Menon, Luke E. Hanna, V. Suresh, M. Sathuvan, M. Manikannan, In vitro anti-HIV-1 activity of fucoidan from *Sargassum swartzii*, International Journal of Biological Macromolecules, Volume 82, 2016, Pages 83-88.

[38]. Siya Wu, Xu Zhang, Jian Liu, Jianxi Song, Ping Yu, Peichao Chen, Zhiyong Liao, Mingjiang Wu, Haibin Tong, Physicochemical characterization of *Sargassum fusiforme* fucoidan fractions and their antagonistic effect against P-selectin-mediated cell adhesion, International Journal of Biological Macromolecules, Volume 133, 2019, Pages 656-662.

[39]. Subramanian Palanisamy, Manoharan Vinosha, Thangapandi Marudhupandi, Periyannan Rajasekar, Narayanan Marimuthu Prabhu, Isolation of fucoidan from *Sargassum polycystum* brown algae: Structural characterization, in vitro antioxidant and anticancer activity, International Journal of Biological Macromolecules, Volume 102, 2017, Pages 405-412.

[40]. Yang Cheng, Luthuli Sibusiso, Lingfeng Hou, Huijing Jiang, Peichao Chen, Xu Zhang, Mingjiang Wu, Haibin Tong, *Sargassum fusiforme* fucoidan modifies the gut microbiota during alleviation of streptozotocin-induced hyperglycemia in mice, International Journal of Biological Macromolecules, Volume 131, 2019, Pages 1162-1170.

[41]. Mohamed Gomaa, Mustafa A. Fawzy, Awatief F. Hifney, Khayria M. Abdel-Gawad, Use of the brown seaweed *Sargassum latifolium* in the design of alginate-fucoidan based films with natural antioxidant properties and kinetic modeling of moisture sorption and polyphenolic release, Food Hydrocolloids, Volume 82, 2018, Pages 64-72.

[42]. Ellya Sinurat and Rinta Kusumawati, Optimization of Crude Fucoidan Extraction Methods from Brown Seaweed *Sargassum binderi* Sonder, Jurnal Pascapanen dan Bioteknologi Kelautan dan Perikanan, Volume 12, 2017, Pages 125-134.

[43]. Lukman Junaidi, Simple Extraction and Molecular Weight Characterization of Fucoidan from Indonesian *Sargassum* sp., Biopropal Industri, Volume 4, 2013, Pages 49-57.

[44]. E. Sinurat, R. Peranginangin, E.Saepudin, Purification and Characterization of Fucoidan from the Brown Seaweed *Sargassum binderi* sonder, Squalen Bulletin of Marine & Fisheries Postharvest & Biotechnology, Volume 10, 2015, Pages 79-87.

[45]. Ellya Sinurat and Diini Fithriani, Effect of Chopping on the Quality of Fucoidan Extracted from *Sargassum filipendula*, IOP Conference Series: Earth Environmental Science, Volume 209, 2018, Pages 012032.

[46]. Amal D. Premarathna, Tamer A.E. Ahmed, Anti Sooäär, Vitalijs Rjabovs, Alan T. Critchley, Maxwell T. Hincke, Rando Tuvikene, Extraction and functional characterization of fucoidans and alginates from *Ecklonia maxima*: A focus on skin, immune, and intestinal health, Food Hydrocolloids, Volume 159, 2025, 110668.

[47]. Jumina, Dwi Siswanta, Abdul Karim Zulkarnain, Sugeng Triono, Priatmoko, Emmy Yuanita, Arif Cahyo Imawan, Nela Fatmasari, and Ikhsan Nursalim, Development of C-Arylcalix[4]resorcinarenes and C-Arylcalix[4]pyrogallolarenes as Antioxidant and UV-B Protector, Indonesian Journal of Chemistry, Volume 19, 2019, 273.

 https://doi.org/10.29165/ajarcde.v9i1.570