

Utilization of Fucoidan Based on Nanodelivery in Health Promotion Perspective, Molecular Mechanism, and Community Empowerment: A Scoping Review

Francisca Diana Alexandra^{1,2*}, Muh. Nassrum Massi³, Yanti Leman⁴, Marianti A. Manggau⁵, Agnes Frethernety⁶, Ira Jayanti⁷

¹Faculty of Medicine, Hasanuddin University, Tamalanrea, Makassar 90245, Indonesia

²Department of Pharmacotherapy, Faculty of Medicine, Palangka Raya University, Palangka Raya 74874, Indonesia

³Department of Microbiology, Faculty of Medicine, University of Hasanuddin, Makassar, Indonesia

⁴Department of Pharmacology, Faculty of Medicine, Universitas Hasanuddin, Makassar, Indonesia

⁵Department of Pharmacy, Faculty of Pharmacy, Hasanuddin University, Tamalanrea, Makassar 90245, Indonesia

⁶Department of Pharmacotherapy, Faculty of Medicine, Palangka Raya University, Palangka Raya 74874, Indonesia

⁷Medical Laboratory Technology Study Program, Faculty of Medicine, University of Palangka Raya, Palangka Raya, 73111, Indonesia

*Corresponding Author: E-mail: francisca.alexandra07@gmail.com

ARTICLE INFO	ABSTRACT
<p>Manuscript Received: 09 Jul, 2025 Revised: 18 Oct, 2025 Accepted: 26 Nov, 2025 Date of Publication: 03 Dec, 2025 Volume: 8 Issue: 12 DOI: 10.56338/mppki.v9i1.9131</p>	<p>Introduction: Fucoidan is a sulfated polysaccharide derived from brown algae with proven anticancer, antioxidant, and immunomodulatory properties. However, its clinical utilization remains limited due to high molecular weight and low bioavailability. Recent advances in nanodelivery systems provide promising strategies to overcome these limitations and align with community-based health promotion initiatives.</p> <p>Methods: This scoping review adopted the PEOS framework (Population, Exposure, Outcome, Study Design) and PRISMA flow to map current evidence on fucoidan's molecular mechanisms, nanocarrier innovations, and community empowerment perspectives. Literature searches were conducted in PubMed, ScienceDirect, EBSCO, and Google Scholar from 2015–2023 using keywords “fucoidan,” “nanoparticle,” “nanocarrier,” “molecular mechanism,” and “health promotion.” Twenty-three eligible articles were critically appraised using Hawker's Quality Assessment Tool.</p> <p>Results: Fucoidan exhibits anticancer effects through upregulation of Bax, downregulation of Bcl-2, activation of caspases, and inhibition of angiogenesis via NF-κB, MAPK, and Nrf2 signaling pathways. Nanodelivery systems including chitosan fucoidan nanoparticles, PEGylated PLGA, hydrogels, and microneedle patches enhanced stability, absorption, and targeted efficacy. Preclinical studies demonstrated tumor inhibition, wound healing, and immunomodulatory benefits. From a public health perspective, fucoidan-based nanotechnology supports health promotion through increased scientific literacy, integration into Health Promoting Hospitals, and economic empowerment of coastal communities producing brown algae.</p> <p>Conclusion: Fucoidan represents a multifunctional bioactive compound whose efficacy is strengthened by nanodelivery innovation. Integrating molecular insights with health promotion and community empowerment creates a sustainable model linking biotechnology, preventive health, and local economic development. This review emphasizes the importance of interdisciplinary collaboration in translating marine biopolymers into accessible, evidence-based complementary therapies.</p>
<p>KEYWORDS</p> <p>Fucoidan; Nanodelivery; Health Promotion; Molecular Mechanisms; Community Empowerment</p>	

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INTRODUCTION

Fucoïdan is a sulfated polysaccharide obtained primarily from brown algae such as *Fucus vesiculosus* and *Undaria pinnatifida*, which has long been used in traditional East Asian medicine for its antioxidant and immunomodulatory properties (1). Various preclinical studies have shown that fucoïdan has antitumor, anticoagulant, antiviral activities, as well as protective effects against oxidative damage through modulation of molecular pathways such as NF- κ B, MAPK, and Nrf2 (2). Recent studies have even shown a regulatory effect on apoptosis through increasing the Bax/Bcl-2 ratio and caspase activation (1). Thus, fucoïdan is an important candidate in the development of natural therapeutic agents based on marine biopolymers.

However, the main limitations of fucoïdan are its large molecular weight and low bioavailability, resulting in very limited oral absorption and tissue penetration (3). To overcome these obstacles, nanocarrier systems approaches have been developed, including chitosan based nanoparticles, PLGA, liposomes, and microneedle patches combined with fucoïdan. This approach has been shown to improve stability, controlled release, and effectiveness of molecular targets (4). Etman SM's study (2021) reported that nanofucoïdan showed increased anticancer activity in an in vitro model of HCT-116 cells compared to free fucoïdan (5).

In addition to the molecular aspects, the development of fucoïdan also needs to be viewed from the perspective of health promotion and community empowerment, especially coastal communities that have abundant marine algae resources. A community based approach has the potential to increase the economic value and health of the community through health literacy and the utilization of local resources. According to the World Health Organization (WHO), community empowerment and increasing health literacy are the main pillars of a sustainable health promotion strategy (6). In this context, fucoïdan is not only seen as a bioactive agent, but also as a means of increasing community capacity in the production, processing, and utilization of marine products with therapeutic value.

Furthermore, the conceptual orientation of this topic requires engagement with advanced public health frameworks. Health literacy models such as Sørensen's integrated model emphasizing access, understanding, appraisal, and application provide a theoretical lens for explaining how communities process and utilize information about fucoïdan-based innovations. Likewise, empowerment frameworks and capacity-building models clarify the mechanisms through which fucoïdan-related activities may enhance community participation, economic productivity, and sustainable health behaviors. Embedding these theoretical constructs strengthens the analytical foundation of this review and underscores the relevance of nanodelivery fucoïdan within broader health-promotion paradigms.

Therefore, a mapping of the current literature is needed to understand how the molecular mechanisms of fucoïdan, nanodelivery innovations, and their potential applications in community empowerment interact and reinforce each other. This scoping review aims to identify the molecular mechanisms underlying fucoïdan's therapeutic properties, describe nanodelivery approaches used to enhance bioefficacy, and explore opportunities for their integration into health promotion and community empowerment. The findings are expected to provide an integrative research landscape connecting molecular science, nanotechnology, and public health development.

METHOD

A six-step scoping review study will be conducted according to the available guide-lines by Arksey and O'Malley, in addition, the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-scr) will be followed to promote the quality of the review process

Identifying research questions

Question development is an important step that forms the basis of the entire review protocol in determining the search strategy, inclusion and exclusion criteria and data extraction. This review uses the Population, Exposure, Outcome, Study Design (PEOS) framework to help identify key concepts in the focus of the review. The PEO framework can be seen in the table below.

Table 1. PEOS Framework

P (Population)	E (Exposure)	O (Outcome)	S (Study Design)
The use or application of fucoidan, both at the individual (cell, animal, human) and community levels.	Administration, formulation, or application of fucoidan based on nanocarriers (nanocarriers, nanoparticles, nanotechnology) aimed at increasing therapeutic effects.	Molecular mechanisms involved in enhancing therapeutic effects (apoptosis, anti-inflammatory, immunomodulation, antioxidant, antitumor) and their implications for community empowerment, health promotion, and health literacy.	Experimental studies (in vitro, in vivo), clinical trials, and systematic reviews/scoping reviews published in internationally indexed journals

Identifying relevant articles

There are three steps in identifying relevant articles. The first step is to determine the database. The databases used are PubMed, Sciences Direct, EBSCO and Google Scholar. The second step is to determine the inclusion and exclusion criteria. Articles are filtered according to the inclusion criteria published in 2015-2023, primary research articles (original research) and review articles that describe data on the use or application of fucoidan, both at the individual (cell, animal, human) and community levels. The exclusion criteria are opinion articles, peer reviews, theses manuscripts and theses. The third step is to determine the keywords that are focused on based on the framework, expanded by determining the Thesaurus and Boolean synonyms (can be seen in table 2).

Table 2. Article search keywords

Database	Keyword Search
PubMed	(fucoidan) OR (“sulfated polysaccharide”) AND (“nanoparticle”) OR (“nanocarrier”) OR (“nanodelivery”) OR (“chitosan-fucoidan”) AND (“molecular mechanism”) OR (“therapeutic efficacy”) OR (“apoptosis”) AND (“community empowerment”) OR (“health promotion”) OR (“health literacy”)
Science Direct	(fucoidan) OR (“sulfated polysaccharide”) AND (“nanoparticle”) OR (“nanocarrier”) OR (“nanodelivery”) OR (“chitosan-fucoidan”) AND (“molecular mechanism”) OR (“therapeutic efficacy”) OR (“apoptosis”) AND (“community empowerment”) OR (“health promotion”) OR (“health literacy”)
EBSCO	(fucoidan) OR (“sulfated polysaccharide”) AND (“nanoparticle”) OR (“nanocarrier”) OR (“nanodelivery”) OR (“chitosan-fucoidan”) AND (“molecular mechanism”) OR (“therapeutic efficacy”) OR (“apoptosis”) AND (“community empowerment”) OR (“health promotion”) OR (“health literacy”)
Google Scholar	(fucoidan) OR (“sulfated polysaccharide”) AND (“nanoparticle”) OR (“nanocarrier”) OR (“nanodelivery”) OR (“chitosan-fucoidan”) AND (“molecular mechanism”) OR (“therapeutic efficacy”) OR (“apoptosis”) AND (“community empowerment”) OR (“health promotion”) OR (“health literacy”)

Selection/choice of articles

The screening process is used to assess the relevance of research identified in the search according to the desired literature characteristics. From the search using 4 databases as many as 1.760 articles and review articles. Then the articles are filtered based on duplication, abstract and title and full text reading. So that 23 original articles and review articles were found to be reviewed. Furthermore, a critical appraisal was carried out using the Quality Assessment tool from Hawker and the classification of the total quality of the article and the article screening process are stated in PRISMA. The flowchart in Figure 1.

Data Charting

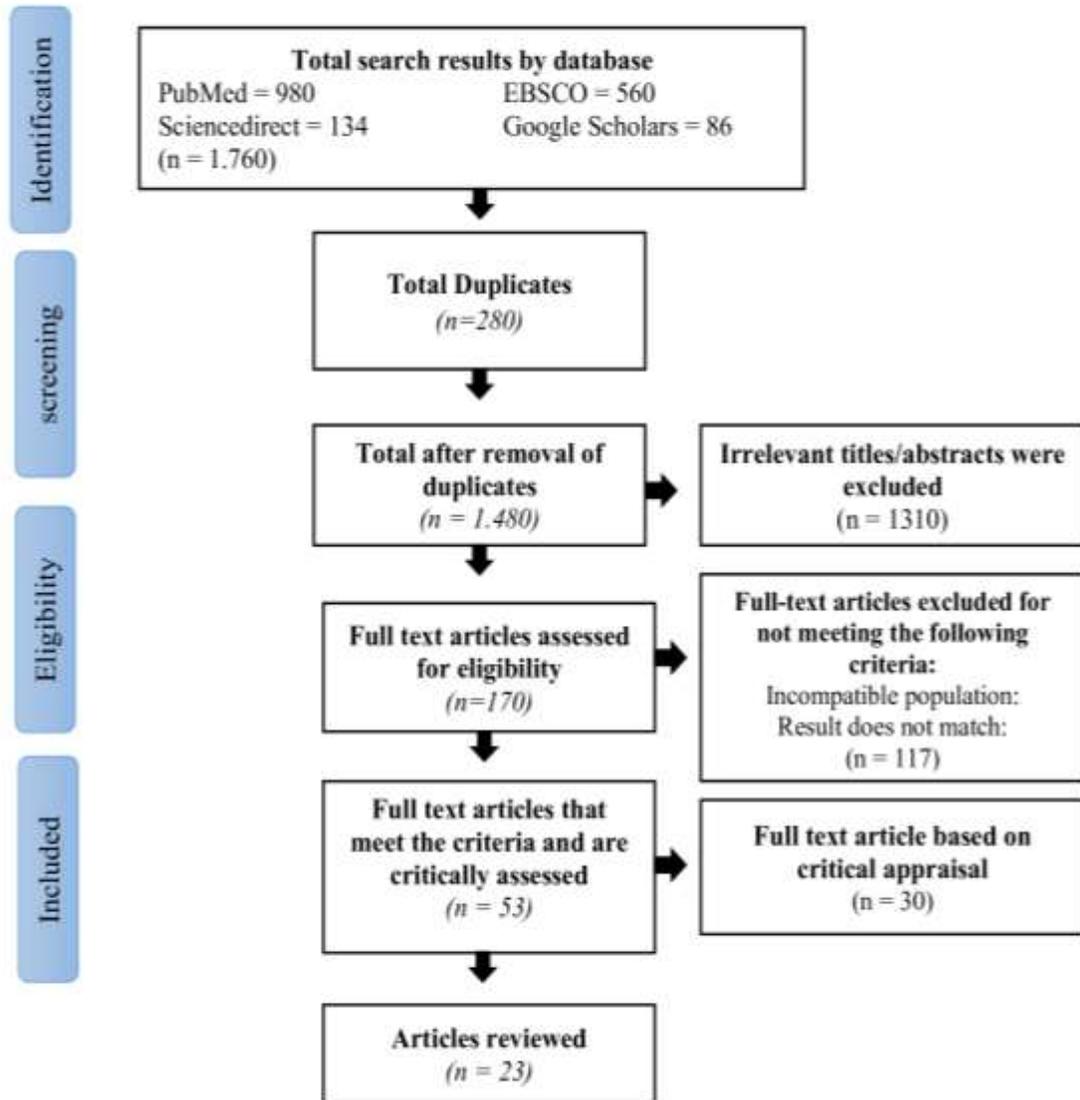


Figure 1. PRISMA

RESULT

23 articles from 4 database including PubMed, ScienceDirect, EBSCO and Google scholar.

Table 1. Summary Article

No	Author/ Year	Article Name	Research Purpose	Research Method	Sample	Result
1	Atazhrazm F, et al. (2015)	Fucoidan and Cancer: A Multifunctional Molecule with Anti-Cancer Properties.	Reviewing the antitumor mechanism of fucoidan.	Narrative review of preclinical evidence.	70 articles focusing on apoptosis, immunomodulation and antimetastasis mechanisms.	Summary of mechanisms: apoptosis, immunomodulation, anti metastasis; suggests the need for translational studies.
2	Fitton JH, et al (2015)	Therapies from Fucoidan: An Update.	Fucoidan therapeutic application update.	The review focuses on immunomodulation, antiviral, and antitumor.	50 articles (consisting of pre clinical and some early human trials).	Demonstrates broad therapeutic potential and translational challenges.
3	Lin Y., et al. (2020)	The anti-cancer effects of fucoidan: a review of both in vivo and in vitro studies.	Summary of anticancer evidence of fucoidan.	Narrative systematic review.	95 studies (consisting of 63 in vitro and 32 in vivo).	Strong preclinical support for antitumor effects; clinical trial recommendations
4	Wang Y., et al. (2019)	Biological Activities of Fucoidan and the Factors Mediating Biological Activities.	Developing an understanding of the structure function factors of fucoidan.	Review	80 articles focusing on structure function relationships, including molecular weight and sulfation level.	Emphasizes the influence of MW, sulfation level, and licensed source on biological activity.
5	Jin JO., et al. (2021)	The Therapeutic Potential of the Anticancer Activity of Fucoidan.	Reviewing anticancer mechanisms.	Review	60 articles focusing on apoptosis pathways, cell cycle arrest, antiangiogenesis	Reviewing apoptosis pathway, cell cycle arrest, antiangiogenesis.
6	Turrini E., et al. (2023)	Ten Years of Research on Fucoidan and Cancer: focus antiangiogenic & antimetastatic activities.	Reviewing decades of pre clinical research related to cancer.	Review of decades of pre clinical research.	112 publications focus on the antiangiogenic & antimetastatic activities of fucoidan.	Emphasizes pre clinical antimetastatic and antiangiogenesis evidence.
7	Venkatesan J., et al. (2022)	Fucoidan-based nanoparticles: Preparations and biomedical applications.	Review of the preparation method and application of fucoidan-NP.	Review of formulation literature.	85 articles focus on nanoparticle synthesis methods (chitosan, PLGA, AuNPs)	Reporting various formulations (chitosan, PLGA, AuNPs) and their applications (drug delivery,

					and their applications.	imaging, antibacterial).
8	Haggag YA., et al. (2023)	Fucoïdan in Pharmaceutical Formulations: A Comprehensive Review for Smart Drug Delivery Systems. (Marine Drugs)	Summarizes the use of fucoïdan in pharmaceutical formulations.	Comprehensive review.	102 articles focus on fucoïdan as a carrier and the influence of physicochemical properties.	Explains the role of fucoïdan as a carrier/gatekeeper and the influence of physical-chemical properties on performance.
9	Zahariev N., et al. (2023)	Novel Fucoïdan Pharmaceutical Formulations and Their Applications.	Review of new formulations (e.g. fucoïdan PLGA) and their applications.	review	76 publications focus on PLGA–fucoïdan formulations, examples of translation to the clinic	Providing an example of Fuc-PLGA for docetaxel and translational discussion.
10	Liu M., et al. (2022)	Synthesis and Characterization of Chitosan Fucoïdan Nanoparticles (CFNs).	Developing CFNs and testing their anti-inflammatory/P-selectin binding potential.	In vitro experiments	Endothelial cell and leukocyte models focus on anti-inflammatory and antioxidant CFNs.	CFNs inhibit leukocyte recruitment via P selectin; exhibit antioxidant & anti-inflammatory properties.
11	Flórez-Fernández N., et al. (2023)	Fucoïdan From Fucus vesiculosus: Evaluation of the Impact on Nanoparticle Formation and Properties.	Evaluating the ability of fucoïdan to form nanoparticles (with chitosan counterion).	Formulation & physicochemical characterization.	Combination of fucoïdan–chitosan at several ratios; physicochemical tests without biological tests. Number of formulation batches:±10 polymer ratio variations.	Polymer ratio parameters affect size, PDI, and potential delivery applications.
12	Obluchinska ya ED., et al. (2022)	In Vitro Anti-Inflammatory Activities of Fucoïdians from Five Brown Algae.	In Vitro Anti-Inflammatory Activities of Fucoïdians from Five Brown Algae.	In vitro immune cells.	5 types of brown algae; immune cell model RAW264.7.	Various efficacy studies support the use of fucoïdan as an anti-inflammatory agent.
13	Dubey A., et al. (2023)	Investigating anti-inflammatory and apoptotic actions of fucoïdan using molecular docking and in vitro assays.	Testing the anti-inflammatory/apoptotic activity of fucoïdan.	In vitro plus in silico docking	Macrophages and HeLa cells; docking on 5 protein targets.	Molecular support for modulation of inflammatory pathways and induction of apoptosis.

14	Chiang CS., et al. (2021)	Fucoidan-Based Nanoparticles with Inherently Therapeutic Efficacy for Cancer Treatment. (Pharmaceutics)	Developing self-assembled fucoidan nanoparticles (FuNPs) and antimetastasis assay.	Nanoparticle synthesis; in vitro & in vivo tests.	Three types of cancer cells (HeLa, MDA-MB-231, B16F10) and a mouse model of metastasis. Number of samples:±30 animals (2 main treatment groups).	FuNPs exhibited in vivo antimetastatic activity and an increased therapeutic window compared to free fucoidan.
15	Etman SM., et al. (2020)	Undaria pinnatifida fucoidan nanoparticles loaded with quinacrine attenuate growth and metastasis of pancreatic cancer.	Testing fucoidan NPs carrying quinacrine in a pancreatic model	Polyelectrolyte NPs; in vitro & in vivo tests.	Pancreatic cancer cells PANC-1; test animals (BALB/c nude mice, n=24). Number of samples:±24 test animals.	Reduction of tumor growth & metastasis in animal models.
16	Abdelkader DH., et al. (2022)	Insight into Fucoidan Based PEGylated PLGA Nanoparticles as an Anti Inflammatory Delivery System.	Develop PEGylated PLGA-fucoidan NPs for anti inflammatory delivery.	NPs preparation, characterization, in vitro testing.	RAW264.7 and Caco-2 macrophage cells. Number of samples:2 cell lines; several batches of NPs for physical characterization.	Controlled anti inflammatory delivery potential.
17	Souza AO., et al. (2022)	Silver Nanoparticles Containing Fucoidan Synthesized by Green Route: Characterization and Bioactivities	Synthesis of AgNPs with fucoidan as reducer/stabilizer; antibacterial & bioactivity test.	Synthesis + bioactivity test.	4 test bacterial strains (S. aureus, E. coli, P. aeruginosa, B. subtilis). Number of samples;4 main types of biological tests.	Ag@fucoidan exhibits antibacterial activity and interesting bioactive properties for wound dressings.
18	Dubashynskaya NV., et al. (2023)	Nano-sized fucoidan interpolyelectrolyte complexes (PECs) for drug delivery	Review of FUC based PECs strategies for drug delivery.	Technical review.	55 publications focus on strategies for the preparation of fucoidan chitosan polyelectrolyte complexes.	Describes the manufacturing strategy of FUC chitosan PECs and their applications (oral pH-sensitive, core shell, etc.)
19	Ohmes J., et al. (2022)	Injectable Thermosensitive Chitosan Collagen Hydrogel as Delivery System	Develop thermosensitive hydrogels to deliver fucoidan + stem cells.	Hydrogel formulation & in vitro / ex vivo testing.	3 test groups (control, fucoidan, fucoidan+MSCs)	The system supports delivery of fucoidan & cells, relevant for tissue engineering.

		for Fucoidan and MSCs in Regenerative Medicine.			Number of samples:±9 replications per group.	
20	Younas A., et al. (2023)	A chitosan/fucoidan nanoparticle-loaded pullulan microneedle patch for differential drug release to promote wound healing.	Design of microneedle patch with MOX loaded chitosan/fucoidan NPs.	Synthesis of NPs, integration into pullulan microneedles, in vivo wound healing assay.	30 mice were divided into 5 groups (6 mice/group).	Accelerated wound healing, controlled antibiotic release, clinical potential for wound care.
21	Lee ZH. et al., 2022	Fucoidan with three functions extracted from Sargassum aquifolium integrated with rice husk synthesis dual imaging mesoporous silica nanoparticles.	Developing a fucoidan MSN system for dual therapy and imaging.	Integration of fucoidan in rice husk based silica nanoparticles.	Fucoidan Sargassum aquifolium, cancer cells (in vitro).	Nanoparticles are biocompatible, selectively cytotoxic, and dual functional (therapy & imaging).
22	Liu Y. et al., 2022	On demand release of fucoidan from a multilayered nanofiber patch for killing oral squamous cancer cells and promoting epithelial regeneration.	Developing fucoidan nanofiber patches for oral cancer therapy.	Multilayer patch with controlled fucoidan release.	Oral squamous cell carcinoma & epithelial cells.	Inhibits the growth of cancer cells and accelerates epithelial regeneration.
23	Hamami SMA. et al., 2022	Nano transdermal delivery potential of fucoidan from Sargassum sp. (brown algae) as a chemoprevention agent for breast cancer treatment.	Evaluating nano transdermal fucoidan as a breast cancer chemopreventive agent.	Transdermal fucoidan nanogel formulation; penetration & antiproliferation assay.	Fucoidan Sargassum sp., MCF-7 cells.	Nanogels are stable, well absorbed, and suppress cancer cell proliferation.

Brief Thematic Analysis (Synthesis Results)

Repetitive mechanism: apoptosis, anti angiogenesis, immunomodulation, anti oxidant via Nrf2 (1,7,8,9).

Frequently occurring formulations: chitosan fucoidan PECs, PLGA fucoidan NPs (PEGy lated), self assembled fucoidan NPs, fucoidan coated metal NPs, fucoidan loaded hydrogels, microneedle patches (10,11,12,13,14).

Pre clinical outcomes: decreased tumor/metastasis volume, increased wound healing, antibacterial & anti inflammatory activity, improved oxidative biomarkers (4,5,14,15).

Implications for Health Promotion and Community Empowerment

Health literacy: use evidence summaries (simple clauses) about what fucoidan is, evidence of benefits & risks, and the role of nanodelivery to improve effectiveness (10,11).

Economic empowerment of coastal communities: potential for development of value added products (supplements, wound dressings) with small scale production training and simple quality control but requires standardization of extracts (MW, sulfation content) for safety (16),

Hospital with a health promotion perspective: integration of evidence briefs on fucoidan (safety, evidence status) into patient education materials, supplement use policies, and community hospital partnership pilot studies (11,12).

DISCUSSION

Fucoidan as a Multifunctional Bioactive Molecule in Cancer Prevention and Therapy

Fucoidan is a sulfated polysaccharide derived from brown algae and has various biological activities, including anticancer, antioxidant, immuno modulatory, and anti inflammatory properties. Several studies have shown that fucoidan can inhibit cancer cell proliferation and metastasis through induction. apoptosis, ratio settings Bax/ Bcl-2, activation caspase, as well as inhibition angiogenesis (7,8,19). Modulated molecular pathways, such as PI3K/Akt, MAPK, and caspase pathway, confirming its potential as a complementary therapeutic agent in healthy lifestyle based cancer prevention. Public education about the natural sources of fucoidan and its benefits in functional diets can streng then health literacy and public acceptance of natural based therapies.

Molecular Mechanism and Immunomodulatory Effects of Fucoidan

Fucoidan plays a role in increasing phagocytosis, secretion cytokines (IL-2, IL-6, TNF- α), as well as modulation of the balance between helper T cells and T regulator which is important in maintaining immune homeostasis (1,9,16). This immuno modulatory activity supports its use in strategies community health promotion, especially for preventionnon communicable diseases (NCDs) such as cancer and metabolic disorders. Public understanding of the immunological mechanisms of fucoidan will improve health literacy and can be integrated into the program Health Promoting Hospital (HPH) as part of a science based educational intervention.

Development of Fucoidan Nanodelivery Technology to Enhance Therapeutic Efficacy

The limitations of fucoidan in bioavailability and molecular stability can be overcome through the development of a system nanodelivery based chitosan–fucoidan, PEGy lated PLGA, and metal nanoparticles (10-13). This system improves stability, specific targeting, and controlled drug release, while reducing systemic toxicity. fucoidan nanoparticles synergistically with conventional chemotherapy has been shown to enhance the anticancer effect (4,5). Integration of this concept in health technology literacy introducing the public to innovation natural nanomedicine which is safe, effective, and supports the preventive health paradigm.

Anti Inflammatory and Regenerative Activities of Fucoidan in Community Therapeutic Applications

In addition to its anticancer effects, fucoidan has demonstrated the ability anti inflammatory and regenerative, through decreased expression COX-2 AndNF- κ B, as well as increased activity endogenous antioxidants (17,18,20). The combination of fucoidan with natural biomaterials such as collagen and chitosanproven to increasetissue regeneration (15,22). This application can be applied in health promotion in the hospital and industrial sectors through the development of wound and skin biomaterial products. In context occupational health promotion and reproduction health, fucoidan can be used for postpartum wound healing and infection prevention.

Synergy Between Nanotechnology Innovation and Coastal Community Empowerment

The integration of fucoidan based nanotechnology not only has biomedical value, but also has the potential to become a means economic and social empowerment coastal communities as producers of brown algae. Innovations such as microneedle patch and nanointerpolyel ectrolyte complex increase comfort and effectiveness of use (14,18,21). This approach supports community empowerment model which combines local culture based health education, production of high value natural materials, and sustainable economic development. Thus, the utilization of fucoidan in nanodelivery systems can be an integrative model between biomedicine, health technology, and community health promotion (23-29).

CONCLUSION

Fucoidan is a multi functional bioactive molecule that shows significant potential in cancer prevention and therapy through apoptosis induction, angiogenesis inhibition, and modulation of molecular and immunological pathways. The development of a fucoidan based nanodelivery system significantly improves its stability, bioavailability, and therapeutic efficacy, while also opening up opportunities for integration into nanomedicine innovation. Physicochemical characteristics such as molecular weight and sulfation level play a crucial role in determining its biological activity.

In addition to its biomedical value, fucoidan utilization has social relevance through community empowerment, particularly in coastal areas where brown algae are produced. Educational and health promotion approaches that explain fucoidan's mechanism of action at the cellular level can increase health literacy and public trust in natural based products. Therefore, the synergy between biotechnology innovation, nanotechnology, and community empowerment is a strategic step towards achieving sustainable, safe, and highly effective fucoidan implementation for public health.

AUTHOR'S CONTRIBUTION STATEMENT

Francisca Diana Alexandraa, Agnes Frethernety, Ira Jayantiwas responsible for the research design, data collection, analysis, and drafting of the manuscript Muh. Nassrum Massi, Yanti Leman, Marianti A. Manggau supervised the research process, contributed to the theoretical framework and literature review, and revised the manuscript critically for intellectual content.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

Artificial intelligence tools were used to assist with language editing and grammar checking. No content generation, data analysis, or critical interpretation was performed by AI. All intellectual contributions are the sole responsibility of the authors. All research design, data collection, analysis, and interpretation were performed by the authors without AI assistance.

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