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Fucus vesiculosus: Nature's Brown Algae with Multifaceted Importance

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Abstract: This study investigates the nutritional potential and functional properties of Fucus vesiculosus, a brown macroalga recognized for its bioactive compounds, including phlorotannins, fucoidan, and fucoxanthin. F. vesiculosus demonstrates significant ecological, pharmaceutical, and industrial relevance, particularly in marine ecosystems and animal nutrition. The research highlights its seasonal ecophysiological variations driven by environmental factors, emphasizing the importance of its nutrient profile, which includes essential amino acids, minerals, and antioxidants beneficial for animal health and growth. The study further explores the hypolipidemic effects of phlorotannin-rich extracts, which have shown promise in improving lipid metabolism and mitigating hyperlipidemia in animal models, thereby potentially reducing atherosclerosis risk. Additionally, the antioxidant and anti-inflammatory properties of fucoidan are examined, revealing its role in modulating immune responses and preventing chronic inflammation-related diseases. Despite the limited research on F. vesiculosus in animal nutrition, its unique bioactive profile positions it as a valuable candidate for further exploration. This comprehensive characterization of F. vesiculosus aims to bridge existing gaps in literature and facilitate its empirical application in enhancing animal productivity and health, setting the stage for subsequent in vivo studies.

Keywords - Fucus vesiculosus, Fucoidan, Fucoxanthin, Phlorotannins, Anti-cancer activity.

INTRODUCTION

Marine algae have been studied worldwide for antimicrobial compounds, and several promising candidates have been identified, including algal lectins, bromo-diterpenes, halogenated furanones, phlorotannins, and sesquiterpenes. Among the various species of algae, Fucus vesiculosus, commonly known as bladderwrack, is a brown macroalga that possesses significant ecological, pharmaceutical, and industrial importance. It thrives in temperate rocky coastal areas and exhibits notable seasonal variations in its ecophysiology, influenced by factors such as temperature and macronutrient availability, which affect its photosynthetic efficiency and elemental composition.

The nutrient profile of seaweeds, which includes essential amino acids, minerals, polyunsaturated fatty acids, antioxidants, and pigments, is crucial for the health, growth, and performance of animals, making them a valuable supplement to animal feed. Additionally, the antioxidant properties of seaweeds can enhance animal health and meat quality by improving redox balance and immune function; however, high consumption, particularly of brown seaweeds, should be avoided due to their elevated levels.

This seaweed's health-promoting properties are attributed to its abundance of bioactive substances, such as phlorotannins, peptides, fucoxanthin, and fucoidans. The ability of F. vesiculosus to regulate lipid metabolism and lower hyperlipidemia is one of its main functional characteristics. Phlorotannin-rich F. vesiculosus extracts have been found in animal models to dramatically reduce blood cholesterol, triglycerides, and free fatty acids while raising levels of high-density lipoprotein cholesterol.

These results imply that F. vesiculosus may be useful in controlling animal lipid profiles, which may lower the risk of atherosclerosis. Furthermore, because of its fucoidan content, F. vesiculosus has antioxidant and anti-inflammatory qualities. Fucoidan may help prevent chronic inflammation-related illnesses in animals because it has been demonstrated to alter immunological responses, suppress inflammation, and scavenge free radicals.

High antioxidant activity is correlated with the presence of phlorotannins and flavonoids, which can shield animals from oxidative stress and enhance their health. This is especially important for animal feeding since oxidative stress can affect production and growth. Despite the paucity of research on F. vesiculosus's application in animal nutrition, this macroalga was chosen in particular due to its great potential and encouraging bioactive profile. Focusing on F. vesiculosus instead of more well researched algae species is justified by its understudied status. It is an excellent candidate for additional research due to its abundance of bioactive chemicals as well as its proven anti-inflammatory, antioxidant, hypolipidemic, and gut-modulating qualities.

In order to evaluate Fucus vesiculosus's nutritional potential and qualities for use in animal nutrition, this study set out to conduct a thorough chemical and functional characterisation of the plant. Furthermore, our objective was to assess the durability of the bioactive components and associated functional characteristics after the simulated in vitro digestive process in order to best integrate visible in vitro results with subsequent in vivo studies. This method helps close a gap in the literature and may help create new, empirically supported uses of F. vesiculosus in animal productivity and health.

COMPOSITION OF *Fucus vesiculosus*

FUCOIDAN

Fucoidans are a group of heterogeneous polysaccharides isolated from marine organisms such as brown algae and marine invertebrates. The biological activity of fucoidan has attracted great interest in the pharmaceutical industry over the past few decades. These polysaccharides are characterized by a negatively charged surface, low/high molecular weight, and the presence of sulfate ester groups that confer water solubility. Additionally, various promising biological activities have been reported, including antitumor, immunomodulatory, and antiviral effects.

Fucoidan is composed of heterogeneous polysaccharides present in the extracellular matrix and cell walls of brown algae and marine invertebrates with potential physiological functions. It acts as a cross-linker between cellulose and hemicellulose and plays an important role in cell wall integrity, preventing algae from drying out, especially during summer and low tide. Chemically, fucoidan consists of sulfated structure of various sugar monomers, primarily L-fucose, as well as galactose, glucose, xylose, mannose, and uronic acids.

PROPERTIES

ANTI-PARKINSONISM

In this study, four species of fucoidans were isolated and purified with different chemical structures from Holothuria polii (HpF), Laminaria japoni-ca (LjF), Ascophyllum nodosum (AnF), and Fucus vesiculosus (FvF). We found that type II fucoidan (FvF) had the best neuroprotective effect in the MPTP-PD mouse model[1]. Fucoidan derived from Fucus vesiculosus improved dendritic cell maturation, cytotoxic T cell activation, Th1 immune responses, antibody production upon antigen challenge, and memory T cell production for immunomodulatory effect[2].

ANTI-IMPAIR COGNITIVE ACTIVITY

A previous study was conducted by Gao, Yonglin et al. and showed the effect of fucoidan and its possible mechanism on learning enhancement and memory impairment in rats induced by Aβ(1-40) injection. The results showed that fucoidan could improve Aβ-induced learning and memory impairment in animal behavioral tests. Moreover, fucoidan reversed the decrease in the activities of choline acetyltransferase (ChAT), superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), and acetylcholine (Ach), as well as the increase in acetylcholinesterase (AchE) activity and malondialdehyde (MDA) content in rat hippocampal tissue. Treat with Aβ. Furthermore, this was accompanied by an increase

in the Bcl-2/Bax ratio and a decrease in caspase-3 activity. These results suggest that fucoidan may improve the learning and memory abilities of Aβ-induced Alzheimer's disease rats and that these mechanisms may be related to modulating the cholinergic system, reducing oxidative stress, and inhibiting cell apoptosis[3].

ANTI-ALLERGIC ACTIVITY

The marine environment contains a vast source of secondary metabolites with great potential for drug discovery. Among them, fucoidan derived from wakame seaweed has been proven to have various biological activities and health effects. In particular, much interest has been expressed regarding the antiallergic activity of fucoidan. Therefore, this contribution provides an overview of the potential antiallergic therapeutics of fucoidan derived from brown algae to highlight the functions of fucoidan in the prevention and treatment of allergic diseases. Fucoidans from brown algae have been studied for their antiallergic activity. Fucoidans suppress allergic reactions and block the accumulation of leukocytes. Fucoidans inhibit B cells that express and secrete IgE. Fucoidan regulates the TH1/TH2 balance in favor of TH1 and induces dendritic cell function[4].

ANTI- ARTHRITIS ACTIVITY

Freund's adjuvant-induced anti-arthritic complete arthritis rat model, an inflammation inhibition capacity of 79.38% was recorded. Substantial ameliorative effects on changes in hematological and biochemical parameters in arthritic rats were also observed. In summary, the results of this study suggest that fucoidan is a potential antioxidant that can effectively suppress arthritis-mediated oxidative stress, swelling, and inflammation, and research on its mechanism of action is recommended for the observed activity. The mechanism of action of fucoidan on arthritis is as follows. The effect of fucoidan on arthritis induced by complete Freund's adjuvant was studied. Fucoidan improved the physical, biochemical, and hematological changes caused by arthritis. Fucoidan reduced the inflammatory response in rats. Fucoidan reduces COX-2 activity in rabbit articular chondrocytes. Fucoidan showed significant antioxidant activity[5].

ANTI- DEPRESSANT LIKE ACTIVITY

Major depressive disorder (MDD) is a significant cause of morbidity and a leading cause of disability worldwide. There is an urgent need to elucidate the pathophysiological mechanisms of depression and to identify new antidepressants with milder side effects and more reliable efficacy. As chronic administration of fucoidan prevents the stress-induced increase in the caspase-1-IL-1β pathway and reverses the stress-induced attenuation of the BDNF signaling pathway in the hippocampus of mice. Ultimately, it induces antidepressant-like effects by modulating surface AM-PAR stability in mice[6].

ANTI- ALZHEIMER ACTIVITY

Attenuating acetylcholinesterase and insulin/insulin-like growth factor-1 signaling in the hippocampus is associated with Alzheimer’s disease (AD) development. AD-related pathologies mainly include amyloid-β (Aβ) accumulation, neurofibrillary tangles, and neuronal necrosis. Fucoidan and carrageenan are brown and red algae, respectively, with strong antibacterial, anti-inflammatory, antioxidant, and antiviral activities. This study investigated how low molecular weight (MMW) and high molecular weight fucoidan and λ-carrageenan ameliorate memory impairment in Alzheimer's disease[7].

FUCOXANTHIN

Fucoxanthin was first isolated by Willstätter in 1914 from the brown marine algae Fucus, Dictyota, and Laminaria. Since 2017, there has been an increase in research papers on the pharmacological properties was founded. Fucoxanthin, a member of the xanthophyll carotenoid class, is a natural antioxidant pigment found in algae such as brown macroalgae and diatoms. It accounts for 10% of total natural carotenoids. The potential benefits of fucoxanthin's nutraceutical and pharmaceutical applications for improving human health are supported by sufficient scientific evidence[8].

Recent reports on the overall pharmacological potential of fucoxanthin, anti-cancer and anti-tumor research ranked first (16%), followed by anti-inflammatory agents (15%), antioxidants (11%), neuroprotective agents (10%), and antihyperlipidemic and antiobesity agents (9%). The protective effects of fucoxanthin against liver, diabetes, kidney, heart, skin, and respiratory tract diseases were similarly significant (4-5%). Only one clinical study on fucoxanthin's ability to prevent obesity has been published in the past five years[9].

PROPERTIES

ANTI-OXIDANT ACTIVITY

Oxygen was an essential molecule for all living cells. It plays an important role in cell maintenance and the associated regulation of energy production through the generation of ROS. Excessive levels of ROS cause various pathological events as well as the deterioration of the body's antioxidant defense system. Antioxidants can scavenge free radicals. It uses singlet oxygen, hydrogen peroxide, superoxide anion, and DPPH to protect cells from the damaging effects of oxidative stress. Oxidative stress results from an imbalance between oxidative and antioxidant molecules[10]. In cell-free in vitro assays, the antioxidant activity of fucoxanthin extracted from brown algae increased the levels of DPPH radical scavenging activity and iron chelating activity, and decreased reducing capacity in cell-free in vitro[11]. In mice with alcoholic liver injury, hepatic total antioxidant capacity (T-AOC) and increased levels of glutathione peroxidase(GSH-Px), Superoxide dismutase (SOD) and catalase (CAT) are probably caused by activation of Nrf2-mediated antioxidant pathway[12].

ANTI-CANCER AND ANTI TUMOR ACTIVITY

Nowadays, through research, the underlying molecular pathways have been discovered, paving the way for the introduction of various anti-cancer drugs. However, synthetic drugs failed to improve overall patient survival, prompting the scientific community to develop them. new therapeutic agent. Phytochemicals may be a potential source of new anticancer drugs. It subsequently achieved antitumor activity in a mouse model exposure (AOM/DSS), fucoxanthin administration led to suppression of colorectal adenocarcinoma numbers and cyclin D1 levels, and signal Ccr1, Cyclin D1, pSmad2, MAPK, PI3K/AKT, p53, RAS, STAT, TGF-β, Wnt, etc. By transcriptome analysis[13,14].

Fucoxanthin also demonstrated anticancer activity against a breast cancer cell line and a human glioblastoma cell line by reducing cell viability, proliferation and clonogenic potential, migration and invasion, tubulogenesis and angiogenesis. Fucoxanthin treatment caused cytotoxicity and death of HepG2 cancer cells by apoptotic, antioxidant and anti-inflammatory pathways. It showed anticancer activity in MDA-MB-231 human breast cancer cells by reducing VEGF-C, VEGF receptor 3, nuclear factor kappa B, phospho-Akt and phospho-PI3K, micro-LVD, and fucoxanthin[15]. Some reports also suggest that fucoxanthin can be used in combination with other chemotherapeutic agents to achieve maximum benefit from chemotherapy. The above preclinical evidence suggests that fucoxanthin may have the potential to curb one of the most challenging diseases our time and could be considered a novel therapeutic agent against cancer.

ANTI HYPERLIPIDEMIC AND ANTI OBESITY

Obesity, especially central obesity, has a long history of association with hyperlipidemia. For example, high plasma triglyceride levels, high LDL cholesterol, low HDL cholesterol, etc. they are responsible for higher blood glucose, insulin, and high blood sugar levels and all are associated with an increase in cardiovascular risk. Empirical evidence indicates that fucoxanthin may possess anti-obesity and anti-hyperlipidemic properties.

Dietary supplementation of fucoxanthin in HFD-induced obese mice reduced obesity, hyperglycemia, and hyperlipidemia, and improved insulin resistance, possibly through the regulation of IRS-1/PI3 K/Akt and PPARγ/SREBP-1/FAS signaling pathways. Meanwhile, through the IRS-1/PI3K/Akt and AMPK pathways, fucoxanthin reduces hyperglycemia, hyperlipidemia, and insulin resistance in diabetic mice. In oleic acid-induced hepatic adipocytes, fucoxanthin significantly suppresses lipid accumulation, Reduction of lipid peroxidation in hepatocytes via Sirt1/AMPK pathway[16].

CARDIOPROTECTIVE ACTIVITY

Fucoxanthin improved ventricular heart rate and muscle function in an aged C57BL mouse model. The study was conducted using low molecular weight fucoidan and low molecular weight fucoidan (^{LMWF}) and highly stable fucoxanthin alone or in combination. Fucoidan and fucoxanthin improved cardiac morphology and blood expression sevenless 1 (SOS1), growth factor receptor-related protein (GRB2), glycogen synthase kinase 3 beta (GSK3), cAMP response element binding protein (CREB), and insulin receptor substrate 1 (IRS). In another study using an ICR mouse model treated with doxorubicin, fucoxanthin prevented cardiotoxicity. It significantly reduced AST, LDH, and creatine kinase MB (CKMB) levels. In an in vitro

study of rat cardiomyocytes, fucoxanthin prevented doxorubicin-induced oxidative damage and apoptosis. The antioxidant and antiapoptotic effects of fucoxanthin involve the p38, c-Jun N-terminal kinase (JNK), and p53 pathways[17]. H2O2 induced oxidative stress and subsequent apoptosis in rat valve interstitial cells. Fucoxanthin prevented oxidative stress-induced apoptosis by increasing antioxidant activity and inhibiting apoptotic markers caspase-3, caspase-8, and caspases, Caspase-9 etc. Furthermore, it aided cell survival and protected from calcification[18].

RENO-PROTECTIVE ACTIVITY

Kidney disease is a major public health problem worldwide. Inflammation, oxidative stress, apoptosis and fibrosis are the main causes of acute kidney injury (AKI) and chronic kidney disease (CKD) . Evidence suggests that patients with a history of AKI are more likely to develop chronic kidney disease . Progression of CKD increases the risk of death and leads to end-stage renal failure[19]. Fucoxanthin influenced diabetic nephropathy by reducing oxidative stress and fibrosis. If your blood sugar (HG) levels are high -Mesangial cells treated with fucoxanthin significantly reversed the expression of fibronectin (FN), collagen IV, and reactive oxygen species (ROS) induced by HG. Attenuation of oxidative stress and fibrosis by fucoxanthin involves the Akt/Sirt1/FoxO3 signaling pathway. In a mouse model treated with cadmium chloride, fucoxanthin protected the kidney by inhibiting oxidative stress and apoptosis and restoring mitochondrial structural integrity. This resulted in a significant decrease in apoptosis-related markers such as caspase-3 and caspase-9. It improved antioxidant activity by increasing SOD, CAT, and peroxidase (POD) levels[20].

NEUROPROTECTIVE ACTIVITY

The brain is constantly exposed to numerous toxic insults that cause oxidative stress and neuroinflammation, leading to pathological changes in brain tissue. These phenomena are thought to be related to the pathobiology of neurodegenerative diseases and secondary brain injuries (such as ischemic stroke and head trauma), which are the main causes of cognitive impairment in older adults. Many bioactive compounds, including marine natural products, have been shown to be effective in reducing neuronal damage and ameliorating cognitive impairment[21]. Fucoxanthin provided neuroprotection against H2O2-induced oxidative damage in primary cerebellar granule neurons using a similar protective mechanism. Modified oligomer A 1–42 exhibited lower toxicity in SH-SY5Y cells compared to oligomer A 1–42 when co-incubated with fucoxanthin, suggesting that fucoxanthin mediates structural modification of oligomer A 1–42, resulting in reduced neurotoxicity[22]. Fucoxanthin suppresses OGD/R-induced apoptosis and ROS accumulation in cultured neurons through activation of Nrf2/HO-1 signaling. Neuroprotective effects against hypoxia/reoxygenation (H/R)-induced excitotoxicity in primary hippocampal neurons were reported when fucoxanthin and its derivative fucoxanthinol were added to cultures. The above preclinical data suggest that fucoxanthin has the potential to be developed as a novel therapeutic agent for degenerative brain diseases. Administration of fucoxanthin nanoparticles increases bioavailability in the brain, but further clinical trials are needed[23].

PHLOROTANNINS

Phlorotannins are a group of phenolic secondary metabolites isolated from various species of brown algae belonging to the families Fucaceae, Sargassaceae and Alariaceae. Isolation of phlorotannins from various algae species have attracted much interest due to the fact that they have a number of biological features and are highly biocompatible in their applications. The present review examines in detail the uses of phlorotannins, which have been widely studied for their above-mentioned biological effects and their underlying mechanism of action. Additionally, the current review suggests many ways to use phlorotannins to avoid some drawbacks such as low stability. This review article will help the scientific community explore the broader biological significance of phlorotannins and develop innovative treatments for human infectious and non-infectious diseases. Phlorotannins have a wide range of biological therapeutic effects, including antibacterial, antidiabetic, antioxidant, anticancer, anti inflammatory, antiadipogenic, and many other biomedical applications.

PROPERTIES

ANTI-INFLAMMATORY AND IMMUNOMODULATORY

Inflammation is the body's response to a harmful stimulus, such as an infection or injury, and causes symptoms such as cramps, pain, fever, and swelling. The inflammatory response is an immunological

response to exogenous and endogenous signals that serves as a host defense system against potentially harmful stimuli[24]. Inflammatory responses are essential for survival and play important roles in cell physiology. Further, uncontrolled excessive inflammation causes various chronic diseases. Anti-inflammatory drugs include both steroidal and non-steroidal drugs used to treat inflammation. Phlorotannins isolated from Fucales were found to be non-toxic at concentrations between 31.25 and 500 g/mL. In LPS-activated RAW 264.7 cells, phloroglucinol decreased the production of inflammatory mediators such as interleukin-6 (IL-6), interleukin-1 (IL-1), tumor necrosis factor (TNF-), and prostaglandin E2 (PGE2) in LPS-stimulated RAW 264.7 cells[25].

ANTI-CANCER ACTIVITY

Over the years, treatments for various forms of cancer have been developed. However, both normal cells and cancer cells. Similarly, anticancer drugs can have negative effects on normal cells. Additionally, cancer drugs are highly toxic, and cancer patients often experience side effects after treatment. These issues explain why research is being conducted to find new treatments to replace existing ones. The anticancer properties of many metabolites isolated from living organisms have been studied. Research shows that most natural anti-cancer compounds have no side effects and control the growth of cancer cells[26].

Phlorotannins prevent cancer by increasing the number of cytotoxic T lymphocytes, dendritic cells, epithelial-mesenchymal transition process, matrix metalloproteinases, phagocyte release, and decreasing the expression of SLUG and VEGF. Furthermore, phlorotannins regulate the induction of apoptosis by increasing the expression of apoptotic antigen 1 (APO-1), B cell lymphoma protein 2 (Bcl-2), caspase-3, -7, -9, cysteinyl aspartate-specific proteinase (casp), and suppressing the expression of protein kinase B (AKT), B cell lymphoma extralarge protein (Bcl-xL), extracellular signaling kinase (ERK) pathway, FLICE (FADD-like IL-1 converting enzyme) inhibitory protein (FLIP), nuclear factor kB (NF-B), phosphoinositide 3-kinase (PI3K) pathway, and X-related pathway. Inhibitor of apoptosis (XIAP) Diekol extracted from E. cava is cytotoxic to A2780 and SKOV3 ovarian cancer cells as reported[27].

ANTI-ADIPOGENESIS ACTIVITY

Adipogenic transcription factors, which control enzymes involved in lipid metabolism, induce adipogenesis. transcription factors such as CCAAT/enhancer binding protein (C/EBP) and peroxisomes; In particular, growth factor-activated receptors (PPARs) directly influence adipogenesis. Adipocyte hypertrophy and hyperplasia are induced during adipogenesis by the expression of adipogenesis-specific genes. The model used to evaluateadipogenesis and adipocyte differentiation is the 3T3-L1 cell model. Although several anti-obesity drugs have been developed to treat obesity, current obesity treatments have serious side effects[28].

CONCLUSION

These bioactive constituents not only offer promising avenues for regulating lipid metabolism and combating oxidative stress but also demonstrate potential in addressing complex conditions such as arthritis, depression, cognitive impairment, and cancer.

The multifaceted benefits of Fucus vesiculosus highlight the intricate interplay of its chemical components in enhancing animal well-being, improving immune function, and possibly mitigating chronic diseases. Moreover, the durability of its bioactive compounds through digestive processes suggests feasibility for practical applications in animal feed, which could translate into improved productivity and health outcomes. Despite its demonstrated potential, the relative underexploration of this species compared to other algae underscores the need for more comprehensive research to fully elucidate its mechanisms and optimize its use.

Looking ahead, the integration of Fucus vesiculosus into animal nutrition and pharmaceutical fields promises to unlock novel, sustainable strategies for health management. Continued investigation into its bioactive profile and functional resilience will not only deepen our understanding of marine algae's role in biological systems but also pave the way for innovative applications that harness nature's complexity to address pressing health challenges. In embracing the untapped potential of Fucus vesiculosus, we stand at the threshold of advancing both animal health and broader biomedical science through the gifts of the marine environment.

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