IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

"Marine Drugs In The Management Of Diabetes Mellitus: Pharmacognostic And Therapeutic Perspectives"

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Abstract

The marine ecosystem represents one of the richest sources of bioactive natural products, many of which possess remarkable therapeutic potential against chronic human diseases. Among these, diabetes mellitus (DM)—a complex metabolic disorder characterized by chronic hyperglycemia—has emerged as a global health challenge requiring innovative treatment strategies. Conventional antidiabetic drugs often exhibit limitations such as side effects, drug resistance, and limited efficacy in long-term glycemic control. Consequently, the exploration of marine-derived compounds has gained significant scientific attention as an alternative or complementary therapeutic approach.Marine organisms, including sponges, algae, seaweeds, tunicates, mollusks, corals, cyanobacteria, and marine fungi, produce diverse secondary metabolites such as alkaloids, terpenoids, peptides, polysaccharides, sterols, and polyphenols, many of which exhibit antidiabetic, antioxidant, and anti-inflammatory activities. These compounds act through multiple mechanisms, including enhancement of insulin secretion, inhibition of carbohydrate-digesting enzymes (α-amylase and α-glucosidase), modulation of glucose uptake, and protection of pancreatic β-cells against oxidative stress.Recent pharmacological and molecular studies have identified several marine bioactives—such as fucoidan, phlorotannins, bromophenols, and marine peptides—with significant potential for development into new classes of antidiabetic agents. Furthermore, advances in biotechnological extraction, purification, and molecular docking techniques have accelerated the discovery of novel marine-based compounds targeting key enzymes like DPP-IV, PTP1B, and α-glucosidase.This review provides a comprehensive overview of marine pharmacognosy, summarizing the chemical nature, pharmacological mechanisms, and therapeutic implications of marine-derived antidiabetic drugs. It also highlights recent advances, challenges, and future prospects in harnessing marine biodiversity for sustainable diabetes management and drug discovery.

Keywords

Marine drugs; Diabetes mellitus; Marine pharmacognosy; Antidiabetic activity; Marine algae; Seaweed bioactives; Fucoidan; Phlorotannins; α-glucosidase inhibitors; Insulin secretion; Marine peptides; Natural product drug discovery.

1. Introduction

Diabetes mellitus (DM) is one of the most prevalent metabolic disorders worldwide, characterized by chronic hyperglycemia resulting from defects in insulin secretion, insulin action, or both. It leads to severe long-term complications including neuropathy, nephropathy, retinopathy, cardiovascular diseases, and impaired wound healing. According to the International Diabetes Federation (IDF, 2023), more than 530 millionadults globally are living with diabetes, a number projected to rise significantly by 2030.

The management of diabetes primarily involves oral hypoglycemic agents such as sulfonylureas, biguanides (metformin), DPP-IV inhibitors, and insulin therapy. However, despite their clinical effectiveness, these synthetic drugs are often associated with adverse effects, high costs, and reduced efficacy over long-term use due to tolerance and drug resistance. Consequently, there is an urgent need to identify novel, safer, and more effective antidiabetic agents, especially those derived from natural sources.

1.1 The Role of Marine Pharmacognosy in Drug Discovery

Marine pharmacognosy—the study of bioactive compounds derived from marine organisms—has emerged as a promising field in natural product research. The marine environment, covering nearly 70% of the Earth's surface, harbors an extraordinary diversity of organisms that produce unique chemical structures not found in terrestrial plants.

These organisms are exposed to extreme conditions of salinity, pressure, and temperature, leading to the biosynthesis of structurally diverse secondary metabolites such as alkaloids, peptides, polysaccharides, terpenoids, sterols, and phenolic compounds with potent pharmacological activities.

Marine organisms such as macroalgae (seaweeds), microalgae, cyanobacteria, sponges, mollusks, corals, and tunicates have been identified as valuable sources of bioactive compounds with potential applications in treating diabetes and other metabolic disorders.

1.2 Importance of Marine-Derived Compounds in Diabetes Management

Marine natural products have shown multifunctional antidiabetic activities, including:

- Inhibition of key enzymes involved in carbohydrate metabolism such as α-amylase, α-glucosidase, and dipeptidyl peptidase-IV (DPP-IV), thereby delaying glucose absorption.
- Enhancement of insulin secretion and increased glucose uptake by peripheral tissues.
- Antioxidant and anti-inflammatory effects, reducing oxidative stress-mediated β-cell damage.
- Modulation of lipid metabolism and protection against diabetic complications.

Moreover, marine-derived polysaccharides such as fucoidan, alginate, and laminarin, and phenolic compounds like phlorotannins and bromophenols, exhibit excellent biocompatibility, low toxicity, and high efficacy, making them potential candidates for nutraceutical and pharmaceutical development.

1.3 Need for Exploration and Sustainable Utilization

Despite significant progress, only a small fraction of marine biodiversity has been explored for medicinal purposes. Continuous efforts in bioprospecting, bioassay-guided isolation, and molecular characterization are essential to identify and develop new marine-derived antidiabetic drugs. Additionally, the application of computational biology, molecular docking, and structure–activity relationship (SAR) studies further supports the rational design of marine-based therapeutic agents.

In summary, marine pharmacognosy represents a frontier in diabetes management research, offering a sustainable and rich reservoir of bioactive compounds capable of addressing the limitations of conventional therapies.

2. Marine Sources with Antidiabetic Potential

The marine environment is an inexhaustible reservoir of bioactive natural compounds exhibiting diverse pharmacological activities. Various marine organisms—including algae, sponges, tunicates, mollusks, cyanobacteria, and marine fungi—produce metabolites that exhibit antidiabetic, antioxidant, and anti-inflammatory properties.
These compounds act via multiple mechanisms such as enzyme inhibition, enhancement of insulin sensitivity, and amelioration of oxidative stress, thereby offering new avenues for diabetes management.

Marine-derived compounds are structurally distinct from terrestrial metabolites due to unique environmental pressures like high salinity, extreme pressure, and variable temperatures. This biochemical diversity provides novel scaffolds for drug discovery.

2.1 Marine Algae (Seaweeds)

Marine algae—classified as brown (Phaeophyceae), red (Rhodophyceae), and green (Chlorophyceae) algae—are among the richest sources of antidiabetic compounds. They contain polysaccharides, phenolic compounds, carotenoids, sterols, and peptides, many of which demonstrate α-glucosidase and α-amylase inhibitory activities, reduction in postprandial hyperglycemia, and improved insulin sensitivity.

- Brown algae (e.g., *Fucus vesiculosus*, *Sargassum spp.*) contain fucoidan, laminarin, and phlorotannins with potent hypoglycemic properties.
- Red algae (e.g., *Gracilaria spp.*, *Palmaria palmata*) contain bromophenols and sulfated galactans that act as natural α-glucosidase inhibitors.
- Green algae (e.g., *Ulva lactuca*, *Caulerpa racemosa*) are rich in chlorophyll derivatives and flavonoids, which exhibit antioxidant and glucose-lowering effects.

2.2 Marine Sponges

Marine sponges are prolific producers of alkaloids, peptides, and sterols that exhibit enzyme inhibitory and insulin-sensitizing properties.
Compounds like sesterterpenes, brominated alkaloids, and quinone derivatives from sponges have shown inhibition of protein tyrosine phosphatase 1B (PTP1B)—a key enzyme regulating insulin signaling.

Examples include:

- Discorhabdins (from *Latrunculia spp.*) – potent PTP1B inhibitors.
- Manzamine A (from *Haliclona spp.*) – shows glucose-lowering and anti-inflammatory activity.

2.3 Marine Cyanobacteria

Cyanobacteria (blue-green algae) produce unique bioactive peptides such as microcystins, cryptophycins, and cyclopeptides with potential metabolic regulatory effects.
Their protein and pigment extracts (phycocyanin, allophycocyanin) exhibit strong antioxidant and glucose-lowering properties through inhibition of lipid peroxidation and oxidative stress modulation in pancreatic β-cells.

2.4 Marine Mollusks and Tunicates

Marine mollusks (e.g., *Conus spp.*, *Aplysia spp.*) and tunicates (e.g., *Didemnum spp.*) produce bioactive peptides and alkaloids that modulate glucose metabolism.
Some peptides from these organisms mimic the action of insulin or enhance GLP-1 receptor activation, improving glucose utilization.

2.5 Marine Fungi and Bacteria

Marine fungi and bacteria are emerging sources of novel bioactive metabolites such as polyketides, terpenoids, and flavonoid-like compounds.
Examples include:

- Aspergillus and Penicillium species producing compounds that inhibit α-glucosidase and DPP-IV.
- Streptomyces-derived polyphenols with insulin-sensitizing effects.

Table 1: Major Marine Sources, Bioactive Compounds, and Antidiabetic Mechanisms

Marine Source	Bioactive Compound(s)	Mechanism of Action	Biological Effect	Reference Example
Brown algae (*Fucus vesiculosus*)	Fucoidan, Phlorotannins	Inhibition of α-glucosidase and α-amylase	↓ Blood glucose, ↑ insulin sensitivity	Kim et al., 2016
Red algae (*Gracilaria spp.*)	Bromophenols, Sulfated polysaccharides	Enzyme inhibition, antioxidant	↓ Postprandial glucose	Li et al., 2017
Green algae (*Ulva lactuca*)	Flavonoids, Chlorophyll derivatives	Antioxidant, β-cell protection	↓ Lipid peroxidation	Suresh et al., 2019
Sponges (*Haliclona spp.*)	Manzamine A	PTP1B inhibition, anti-inflammatory	↑ Insulin sensitivity	Hirata et al., 2018
Cyanobacteria (*Spirulina platensis*)	Phycocyanin	Enhances insulin secretion, antioxidant	↓ Fasting glucose	Singh et al., 2020
Marine fungi (*Aspergillus niger*)	Polyketides	DPP-IV and α-glucosidase inhibition	↓ Glucose absorption	Chen et al., 2021
Marine bacteria (*Streptomyces spp.*)	Phenolic metabolites	Improves glucose uptake	↑ GLUT-4 translocation	Zhao et al., 2022

3. Mechanisms of Antidiabetic Action of Marine-Derived Compounds

Marine-derived compounds exert antidiabetic effects through multiple cellular and molecular mechanisms, often involving modulation of insulin secretion, glucose absorption, oxidative stress, and inflammatory pathways.
Unlike synthetic drugs that act via a single target, marine natural products display multi-target pharmacology, which contributes to both glycemic control and protection against diabetic complications.

The major mechanisms can be broadly categorized into the following pathways:

3.1 Inhibition of Carbohydrate Digestive Enzymes

One of the primary mechanisms is the inhibition of key digestive enzymes such as α-amylase and α-glucosidase, responsible for the hydrolysis of complex carbohydrates into glucose.

- Marine polysaccharides (fucoidan, alginate) and bromophenols competitively inhibit these enzymes.
- This delays carbohydrate digestion and glucose absorption, thereby reducing postprandial hyperglycemia.
- The mechanism resembles the action of acarbose, a synthetic α-glucosidase inhibitor.

Example:
Phlorotannins from *Ecklonia cava* (brown algae) show potent α-glucosidase inhibition with IC_{50} values lower than acarbose.

3.2 Enhancement of Insulin Secretion and β-Cell Function

Several marine-derived compounds enhance insulin secretion from pancreatic β-cells or protect them from oxidative damage.

- Phycocyanin from *Spirulina platensis* increases insulin gene expression and promotes β-cell regeneration.
- Marine peptides from *Conus* species mimic insulin-like activity, stimulating glucose uptake in peripheral tissues.
- Fucoxanthin, a carotenoid from brown algae, has been shown to preserve pancreatic architecture and reduce apoptosis of β-cells.

3.3 Improvement of Insulin Sensitivity

Marine-derived bioactives improve insulin sensitivity through regulation of insulin receptor substrate (IRS) and GLUT-4 translocation in muscle and adipose tissues.

- Manzamine A from sponges and polyphenols from seaweeds activate AMP-activated protein kinase (AMPK), enhancing glucose utilization.
- Certain marine lipids modulate PPARγ (Peroxisome proliferator-activated receptor gamma), improving insulin receptor signaling.

This mechanism is particularly relevant in type 2 diabetes, where insulin resistance is the major pathological factor.

3.4 Antioxidant and Anti-inflammatory Activity

Oxidative stress plays a major role in β-cell dysfunction and insulin resistance. Marine bioactives provide powerful antioxidant protection.

- Fucoidan, astaxanthin, and phlorotannins scavenge free radicals and upregulate endogenous antioxidant enzymes (SOD, CAT, GPx).
- Marine carotenoids reduce NF-κB and TNF-α expression, lowering systemic inflammation.
- This dual antioxidant–anti-inflammatory action protects against diabetic complications such as nephropathy, neuropathy, and retinopathy.

3.5 Modulation of Gut Microbiota

Recent studies indicate that marine polysaccharides act as prebiotics, modulating the gut microbiome and enhancing metabolic homeostasis.

- Alginate and laminarin increase the abundance of beneficial bacteria (*Lactobacillus*, *Bifidobacterium*), leading to improved glucose tolerance.
- This emerging mechanism highlights the role of marine nutraceuticals in metabolic regulation through the gut-brain axis.

Table 2: Mechanisms of Antidiabetic Action of Marine Bioactives

Mechanism	Marine Compound(s)	Source	Pharmacological Effect	Experimental Model
α-glucosidase inhibition	Phlorotannins, Bromophenols	Brown and Red Algae	↓ Postprandial glucose	In vitro, rat models
β-cell protection & insulin secretion	Phycocyanin, Fucoxanthin	Cyanobacteria, Brown algae	↑ Insulin release, ↓ β-cell apoptosis	STZ-induced diabetic rats
Insulin sensitization	Manzamine A, Marine polyphenols	Marine sponges, seaweeds	↑ GLUT-4 expression, ↑ AMPK activation	Type 2 diabetic mice
Antioxidant/anti-inflammatory	Fucoidan, Astaxanthin	Brown algae, microalgae	↓ ROS, ↓ NF-κB signaling	Diabetic cell lines
Gut microbiota modulation	Alginate, Laminarin	Brown algae	↑ SCFA production, improved glucose tolerance	In vivo mouse studies

4. Pharmacognostic Aspects of Marine Drugs

Pharmacognostic studies are essential for the identification, authentication, extraction, and characterization of bioactive compounds derived from marine organisms. Unlike terrestrial plants, marine organisms require specialized collection, preservation, and extraction techniques due to their delicate structures and the influence of environmental conditions (salinity, temperature, pressure, and habitat depth).
These studies ensure quality control, standardization, and reproducibility of marine-derived therapeutic agents.

4.1 Collection and Authentication

Marine organisms such as algae, sponges, mollusks, cyanobacteria, and fungi are collected from coastal or deep-sea environments through manual collection, trawling, or scuba-assisted sampling.

- Identification is performed based on morphological, anatomical, and molecular features.
- Taxonomic authentication is done using microscopy and DNA barcoding (using COI, 18S rRNA, or ITS sequences).
- The authenticated samples are preserved by freeze-drying or ethanol fixation to maintain bioactive integrity.

4.2 Morphological and Microscopic Characteristics

Marine drugs exhibit distinctive features based on their source:

Marine Source	Morphological Characteristics	Microscopic/Histological Features
Brown Algae (Phaeophyceae)	Brown to olive color; leathery texture; fronds with air bladders	Multicellular thallus, medullary and cortical layers with alginates
Red Algae (Rhodophyceae)	Reddish or purple thallus; gelatinous consistency	Presence of floridean starch, carrageenan vesicles
Green Algae (Chlorophyceae)	Bright green filaments or sheets	Cell walls rich in cellulose and ulvan polysaccharides
Marine Sponges	Porous, soft to fibrous body; various colors	Network of spicules and spongin fibers
Marine Fungi	Cottony or powdery colonies on sea substrates	Hyaline septate hyphae with conidial structures

4.3 Extraction and Isolation of Marine Bioactives

Marine samples undergo specialized extraction techniques to isolate bioactive metabolites:

- **Solvent extraction:** Methanol, ethanol, ethyl acetate, and water are used based on polarity.
- **Ultrasonic-assisted extraction (UAE):** Enhances yield without degradation of thermolabile compounds.
- **Supercritical fluid extraction (SFE):** Eco-friendly method using CO_2 for lipophilic compound extraction.
- **Liquid–liquid partitioning:** Used to fractionate polar and nonpolar components.

After extraction, the crude extract is subjected to fractionation and purification using:

- Column chromatography (Silica gel, Sephadex LH-20)
- High-performance liquid chromatography (HPLC)
- Gas chromatography–mass spectrometry (GC–MS)
- Liquid chromatography–mass spectrometry (LC–MS/MS)

4.4 Phytochemical Screening

Preliminary phytochemical analysis helps determine the chemical nature of the marine extract. Common tests include:

Phytochemical Class	Test Method	Expected Result (Positive Indication)
Alkaloids	Dragendorff's and Mayer's reagents	Orange/red precipitate
Flavonoids	Shinoda and Alkaline reagent test	Pink or red coloration
Steroids and Terpenoids	Liebermann–Burchard test	Blue-green color
Phenolic compounds	Ferric chloride test	Blue/black coloration
Carbohydrates/Polysaccharides	Molisch's and Benedict's test	Violet ring or red precipitate
Proteins/Peptides	Biuret test	Violet coloration
Saponins	Froth test	Persistent foam formation

4.5 Spectroscopic Characterization

To confirm the chemical identity and structural elucidation of isolated marine compounds, **spectroscopic techniques** are applied:

- **UV-Visible spectroscopy** – Determines conjugation and chromophore presence.
- **FTIR (Fourier Transform Infrared Spectroscopy)** – Identifies functional groups (OH, C=O, NH).
- **NMR (^{1}H and ^{13}C Nuclear Magnetic Resonance)** – Provides molecular structure information.
- **Mass spectrometry (MS)** – Determines molecular weight and fragmentation pattern.
- **X-ray crystallography** – Confirms the 3D arrangement of atoms in crystalline metabolites.

4.6 Quality Control and Standardization

Pharmacognostic standardization ensures the purity, potency, and reproducibility of marine-derived products.
It involves:

- Moisture content determination (Karl Fischer or oven drying method).
- Ash values (total, acid-insoluble, and water-soluble ash).
- Extractive values in different solvents.
- Chromatographic fingerprinting using HPTLC or HPLC for chemical consistency.

These parameters ensure compliance with WHO guidelines for natural product standardization.

5. Pharmacological Evaluation and Clinical Studies of Marine-Derived Antidiabetic Agents

The pharmacological evaluation of marine-derived antidiabetic compounds involves a series of in vitro, in vivo, and clinical studies designed to elucidate their mechanism of action, efficacy, and safety.
These studies validate the traditional and experimental claims of marine bioactives in diabetes management and establish their therapeutic potential as novel antidiabetic drugs.

5.1 In Vitro Evaluation

In vitro assays are conducted to determine the biochemical and cellular effects of marine extracts or isolated compounds. They help identify potential enzyme inhibitors, antioxidants, and insulin-mimetic agents before in vivo testing.

Commonly Used In Vitro Methods:

1. **α-Amylase and α-Glucosidase Inhibition Assays** – Measure carbohydrate hydrolysis inhibition.
2. **DPP-IV Enzyme Inhibition** – Evaluates incretin (GLP-1) regulation.
3. **Glucose Uptake Assays** – Performed using 3T3-L1 adipocytes or L6 myotubes to assess insulin sensitivity.
4. **β-Cell Protection and Insulin Secretion Assays** – Using INS-1 or MIN6 pancreatic cells.
5. **Antioxidant Assays** – DPPH, ABTS, and FRAP methods to determine radical scavenging ability.

Table 3: In Vitro Pharmacological Studies of Marine Antidiabetic Compounds

Marine Source	Bioactive Compound/Extract	Test System	Activity Observed	Reference
Ecklonia cava (Brown Algae)	Phlorotannins	α-glucosidase assay	Strong inhibitory activity (IC_{50} < 50 µg/mL)	Kim et al., 2016
Spirulina platensis (Cyanobacteria)	Phycocyanin	β-cell line (INS-1)	↑ Insulin secretion and β-cell viability	Singh et al., 2020
Haliclona spp. (Sponge)	Manzamine A	PTP1B inhibition assay	Potent enzyme inhibition, improved insulin sensitivity	Hirata et al., 2018
Aspergillus niger (Marine Fungus)	Polyketide fraction	DPP-IV inhibition assay	Inhibition of incretin degradation	Chen et al., 2021
Ulva lactuca (Green Algae)	Ethanolic extract	Glucose uptake in L6 cells	↑ Glucose uptake by 1.8-fold	Suresh et al., 2019

5.2 In Vivo Evaluation

Animal models provide insights into the systemic antidiabetic effects of marine-derived compounds. They allow assessment of glucose homeostasis, lipid profile, oxidative stress markers, and pancreatic histopathology.

Commonly Used Models:

- Alloxan- or Streptozotocin (STZ)-induced diabetic rats or mice – Mimic type 1 and type 2 diabetes.
- High-fat diet and nicotinamide models – Used for insulin resistance studies.
- Genetic models such as ob/ob or db/db mice – For chronic diabetic investigations.

Table 4: In Vivo Pharmacological Studies of Marine-Derived Antidiabetic Compounds

Marine Source	Compound/Extract	Animal Model	Pharmacological Effect	Reference
Sargassum muticum (Brown Algae)	Fucoidan	STZ-induced diabetic rats	↓ Blood glucose, ↑ insulin, ↓ HbA1c	Li et al., 2018
Spirulina platensis	Phycocyanin	Alloxan-induced diabetic mice	↓ Fasting glucose, ↑ antioxidant enzymes	Singh et al., 2020
Gracilaria changii (Red Algae)	Methanolic extract	HFD + STZ model	↓ Serum cholesterol, ↑ GLUT-4 expression	Tan et al., 2021
Haliclona sp. (Sponge)	Manzamine A	db/db mice	↓ Blood glucose, ↓ TNF-α, ↑ insulin sensitivity	Hirata et al., 2018
Aspergillus fumigatus (Marine fungus)	Ethyl acetate extract	Alloxan-induced diabetic rats	↓ Glucose, ↑ hepatic glycogen	Zhao et al., 2022

5.3 Clinical Studies and Human Applications

Although most marine-derived compounds are in preclinical stages, some marine nutraceuticals have shown promise in human trials.

Notable Clinical Evidence:

- Spirulina supplementation (2 g/day) demonstrated significant reductions in fasting blood glucose and HbA1c levels in type 2 diabetic patients.
- Fucoidan from brown algae improved insulin sensitivity and lipid metabolism in small-scale clinical trials.
- Marine omega-3 fatty acids (EPA, DHA) reduced insulin resistance and inflammation in diabetic and prediabetic subjects.

Table 5: Human Studies on Marine-Derived Nutraceuticals

Marine Product	Study Design	Participants	Outcome	Reference
Spirulina platensis powder	12-week clinical trial	60 Type 2 diabetic patients	↓ FBG, ↓ HbA1c, ↑ antioxidant status	Parikh et al., 2018
Fucoidan-rich seaweed extract	Randomized, double-blind	40 insulin-resistant subjects	Improved glucose tolerance, lipid profile	Kim et al., 2020
Omega-3 fatty acids (Fish oil)	Meta-analysis of RCTs	>800 diabetic participants	↓ Insulin resistance, ↓ triglycerides	Li et al., 2019

5.4 Toxicity and Safety Evaluation

Toxicological assessments ensure that marine-derived compounds are safe for human use.

- Acute toxicity tests (OECD 423) show no mortality at doses up to 2000 mg/kg for most marine extracts.

- Subchronic studies confirm no hepatic or renal toxicity in long-term administration.
- Marine polysaccharides and carotenoids are generally recognized as safe (GRAS) by FDA for nutraceutical applications.

6. Conclusion

Marine environments represent an untapped treasure of bioactive compounds with significant potential in the management of diabetes mellitus. The vast chemical diversity of marine organisms—including algae, sponges, cyanobacteria, fungi, and mollusks—has yielded numerous compounds such as fucoidan, phlorotannins, phycocyanin, and manzamine A, all of which demonstrate promising antidiabetic, antioxidant, and insulin-sensitizing properties.

These marine-derived compounds act through multifaceted mechanisms, including the inhibition of carbohydrate-hydrolyzing enzymes, enhancement of insulin secretion, stimulation of glucose uptake, antioxidant defense, and modulation of gut microbiota. Unlike synthetic oral hypoglycemics, they provide broad metabolic regulation with fewer side effects.

Pharmacognostic studies ensure the identification, standardization, and quality assurance of these marine sources, while pharmacological and clinical studies validate their efficacy and safety. The integration of modern analytical techniques (HPLC, LC–MS, NMR) and biotechnological tools such as molecular docking, metabolomics, and omics profiling further enhances the discovery of novel marine therapeutics.

Despite these advances, challenges remain—such as sustainable harvesting, low yield of active compounds, and complex purification processes. Future research should focus on biotechnological production, structure–activity relationship (SAR) studies, and clinical validation to translate these marine bioactives into standardized, affordable, and effective antidiabetic medications.

In conclusion, marine pharmacognosy provides a promising frontier for the discovery of novel antidiabetic agents, potentially transforming diabetes management through eco-sustainable and biochemically diverse marine resources.

7. References

1. Kim, S. K., & Wijesekara, I. (2016). Development and biological activities of marine-derived bioactive peptides: A review. Journal of Functional Foods, 15, 555–565.
2. Li, Y., Lee, S. H., Le, Q. T., & Kim, M. M. (2017). Antidiabetic activity of marine algal polyphenols. Marine Drugs, 15(10), 301.
3. Hirata, H., Tanaka, T., & Kuroda, T. (2018). Manzamine A from marine sponge Haliclona sp. improves insulin sensitivity in diabetic mice. Bioorganic & Medicinal Chemistry, 26(2), 331–339.
4. Singh, A., Verma, P., & Rajput, R. (2020). Phycocyanin from Spirulina platensis modulates insulin secretion and oxidative stress in diabetic rats. Pharmacognosy Research, 12(4), 245–252.
5. Chen, L., Zhao, X., & Zhou, Y. (2021). Marine fungal metabolites as inhibitors of DPP-IV: Potential antidiabetic applications. Journal of Applied Microbiology, 131(5), 1304–1315.
6. Tan, W. Y., Lim, P. Y., & Chan, K. L. (2021). Antidiabetic potential of Gracilaria changii methanolic extract in experimental rats. Journal of Ethnopharmacology, 275, 114112.
7. Zhao, Q., Wang, Y., & Li, J. (2022). Antidiabetic activity of marine fungal extracts in alloxan-induced diabetic rats. Marine Drugs, 20(2), 72.
8. Parikh, P., Mani, U., & Iyer, U. (2018). Role of Spirulina platensis in the management of type 2 diabetes mellitus. Journal of Medicinal Food, 21(2), 1–7.

9. Kim, E. A., & Jeon, Y. J. (2020). Fucoidan from brown algae as an antidiabetic agent: Clinical evaluation and mechanism of action. Marine Drugs, 18(3), 192.

10. Li, D., Zhao, Y., & Xu, Z. (2019). Marine omega-3 fatty acids and insulin resistance: A systematic review. Nutrients, 11(11), 2432.

11. WHO Guidelines (2021). Quality control methods for medicinal plant materials. Geneva: World Health Organization.

12. Suresh, V., Kumar, M., & Bhatia, R. (2019). Green algae-derived antioxidants as natural antidiabetic agents. Asian Journal of Pharmaceutical Sciences, 14(3), 256–266.