Current Pharmaceutical Research (CPR)
Vol 1, Issue 2, April-June 2025
Journal Homepage: www.cpr.in

Neuroprotective Effects of Seaweeds in Alzheimer's Disease: A Review

[1]Shivmohan, [1]Gurpreet Kaur, [1]Shivam Kumar, [1]Nisha*

[1]*School of Pharmacy, Desh Bhagat University, Mandi Gobindgarh, Punjab, India*

Keywords

Alzheimer's disease (AD), Neurodegenerative disease, Cognitive impairment, Memory impairment, Neuropsychiatric symptoms, Marine compounds, Seaweeds.

Abstract

Alzheimer's disease (AD) is a progressive neurodegenerative disorder with symptoms of progressive cognitive decline, including memory loss. The rapid worldwide increase in prevalence of AD highlights a high unmet need for novel AD therapies beyond symptom management. Current pharmacologic interventions, such as cholinesterase inhibitors and NMDA receptor antagonists, provide a marginal benefit in ameliorating disease progression. Thus, we look to onboard alternative ocean-derived bioactive constituents as therapeutics. Some of the bioactive compounds present in brown algae (seaweeds), in particular, such as fucoidan, phlorotannin's, and alginate, demonstrate neuroprotective action by inhibition of oxidative stress and neuroinflammation in addition to the amyloid-induced plaques (the major hallmarks of AD pathology). Antioxidant and anti-inflammatory polysaccharides from green and red algae may also play a role in the preservation of cognitive functions due to their content in species. Preclinical trials in the past have shown that these compounds can be useful for neuroprotection and even disease modification. While this is promising, further research and clinical trials are needed to demonstrate the impact on AD treatment with seaweed-derived compounds. Placing a bet on the new advances of science, marine bioresources, while not neglecting the progress noticed these days in enhancing the lives of AD creatures.

***Corresponding Author:**
Nisha (sharmanishii8@gmail.com)

Article Info
Received: 30 April 2025, Received in revised form: 17 June 2025, Accepted: 18 June 2025, Available online: 30 June 2025

DOI: https://doi.org/10.63785/cpr.2025.1.1.137149

1. Introduction

Alzheimer's disease (AD) is a progressive neurodegenerative disorder that significantly impacts memory, cognition, and behavior [1]. It accounts for 60-80% of all dementia cases globally [2]. AD, also referred to as "tensile dementia," arises from multiple pathogenic mechanisms, including the destruction of the blood-brain barrier (BBB), oxidative stress, and the accumulation of amyloid-beta (Aβ) plaques [3]. As the disease progresses, individuals exhibit neuropsychiatric symptoms such as memory loss, confusion, communication difficulties, mood disturbances, personality changes, and the loss of motor skills [4]. The hallmark feature of Alzheimer's disease is amnestic cognitive impairment [5]. In its early stages, AD often manifests through symptoms such as depression, anxiety, social withdrawal, and changes in sleep patterns [6]. AD is considered the most common cause of dementia and neurodegeneration worldwide, affecting an estimated 55 million people as of the 2021 World Alzheimer Report [7]. The incidence of Alzheimer's disease increases significantly with age, especially in individuals over 65 [8]. Women are at a slightly higher risk than men, with a reported incidence ratio of 1.2 to 1.5. The number of new cases per year is estimated at 360,000, or approximately 980 new cases daily [9]. If current trends continue, the global population of individuals with AD is projected to nearly quadruple over the next 50 years [10].

Historically, Alzheimer's disease was first described by Alois Alzheimer in 1907, with the defining features of amyloid-beta plaques and neurofibrillary tangles [11]. In 2018, nearly 6 million individuals in the United States alone were living with Alzheimer's, with approximately 20,000 cases being early-onset individuals below the age of 65 [12]. The number of AD patients is projected to exceed 100 million by 2050, and the number of cases is expected to double every 20 years, with an estimated 80 million cases by 2040 [13]. The neuropathological hallmark of AD is the accumulation of misfolded tau protein in the

hippocampus, forming neurofibrillary tangles [14]. In addition, mitochondrial Dysfunction, especially mutations in mitochondrial DNA, has been involved in the pathogenesisof AD, thereby causing oxidative stress and neurodegeneration. Apoptosis, oxidative stress, neuroinflammation, mitochondrial dysfunction, cholinergic dysfunction, and aberrant protein production are some of the mechanisms that contribute to the onset and progression of AD [15].

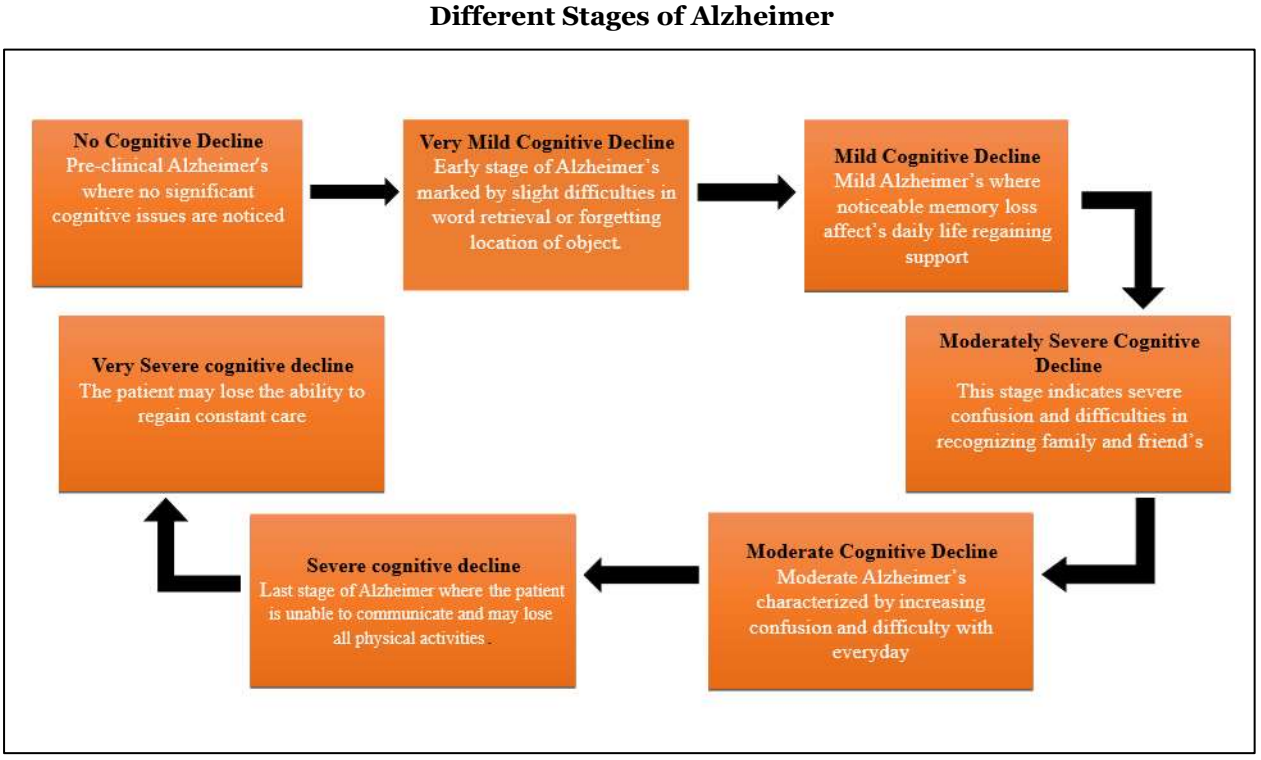

Figure 1: The image illustrates the pathological progression of Alzheimer's disease, beginning with genetic mutations leading to beta-amyloid accumulation, tau hyperphosphorylation, and culminating in neuronal death characteristic of the disease. It provides a visual summary of the key molecular events underlying Alzheimer's pathology.

Currently, treatment for Alzheimer's disease primarily focuses on alleviating symptoms rather than addressing the underlying causes of the disease. As a result, existing therapies do not halt the progression of AD, highlighting the need for more effective treatments [16]. This has sparked significant interest in exploring alternative therapies that may offer better long-term outcomes. One promising avenue of research involves the use of bioactive compounds derived from marine organisms, particularly seaweeds [17]. Seaweeds, or macroalgae, are classified into three major groups: red algae (Rhodophyta), green algae (Chlorophyta), and brown algae (Phaeophyta) [18].

Among these, brown algae are the most widely consumed, accounting for approximately 66.5% of global seaweed consumption. Red algae make up 33%, while green algae represent only 5%. Brown algae thrive in colder, temperate waters, while red and green algae are typically found in warmer, tropical regions [19]. The therapeutic agent derived from brown algae is sodium oligomannate, which is produced through the depolymerization and oxidation of marine brown algae [20]. This compound received conditional approval in China in November 2019 for the treatment of mild to moderate Alzheimer's disease. Seaweed is rich in polysaccharides, which are essential carbohydrates that contribute to both energy storage and structural integrity in living organisms [21]. These polysaccharides, especially sulfated polysaccharides, play a critical role in seaweed's ability to withstand environmental stresses such as ocean waves. Research indicates that sulfated polysaccharides possess significant anti-inflammatory and antioxidant properties, making them potential candidates for therapeutic use in Alzheimer's disease [22].

Oxidative stress and inflammation are key contributors to neurodegenerative diseases like Alzheimer's. Nutraceuticals, which are foods with medicinal benefits, can help prevent cellular damage by combating harmful reactive oxygen species (ROS). Given that seaweed polysaccharides exhibit protective effects, they may offer promising nutraceutical options for AD prevention and treatment [23].

2. Epidemiology of Alzheimer disease

Alzheimer's disease (AD) is something we often see in older adults. Back in 1990, the global number of people living with dementia was around 20.3 million. Fast forward to 2016 and that number shot up to 43.8 million – more than doubling and showing an increase of 116%. Between 1990 and 2019, the rates of both new cases and overall cases of Alzheimer's and other forms of dementia rose greatly, by about 148% and 161%, respectively. The likelihood of developing Alzheimer's disease increases significantly with age, doubling approximately every five years after the age of 65. The incidence rate rises from under 1% per year before the

age of 65 to 6% annually after the age of 85. Similarly, the prevalence of Alzheimer's disease grows from 10% in individuals aged 65 and older to 40% after the age of 85. Women, particularly those over 85, tend to have slightly higher incidence rates of Alzheimer's disease compared to men [24].

3. Etiology of Alzheimer Disease

Alzheimer's disease (AD) is a progressive neurodegenerative condition, marked by the gradual death of brain cells. This process typically starts in the entorhinal cortex, located within the hippocampus. Both genetic and environmental elements play a role in the development of AD. For instance, individuals with Down syndrome (Trisomy 21) are at a higher risk of developing early-onset dementia [25]. AD is influenced by various factors, with age being the most significant. Cardiovascular diseases (CVD) are important risk factors for AD. They not only increase the likelihood of developing Alzheimer's but also contribute to dementia caused by strokes or vascular conditions. CVD is considered a modifiable risk factor, meaning changes in lifestyle and treatment could help reduce the risk of developing AD [26].

Obesity and diabetes are also key modifiable risk factors for Alzheimer's. Obesity can interfere with glucose metabolism, increasing the risk of type 2 diabetes. High blood sugar levels can lead to cognitive decline by promoting the buildup of beta-amyloid plaques and inflammation in the brain. Obesity also increases the risk by triggering inflammation and causing insulin resistance [27]. Other factors that may increase the risk of AD include traumatic brain injury, depression, heart and brain blood vessel issues, older parental age at birth, smoking, family history of dementia, high levels of homocysteine, and the presence of the APOE e4 gene. If someone has a first-degree relative (parent or sibling) with AD, their risk of developing it increases by 10% to 30%. For those with two or more siblings with late-onset AD, the risk is three times higher than the general population [28, 29].

On the other hand, certain factors may help reduce the risk of AD. These include higher levels of education, estrogen therapy in women, use of anti-inflammatory medications, engaging in activities like reading or playing music, maintaining a balanced diet, and regular physical exercise [30].

4. Pathophysiology of Ad

Pathologically, Alzheimer's disease (AD) is characterized by an accumulation of amyloid deposits resulting in neurotic plaques, as well as neurofibrillary tangles that build up in the brain [31]. This accumulation is linked to neuronal loss, particularly of cholinergic neurons, in both the basal forebrain and neocortex. Senile plaques (SP) arise from the deposition of Aβ and are considered a significant pathological feature of AD. Normally, Aβ is a soluble small peptide created by cleavage of the amyloid precursor protein (APP), facilitated by α-secretase, β-secretase, and γ-secretase. When there is an imbalance in Aβ production and removal, it can lead to various types of toxic oligomeric species known as protofibrils, which can also appear as fibrils or plaques, depending on their level of oligomerization [32, 33].

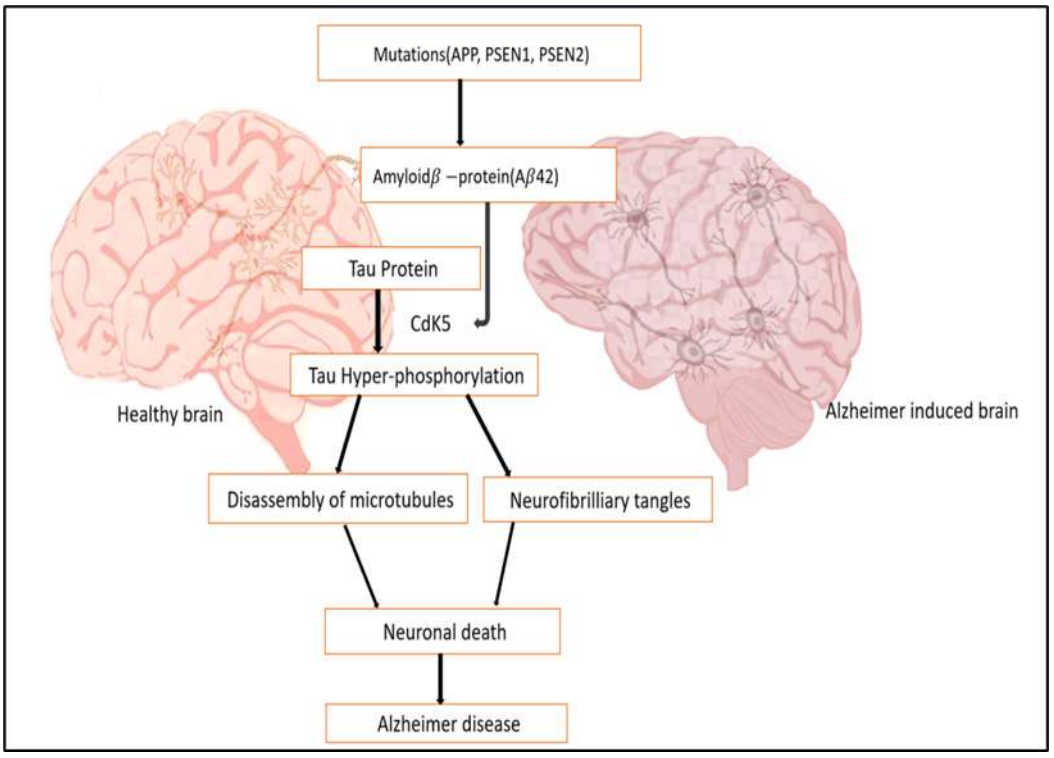

Figure 2: The figure illustrates the pathological progression of Alzheimer's disease, starting with mutations in APP, PSEN1, and PSEN2 genes, leading to amyloid-beta (Aβ42) accumulation. This triggers tau hyperphosphorylation via CdK5, resulting in microtubule disassembly and neurofibrillary tangle formation. Consequently, neuronal death occurs, ultimately leading to Alzheimer's disease.

The reasons behind Aβ generation remain unclear, but factors such as the sequence, concentration, and stability conditions of Aβ are crucial. Several factors, including cholinergic dysfunction, amyloid/tau toxicity, and oxidative stress/mitochondrial dysfunctions, contribute to the pathophysiology of Alzheimer's disease [34]. The amyloid-β pathway is one of the major components of AD pathophysiology. In the brain, the cleavage of amyloid precursor protein (APP) produces amyloid-β peptides. The accumulation of these peptides in the brain prompts an inflammatory response, resulting in damage to nearby brain cells [35].

The tau protein pathway is another fundamental aspect of AD pathophysiology. The hyperphosphorylation of tau protein ultimately leads to its aggregation, forming neurofibrillary tangles through Cdk5. These tangles accumulate inside neurons, disrupting normal cellular function and leading to cell death. According to the cholinergic hypothesis, AD is caused by a deficiency in cholinergic neurotransmitters (such as acetylcholine), which results in memory loss and cognitive decline. The positive effect of acetylcholinesterase inhibitors (AChEIs) for patients suffering from Alzheimer's disease is influenced by the apolipoprotein E (APOE) genotype [36].

The APOE genotype is a significant factor linked to AD, and AChEI medications play a crucial role in AD treatment [37]. The limited impact of APOE is contextualized within the "Cholinergic Hypothesis" of AD, which emerged in 1976, highlighting that cholinergic neurons are not the primary cause of the disease [38]. Additionally, a vascular hypothesis proposes that AD is connected to cerebrovascular disease, resulting in reduced brain perfusion [39]. The increase in hypoxia and oxidative stress, due to diminished blood supply, leads to damage in brain cells and the progression of the disease [40].

5. Histopathology

The typical features of Alzheimer's disease (AD) at the microscopic level include three main elements:

1. Neuritic Plaques: These are tiny, spherical clusters found in the brain. They consist of a central core made up of amyloid beta-peptides (Aβ) surrounded by swollen axon endings. These plaques can form around blood vessels in the brain and the gray matter of the brain's cortex [41]. In some cases, brain scans show amyloid plaques in people who do not have dementia, while some people with dementia may not show any plaques on scans [42].

2. Neurofibrillary Tangles: These are twisted tangles formed inside brain cells, made of a protein called tau. Tau normally helps stabilize the microtubules that transport substances within neurons [43]. In Alzheimer's disease, tau becomes abnormally altered (phosphorylated), which causes it to misfold and form tangles [44]. These tangles start in the hippocampus and later spread to other parts of the brain. The build-up of tau tangles inside neurons contributes to the disease [45].

3. Cortical Neuronal Degeneration: In AD, the neurons in the hippocampus often show signs of damage, including changes known as granulovacuolar degeneration [46]. Cognitive decline in Alzheimer's is more closely linked to a decrease in the number of synaptic connections between neurons in certain layers of the cerebral cortex, particularly in layers III and IV [47]. This reduction in connections likely has a bigger effect on cognitive function than the build-up of amyloid plaques alone [48].

5.1. Evidence and Responses

A wide range of symptoms that accompany Alzheimer's (AD) directly undermine an individual's cognitive and functional skills substantially [49]. Although the manifestations of Alzheimer's disease vary significantly from person to person, some universal signs and symptoms of the same disease are there. Awareness of such signs is crucial for early diagnosis and intervention [50].

5.1.1. Cognitive Symptoms

Memory Loss: Often, the first visible sign, particularly short-term memory loss.
Disorientation: Patients may be confused about time, place, and identity.
Language Issues: Difficulty finding words or following discussions is common.

5.1.2. Non-Cognitive Symptoms

Mood Shifts: Patients may suffer sadness, anxiety, or agitation.
Psychotic Symptoms: They include hallucinations and delusions, which can influence behavior and perception.
Personality Changes: Individuals may show greater paranoia or hostility.

5.2. Functional Impairments

5.2.1. Difficulty with Daily Activities: As the condition develops, individuals may struggle with ordinary duties, increasing reliance.

5.2.2. Behavioral Disturbances: Common symptoms include wandering, social isolation, and irritation. While these symptoms are typical of AD, it is essential to remember that not everyone will have the same symptoms or severity. Furthermore, some individuals may have unusual symptoms, complicating diagnosis and therapy [51-53].

6. Current Treatment and Management of Alzheimer

Latest therapeutic and management strategies of Alzheimer's disease (AD) i.e. focusing on symptomatically symptomatic benefits with little other than a way to improve QOL since no cure is available [54]. Drug treatments: there are cholinesterase inhibitors (Donepezil, Rivastigmine, Galantamine), which work on the cognitive field and may slow down the disease in part benzodiazepines (Memantine)

Neural science research has seen recent breakthroughs too with monoclonal antibodies against amyloid and tau, as well as immunomodulatory and anti-diabetic agents [55, 56]. Cognitive-behavioral strategies, occupational therapy and environmental adaptations are all part of an integrated care [57].

6.1. Pharmacological Treatments

- Cholinesterase Inhibitors: Improve cognitive symptoms by increasing acetylcholine levels.
- NMDA Antagonists: Memantine helps regulate glutamate activity, providing neuroprotective effects.
- Emerging Therapies: Monoclonal antibodies (e.g., donanemab, gantenerumab) target. amyloid plaques and tau tangles.

6.2. Non-Pharmacological Approaches

- Cognitive Interventions: Memory training and cognitive stimulation can enhance daily functioning.
- Behavioral Strategies: Psychoeducation and environmental adjustments help manage neuropsychiatric symptoms.

While current treatments focus on symptom management, ongoing research aims to uncover disease-modifying therapies that could alter the course of AD. However, the complexity of AD suggests that a multifaceted approach combining both pharmacological and non-pharmacological strategies will be essential for effective management [58, 59]. The limitations of current medications for Alzheimer's disease (AD) are significant. Current pharmacological treatments, including cholinesterase inhibitors and NMDA antagonists, primarily offer symptomatic relief rather than addressing the root causes of AD. This means that existing treatments can provide temporary cognitive benefits, they do not halt the underlying neurodegenerative processes [60]. Another major limitation is the difficulty in delivering drugs effectively to the central nervous system due to the blood-brain barrier (BBB). This challenge has led researchers to explore innovative drug delivery methods, such as nanotechnology and intranasal administration, to enhance drug bioavailability in the brain [61].

Furthermore, the incomplete understanding of AD's underlying mechanisms hampers the development of truly disease-modifying treatments. Current research is focused on targeting amyloid and tau pathology, but no clinically approved treatments exist yet. Despite these limitations, ongoing research into novel therapeutic strategies and drug delivery systems holds promise for future advancements in AD treatment. However, the current focus remains on managing symptoms rather than curing the disease [62].

Therapeutic Potential of Seaweeds and Their Bioactive Compounds in Alzheimer's disease. The ocean contains around 90% of the Earth's biomass, with marine creatures accounting for over half of all known species. Marine macroalgae, or seaweed, account for a significant amount of this biomass, with over 10,000 species recorded worldwide. Seaweed has been utilized in medicine for millennia, dating back to 3000 BC, due to its widespread availability worldwide [63].

Seaweeds, or marine macroalgae, are a diverse group of plants that inhabit saltwater environments. They are categorized into three main types: green (Chlorophyceae), brown (Phaeophyceae), and red (Rhodophyceae) algae. Seaweeds have been studied for their ecological roles, nutritional value, and potential applications in various industries [64].

Seaweeds are rich in bioactive compounds that haeve shown promise in combating Alzheimer's disease, Parkinson's disease, and Huntington's disease. These diseases are characterized by progressive neuronal loss and cognitive decline. Current treatments for these conditions are limited and primarily focus on symptom management, rather than disease modification or prevention. Seaweeds, often known as edible marine algae, are an abundant source of phytosterols, carotenoids, and polysaccharides among other bioactive substances [65].

7. Types and Distribution of Seaweeds

Seaweeds are classified into green, brown, and red algae, each with distinct characteristics and ecological roles. Green algae are often found in both freshwater and marine environments, while brown and red algae are predominantly marine. The distribution of seaweeds is influenced by factors such as water temperature, salinity, and nutrient availability [66].

The Brown algae consist of bioactive compounds like fucoidan, phlorotannins, and alginate, which reduce oxidative stress, decrease inflammation, and protect neurons. It can also inhibit the accumulation of beta-amyloid plaques, which are a major contributor to the development of Alzheimer's disease [67]. Brown algae are also rich in iodine and polyphenols, which make them even more effective in managing the disease. In recent years, components produced from seaweed have been shown to not only live in the bloodstream but also pass through the blood-brain barrier and perform neuroactive tasks in both pathological and homeostatic settings as a result, owing to their neuro-immunomodulatory and neuro protective properties, components produced from seaweed are becoming increasingly popular as potential treatments for a variety of neurodegenerative diseases [68].

Seaweed assists in the treatment, probably due to sulfated polysaccharidesare known that these compounds have powerful antioxidant and anti-inflammatory properties, and they may protect brain cells from toxic insult. AD is associated with oxidative stress and brain cell damage due to the presence of free radicals, i.e., free molecules [69]. Seaweed is a rich source of antioxidants that can help to quench this molecular scum and prevent damage to cells associated with seaweed. In addition, inflammation in the brain drives a large portion of AD [70]. Seaweeds, on the other hand, have great anti-inflammatory effects that in theory could potentially help to alleviate brain inflammation and promote brain health.

Seaweeds contain essential nutrients (iodine, fucoidan, and polyphenol) that may be beneficial for memory enhancement, nerve protection. Beta-amyloid plaques in the brain are the build-up of beta amyloid, an abnormal protein cluster responsible for normal brain functioning is a major factor in AD. Several potential studies imply that the compounds in seaweed may be able to eliminate these plaques and consequently reduce the odds of Alzheimer's. Seaweed appears to be a possible natural source of nutrients that may support cognitive function and inhibit Alzheimer's with further study [71].

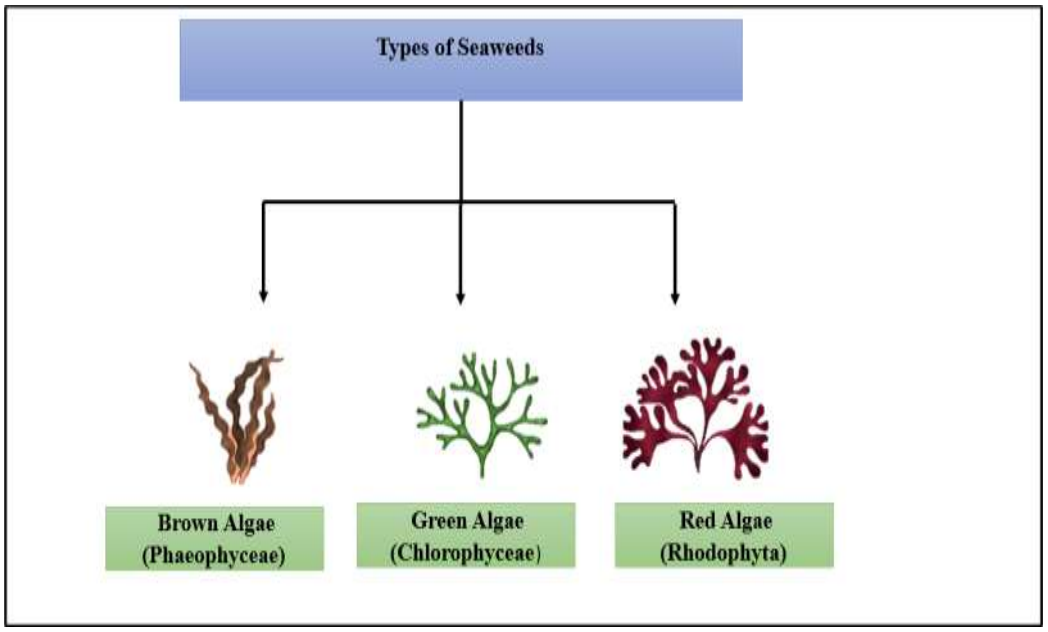

Figure 3: Seaweeds are classified into three major groups: Brown Algae (Phaeophyceae), Green Algae (Chlorophyceae), and Red Algae (Rhodophyta). Each type varies in pigmentation, habitat, and biological functions.

8. Extraction of seaweed

The traditional extraction method commonly used is solvent extraction (SLE), whereas green extraction techniques include microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), supercritical fluid extraction (SFE), pressurized solvent extraction (PSE), and reactive extrusion. These green methods are increasingly recognized as promising alternatives for efficiently extracting hydrocolloids from seaweed [72].

Table 1: Bioactive compound of seaweed.

S. No.	Bioactive Compound	Seaweed type	Seaweed species	Potential benefit	References
1.	fucoidan	Brown seaweed	Fucus vesiculosus	Anti-inflammatory, anti-oxidant, and neuroprotective effects.	[73]
2.	Fucoxanthin	Brown seaweed	Undaria pinnatifida	Antioxidant and anti-inflammatory effects may inhibit amyloid-β aggregation.	[74]
3.	Sargachromanol	Brown seaweed	Sargassum siliquastrum	Antioxidant and anti-inflammatory effects may inhibit acetylcholinesterase.	[75]
4.	Eckol	Brown seaweed	Ecklonia cava	Antioxidant and anti-inflammatory effects may inhibit amyloid-β aggregation.	[76]
5.	Diecko	Brown seaweed	Eckloniacava	Antioxidant and anti-inflammatory effects, may inhibit	[77]

				acetylcholinesterase	
6.	Phlorotannins	Brown seaweed	Eckloniacava	Antioxidant and anti-inflammatory effects, may inhibit amyloid-β aggregation	[78]
7.	Caulerpal	Green	Caulerpa lentillifera	Inhibits oxidative stress in brain cells	[79]
8.	Ulvan	Green	Ulva lactuca	Protects against cell damage caused by free radicals	[80]
9.	Ulvan	Green	Ulva lactuca	Protects against cell damage caused by free radicals	[81]

Use of Brown Algae (Phaeophyceae) in Treating AD: Polysaccharides of brown algae, like fucoidan, alginate, and laminarin are promising to treat Alzheimer's disease (AD) because of their antioxidant, anti-inflammatory, and neuroprotective activities [82]. They decrease oxidative stress, diminish brain inflammation, and inhibit the deposition of beta-amyloid plaques, which are essential components of AD pathogenesis. Moreover, they enhance nerve cell survival and memory performance, rendering them a candidate natural drug to slow cognitive deterioration. Although additional studies are required, brown algae polysaccharides provide a potential solution to safeguard brain function and treat AD [83].

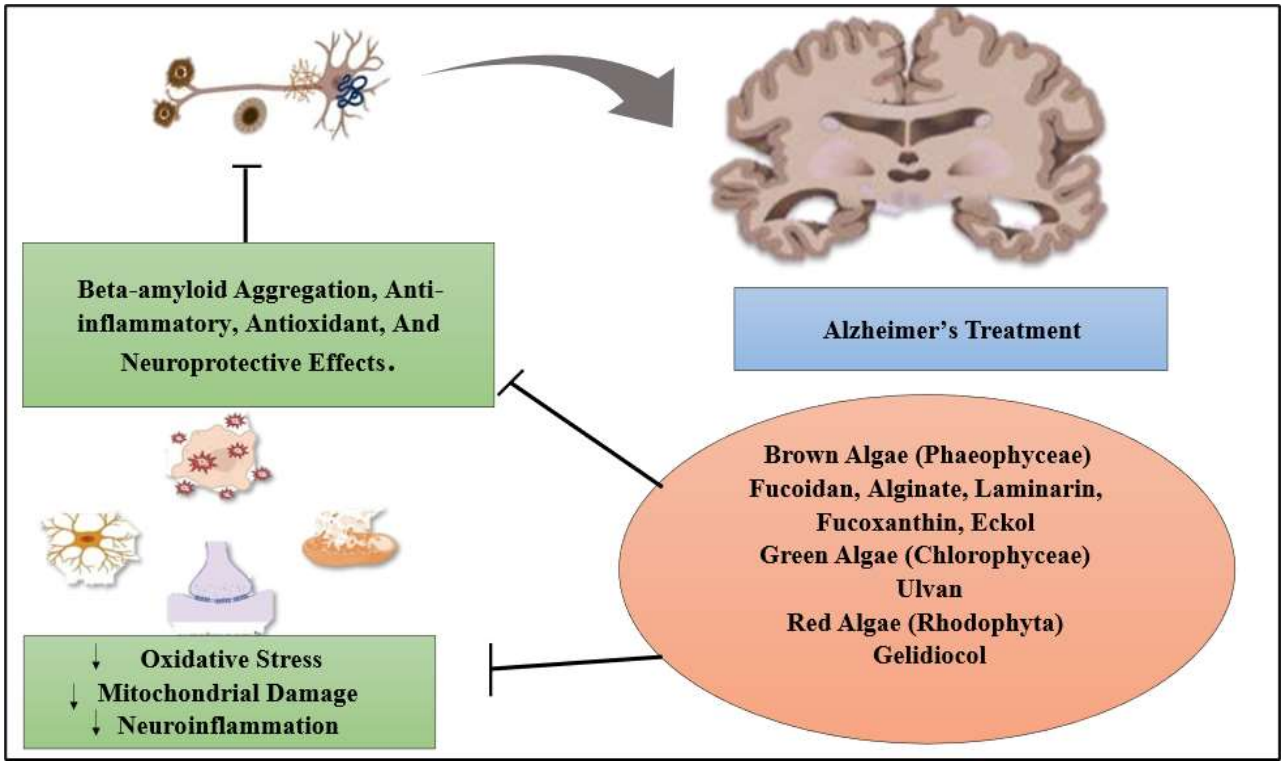

Figure 4: The figure illustrates the potential role of bioactive compounds from brown, green, and red algae in Alzheimer's treatment. These compounds exhibit anti-inflammatory, antioxidant, and neuroprotective effects by reducing beta-amyloid aggregation, oxidative stress, mitochondrial damage, and neuroinflammation. This suggests that algal-derived compounds may contribute to neuroprotection and therapeutic strategies for Alzheimer's disease.

8.1. Fucoidan

A Sulfonated polysaccharide named Fucoidan (Fucus vesiculosus) from a brown marine algae possessing the Possible Neuroprotective Effects on Alzheimer's Disease (AD). Up-to-date research has been established on fucoidan, which could be a candidate to effectively treat AD with multiple mechanisms [84]. Evidence for it is that it can inhibit the formation of beta-amyloid plaques (Aβ); a hallmark of AD and contributor to neurodegeneration. Fucoidan is also anti-inflammatory, in that it suppresses the production of pro-inflammatory cytokines and modulates microglial activation, which have been associated with a likely decrease of neuroinflammation, a major driver for AD [85]. The robust antioxidant activity could also provide additional protection against oxidative stress, a major contributor to the pathogenesis of AD. Also, Fucoidan has been reported to increase autophagy, which is a cellular process that helps to eliminate toxic proteins

(e.g., Aβ and tau tangles in AD patients) [86]. In addition, there is evidence from some trials that fucoidan increases neurogenesis and preserves synapse elements crucial for classical cognitive functions [87]. It is also known to modulate the reciprocal gut-brain axis, as fucoidan exerts its beneficial effects by affecting gut microbiota composition that is linked with the brain and may impact the AD pathogenesis. So preclinical studies have yielded promising results, but human clinical trials are far behind, and more work is needed to establish its efficacy and safety in AD patients [88].

8.2. Alginate

The alginate a natural polysaccharide of brown seaweed origin has been used as a potential therapeutic agent for Alzheimer's disease (AD). Research indicates that alginate has multiple mechanisms through which it may help in the prevention of progression of AD [89]. This is one of its major characteristics in that it prevents aggregation of beta-amyloid (Aβ) plaques ñ the centerpiece to AD and one of the main agents of neurodegeneration in the human brain. Alginate has a strong affinity to Aβ, thus decreasing it toxic character and deposition in the brain [90]. Moreover, it possesses remarkable antioxidant capacity to scavenge free radicals and preserve neurons from the oxidative stress that is an important pathophysiological event of AD [91]. The anti-inflammatory actions are especially important, as alginate has been shown to decrease microglial activation, which reduces chronic neuroinflammation – a strong driver of neuronal death in the CNS [92]. Alginic acid may also chelate heavy metals (e.g. aluminum, iron and copper), which are negatively implicated via their involvement on Aβ aggregation and oxidation in the brain. Moreover, alginate can affect the gut-brain axis by enhancing a normal gut microbiome which is been more elucidated to this idea in neurodegenerative diseases [93]. Although in vitro and in vivo research-based preclinical studies have demonstrated the attributing effects of alginate on AD in cells as well as animal models, clinical trials are required before asserting alginate therapeutic benefit for AD in humans. We also found that alginate-based drug delivery systems might help improve brain targeting therapies [94].

8.3. Laminarin

An active bioactive polysaccharide, laminarin from brown seaweed Laminaria japonica Thunb. and Saccharina latissimaYendo, have been shown to possess neuroprotective property in Alzheimer's disease (AD). Earlier study revealed several action mechanisms by which laminarin might be used in AD treatment [95]. Laminarin then is primarily the prevention from β-amyloid (Aβ) plaque formation, an element of neurotoxicity and cell death in the neurons that characterizes AD. Plus laminarin is highly antioxidant as in a free radical scavenger to mitigate the oxidative stress that accounts for over 80 percent of neuronal death in AD. Its additional anti-inflammatory contribution also helps brain health by downregulating pro-inflammatory cytokines and microglial activation, lessening chronic neuroinflammation that is central to the advancement of AD. Laminarin may moreover increase autophagy, an in-cells process to get rid of pathological proteins such as Aβ and tau tangles common in AD. In parallel with this, recent studies also suggest that laminarin may act to modulate the gut-brain axis by helping to maintain proper gut microbiota—something that is becoming a more discussed aspect of brain health and neuroinflammation. Together, these integrated mechanisms suggest laminarin warrants preclinical assessment as a candidate for AD prevention and treatment [96].

8.4. Sargachromanol

A Sargachromanol bioactive isolated from Sargassum species possess neuro-protective effects in Alzheimer's disease (AD) The one enabling it to prevent beta-amyloid (Aβ) aggregation means its toxicity and neuronal injury are reduced. Proprietary antioxidant (ROS scavenger): it quenches the reactive oxygen species (ROS) and reduces oxidative stress which has been a critical part of driving AD. Moreover, sargachromanol possesses anti-inflammatory properties through inhibition of pro-inflammatory cytokines and affects microglial reactivity to ameliorate neuroinflammation. Furthermore, it promotes neuronal survival and mitochondrial function, whereas mitochondria are the primary source of brain cells energy metabolism. Although promising results provide some pre-clinical proof-of-concept studies, more advanced clinical trials are required for its oral efficacy against AD [97].

8.5. Fucoxanthin

Marine algae fucoxanthin (Undaria pinnatifida or Laminaria japonica) is a carotenoid found in brown seaweed (Fu), showing neuroprotective potential to Alzheimer´s disease (AD). It facilitates the inhibition of beta-amyloid (Aβ) aggregation and accordingly restricts plaque formation with preservation of neuronal damage. Fucoxanthin, acting as a potent antioxidant Fucoxanthin is one of the powerful scavengers against oxidative stress mainly due to losing it’s bound to iron that could induce inflammatory reactions as in AD-related neurodegeneration. It also has anti-inflammatory effects by dampening pro-inflammatory cytokines & normalizing microglial activation, consequently inhibiting neuroinflammation. Furthermore, in addition to this, it promotes mitochondrial function to provide enough energy for neuronal and modulates–brain axis, which could remotely improve the physical state or reduce inflammation in the brain. Though promising in preliminary trials, more clinical trials need to confirm its efficacy for AD treatment [98].

8.6. Eckol

Brown seaweed Ecklonia cava contains the phlorotannin Eckol, which has been pharmacologically studied for potential neuroprotective properties in Alzheimer's disease (AD). Eckol, a natural constituent in brown seaweed Ecklonia cava, has been suggested to have neurological protective effects related to Alzheimer's disease (AD). Research indicates that eckol is involved in the AD treatment by way of several factors. It is an amyloid-precursor protein aggregate antagonist and reduces plaque formation/f frequency

with a direct effect on neuron toxicity [99].

Its potent anti-oxidant effect neutralizes oxidative stress which is one of the main targets in AD-related neurodegeneration. In addition, eckol demonstrates anti-inflammatory actions by hindering pro-inflammatory cytokines and affecting microglia activation, resulting in the amelioration of neuroinflammation. It additionally improves autophagy as well by clearing out excess Aβ and tau tangles that accumulate in AD patients. Further to this, eckol is neuroprotective as it inhibits the acetylcholinesterase (AChE), an enzyme responsible for breaking down acetylcholine, a neurotransmitter integral to memory and cognition. Although it has promising preclinical studies, more clinical trials are needed to confirm if eckol will be an option for AD treatment [100].

Use of green algae (Chlorophyceae) in the treatment of AD: Chlorophyta green seaweed; 77% of the dry weight is polysaccharides. much lower than in brown seaweed, but still a good source of bioactive compounds. The polysaccharides represent 21% of sulfate, and the sulfation degree has been associated directly with their antioxidant and neuroprotective capacity. Among the primary sulfated polysaccharides in the green seaweed, ulvan stands out as a powerful antioxidant scavenging free radicals and acting on reducing oxidative stress a key constituent of Alzheimer's disease (AD) and other neurodegenerative diseases [101]. Moreover, ulvan also decreases the expression of anti-inflammatory cytokines and microglial activation, which are critical components of AD progression through the use of its anti-inflammatory capabilities. These synergistic effects imply that ulvan might act to protect neural cells, attenuate neurodegeneration, and ensure cognitive function. Although pre-clinical studies are encouraging, more clinical trials need to be done to confirm its efficacy against human AD treatment. Increased interest in marine natural products of bioactive origin makes ulvan and other sulfated polysaccharides from laminariaide a potential for future nutraceutical/pharmaceutical use in neuroprotection/cognitive health [102].

9. Use Of Red Algae (Rhodophyta) In the Treatment of Alzheimer

Polysaccharides (agar and carrageenan, 40-50% of dry weight) constitute 60–90% of the biomass in red seaweeds or Rhodophyta, which are promising in bioactive compounds. Antioxidant and anti-inflammatory/synaptogenicantiflogistic sulfated polysaccharides have been highlighted for the treatment of Alzheimer's disease (AD). This rich sulfate content makes them potent to quench reactive oxygen species (ROS) and therefore suppress oxidative stress, one of the main causes of neurodegeneration [103].

Gelidiocol is a bioactive constituent of red seaweed (Rhodophyta). It is an anionic polysaccharide that can scavenge ROS (reactive oxygen species), all of which have been hypothesized to contribute heavily to the neural damage and cognitive deterioration of AD (or oxidative stress). In addition, it also has anti-inflammatory effects by suppressing microglial activation and inflammatory cytokines, which assault subjects to neuroinflammation and the progression of AD. This may allow some benefit in preventing beta-amyloid (Aβ) aggregation, therefore lessening toxicity and number of neurons that will undergo apoptosis. Furthermore, it can be used to predispose gut-brain axis modulation as a prebiotic that could modulate beneficial microbiota hence more and more related to cognitive health, thus neuroprotection. Though its preclinical evidence indicates promising factors in AD management, additional clinical research is needed to assess it as a therapeutic drug. As research on marine-derived compounds increases, so does the potential for their use in pharmaceuticals and nutraceuticals aimed at minimizing neurodegenerative disease, using them as anti-aging strategy for the mind [104].

Conclusion

Alzheimer's disease remains a major global health challenge, with an increasing number of affected individuals as the population 'sages. While current treatments primarily focus on symptom management, there is growing interest in exploring alternative therapeutic approaches. The bioactive compounds found in seaweeds, particularly their polysaccharides, have demonstrated potential in mitigating oxidative stress and inflammation, both of which are implicated in Alzheimer's disease. As research in this area continues, algae-based therapies could offer new, effective treatment options for Alzheimer's disease and other neurodegenerative disorders. A review to summaries the seaweeds and their bioactive compounds, especially polysaccharides, holds promise for therapeutic intervention. Brown algal-derived fucoidan, alginate, and phlorotannin's have been shown to possess neuro-protective, antioxidant, and anti-inflammatory properties targeting the main pathophysiological hallmarks of oxidative stress; neuroinflammation, and amyloid beta aggregation. Similarly, green and red algae bioactive demonstrated their potential to conserve neurological functions as well as modulate the gut-brain axis. Founded on the initial studies indicating their therapeutic potential, but extensive clinical studies are needed to validate their efficacy and safety. In addition, the exploitation of seaweed-derived interventions surfaces the opportunity of novel treatment strategies for Alzheimer's disease and indicates eco-friendly and sustainable ways towards neurodegenerative disorders.

Acknowledgment

The authors sincerely acknowledge the School of Pharmacy, Desh Bhagat University, Mandi Gobindgarh, Punjab, for providing the necessary support and resources for this review work.

Author Contributions

S.M. Conceptualized the study, **G.K.** Supervised the review, **N.** Prepared the manuscript.

Source of Funding

There is no funding available to conduct this study.

Conflicts of Interest

No conflicts of interest are disclosed by the authors.

References

1. Rani A, Khan J, Choudhary L, Kumar M, Jha A, Pandey G, et al. Unraveling the Therapeutic Potential of Alzheimer's Drugs: A Comprehensive Review. Tetrahedron. 2025:134517.
2. Amiri F, Safiri S, Shamekh A, Ebrahimi A, Sullman MJ, Kolahi A-A. Prevalence, deaths and disability-adjusted life years due to Alzheimer's disease and other dementias in Middle East and North Africa, 1990–2021. Scientific Reports. 2025;15(1):7058.
3. Banks WA, Rhea EM. The blood–brain barrier, oxidative stress, and insulin resistance. Antioxidants. 2021;10(11):1695.
4. Liu J, Yang B, Zhang X, editors. Theories of Alzheimer's disease: amyloid hypothesis, blood-brain barrier hypothesis and cholinergic hypothesis. E3S Web of Conferences; 2024: EDP Sciences.
5. Bakker A, Rani N, Mohs R, Gallagher M. The HOPE4MCI study: AGB101 treatment slows progression of entorhinal cortex atrophy in APOE ε4 non-carriers with mild cognitive impairment due to Alzheimer's disease. Alzheimer's & Dementia: Translational Research & Clinical Interventions. 2024;10(4):e70004.
6. Mukherjee U, Sehar U, Brownell M, Reddy PH. Mechanisms, consequences and role of interventions for sleep deprivation: Focus on mild cognitive impairment and Alzheimer's disease in elderly. Ageing Research Reviews. 2024;100:102457.
7. Wang R. Global burden of Alzheimer's disease and other dementias during 1990-2021: a Global Burden of Disease and Risk Factors Study 2021-based study. Neuroepidemiology. 2025:1-24.
8. Saragea PD. Alzheimer's Disease (AD): Environmental Modifiable Risk Factors. International Journal for Multidisciplinary Research. 2024;6(4):1-.
9. Chaudhary RK, Mateti UV, Khanal P, Rawal KB, Jain P, Patil VS, et al. Alzheimer's Disease: Epidemiology, Neuropathology, and Neurochemistry. Computational and Experimental Studies in Alzheimer's Disease: CRC Press; 2024. p. 1-14.
10. Li F, Qin W, Zhu M, Jia J. Model-based projection of dementia prevalence in China and worldwide: 2020–2050. Journal of Alzheimer's Disease. 2021;82(4):1823-31.
11. Nitrini R. The past, present and future of Alzheimer's disease–part 1: the past. Arquivos de Neuro-psiquiatria. 2023;81(12):1070-6.
12. Saido TC. Alzheimer's Disease Research Guide: Animal Models for Understanding Mechanisms and Medications: Elsevier; 2024.
13. Better MA. Alzheimer's disease facts and figures. Alzheimers Dement. 2023;19(4):1598-695.
14. Pluta R, Czuczwar SJ. Trans-and Cis-Phosphorylated Tau Protein: New Pieces of the Puzzle in the Development of Neurofibrillary Tangles in Post-Ischemic Brain Neurodegeneration of the Alzheimer's Disease-like Type. International Journal of Molecular Sciences. 2024;25(6):3091.
15. Xu M, Li T, Liu X, Islam B, Xiang Y, Zou X, et al. Mechanism and Clinical Application Prospects of Mitochondrial DNA Single Nucleotide Polymorphism in Neurodegenerative Diseases. Neurochemical Research. 2025;50(1):1-30.
16. Anitha K, Singh MK, Kohat K, Chenchula S, Padmavathi R, Amerneni LS, et al. Recent insights into the neurobiology of Alzheimer's disease and advanced treatment strategies. Molecular Neurobiology. 2025;62(2):2314-32.
17. Cadar E, Popescu A, Dragan A-M-L, Pesterau A-M, Pascale C, Anuta V, et al. Bioactive Compounds of Marine Algae and Their Potential Health and Nutraceutical Applications: A Review. Marine Drugs. 2025;23(4):152.
18. Priyadharshini M, Mukilan M, Harikrishnan S, Anantharaman P. SEAWEED DIVERSITY AND DISTRIBUTION IN THE SOUTH-EAST COAST OF TAMIL NADU, INDIA. J Exp Zool. 2025;28(1):0000-.
19. Islam MN, Tamanna S, Islam MS, Noman M. Global Scenarios of Seaweed Cultivation: Science-Policy Nexus for Enhancing the Seaweeds and Algae Farming. Global Blue Economy. 2022:309-40.
20. Jia C, Chai J, Zhang S, Sun Y, He L, Sang Z, et al. The Advancements of Marine Natural Products in the Treatment of Alzheimer's Disease: A Study Based on Cell and Animal Experiments. Marine Drugs. 2025;23(3):91.
21. Xie C, Lee ZJ, Ye S, Barrow CJ, Dunshea FR, Suleria HA. A review on seaweeds and seaweed-derived polysaccharides: Nutrition, chemistry, bioactivities, and applications. Food Reviews International. 2024;40(5):1312-47.
22. Singh V, Kumar A, Sood P, Dhiman S, Mehta D, Singh TG. Potential Natural Polysaccharides for the Management of Alzheimer's Disease. Neuro-Nutraceuticals and Drug Discovery and Delivery in Alzheimer's Disease: Apple Academic Press. p. 153-69.
23. Naik RA, Mir MN, Malik IA, Bhardwaj R, Alshabrmi FM, Mahmoud MA, et al. The Potential Mechanism and the Role of Antioxidants in Mitigating Oxidative Stress in Alzheimer's Disease. Frontiers in Bioscience-Landmark. 2025;30(2):25551.
24. Jin W, Pei J, Roy JR, Jayaraman S, Ahalliya RM, Kanniappan GV, et al. Comprehensive review on single-cell RNA sequencing: A new frontier in Alzheimer's disease research. Ageing Research Reviews. 2024:102454.
25. Feij P. The Role of Amyloid Precursor Protein in Accelerated Alzheimer's Disease in Down Syndrome: A Literature Review. 2024.
26. Huszár Z, Solomon A, Engh MA, Koszovácz V,

Terebessy T, Molnár Z, et al. Association of modifiable risk factors with progression to dementia in relation to amyloid and tau pathology. Alzheimer's Research & Therapy. 2024;16(1):238.
27. Abdalla MMI. Insulin resistance as the molecular link between diabetes and Alzheimer's disease. World Journal of Diabetes. 2024;15(7):1430.
28. Clarke AJ, Brodtmann A, Irish M, Mowszowski L, Radford K, Naismith SL, et al. Risk factors for the neurodegenerative dementias in the Western Pacific region. The Lancet Regional Health–Western Pacific. 2024;50.
29. Jakhar D. Abnormal resting-state EEG Alpha rhythms as a neurophysiological biomarker of vigilance dysfunctions in patients with cognitive deficits due to Alzheimer's and Parkinson's diseases. 2025.
30. Alsaleem MA, Al-Kuraishy HM, Al-Gareeb AI, Abdel-Fattah MM, Alrouji M, Al-Harchan NA, et al. Decrypting the Possible Mechanistic Role of Fenofibrate in Alzheimer's Disease and Type 2 Diabetes: The Truth and Mystery. Journal of Cellular and Molecular Medicine. 2025;29(5):e70378.
31. Sönmez G, Yazarkan Y, Aki ÖE, Bodur E. Unraveling the Enigma: Exploring the Periphery's Influence in Alzheimer's Pathophysiology—Cause or Consequence? 2025.
32. Yoo J, Lee J, Ahn B, Han J, Lim MH. Multi-target-directed therapeutic strategies for Alzheimer's disease: controlling amyloid-β aggregation, metal ion homeostasis, and enzyme inhibition. Chemical Science. 2025;16(5):2105-35.
33. Nam Y, Shin SJ, Kumar V, Won J, Kim S, Moon M. Dual modulation of amyloid beta and tau aggregation and dissociation in Alzheimer's disease: a comprehensive review of the characteristics and therapeutic strategies. Translational Neurodegeneration. 2025;14(1):15.
34. Jang Y-J, Kang S-J, Park HS, Lee D-H, Kim JH, Kim J-E, et al. Drug delivery strategies with lipid-based nanoparticles for Alzheimer's disease treatment. Journal of Nanobiotechnology. 2025;23(1):99.
35. Ahn EH, Park J-B. Molecular Mechanisms of Alzheimer's Disease Induced by Amyloid-β and Tau Phosphorylation Along with RhoA Activity: Perspective of RhoA/Rho-Associated Protein Kinase Inhibitors for Neuronal Therapy. Cells. 2025;14(2):89.
36. H Fayek F, K Moftah H, HA Moussa M, Z Elrazaz E, S Kamel A, S Lasheen D, et al. Acetylcholine Esterase Inhibition in Alzheimer's Therapy: Spotlight on Quinzolinone Derivatives. Translational Health Sciences. 2025;1(1):1-24.
37. Cacabelos R, Martínez-Iglesias O, Cacabelos N, Carrera J, Rodríguez D, Naidoo V. The impact of genetic variability on Alzheimer's therapies: obstacles for pharmacogenetic progress. Expert Opinion on Drug Metabolism & Toxicology. 2025:1-28.
38. Scarano N. Druggable targets to contrast Alzheimer's disease: molecular modelling approaches for the drug design process. 2025.
39. Fang X, Fan F, Border JJ, Roman RJ. Cerebrovascular Dysfunction in Alzheimer's Disease and Transgenic Rodent Models. Journal of experimental neurology. 2024;5(2):42.
40. Dakal TC, Choudhary K, Tiwari I, Yadav V, Maurya PK, Sharma NK. Unraveling the triad: hypoxia, oxidative stress and inflammation in neurodegenerative disorders. Neuroscience. 2024.
41. Sebastijanović A, Camassa LMA, Malmborg V, Kralj S, Pagels J, Vogel U, et al. Particulate matter constituents trigger the formation of extracellular amyloid β and Tau-containing plaques and neurite shortening in vitro. Nanotoxicology. 2024;18(4):335-53.
42. Lee C, Friedman A. Generating PET scan patterns in Alzheimer's by a mathematical model. Plos one. 2024;19(4):e0299637.
43. Toader C, Tataru CP, Munteanu O, Serban M, Covache-Busuioc R-A, Ciurea AV, et al. Decoding Neurodegeneration: A Review of Molecular Mechanisms and Therapeutic Advances in Alzheimer's, Parkinson's, and ALS. International Journal of Molecular Sciences. 2024;25(23):12613.
44. Pradeepkiran JA, Baig J, Islam MA, Kshirsagar S, Reddy PH. Amyloid-β and phosphorylated tau are the key biomarkers and predictors of Alzheimer's disease. Aging and disease. 2024;16(2):658.
45. Sahar S, Negam M. Factors impacting Alzheimer's disease: new biological insights, promising diagnostic methods and treatments: an article review. Egyptian Journal of Nutrition. 2025;40(1):14-23.
46. Balusu S, De Strooper B. The necroptosis cell death pathway drives neurodegeneration in Alzheimer's disease. Acta Neuropathologica. 2024;147(1):96.
47. Zhang X, Wu M, Cheng L, Cao W, Liu Z, Yang S-B, et al. Fast-spiking parvalbumin-positive interneurons: new perspectives of treatment and future challenges in dementia. Molecular Psychiatry. 2024:1-12.
48. Karati D, Mukherjee S, Roy S. The antioxidant potential of bacoside and its derivatives in Alzheimer's disease: The molecular mechanistic paths and therapeutic prospects. Toxicology Reports. 2025:101945.
49. Zhang J, Zhang Y, Wang J, Xia Y, Zhang J, Chen L. Recent advances in Alzheimer's disease: Mechanisms, clinical trials and new drug development strategies. Signal transduction and targeted therapy. 2024;9(1):211.
50. Safiri S, Ghaffari Jolfayi A, Fazlollahi A, Morsali S, Sarkesh A, Daei Sorkhabi A, et al. Alzheimer's disease: a comprehensive review of epidemiology, risk factors, symptoms diagnosis, management, caregiving, advanced treatments and associated challenges. Frontiers in Medicine. 2024;11:1474043.
51. Stewart T. Neurocognitive Disorders and Geriatric Mental Health. Psychiatric-Mental Health Nurse Practitioner Program Companion and Board Certification Exam Review Workbook: Springer; 2024. p. 293-328.
52. Hayer RK, Tadros G. Behavioural and

Psychological Symptoms of Dementia in Hospital Settings. Handbook of Old Age Liaison Psychiatry. 2024:124.
53. Sharifi F, Ghandali R, Alimohammadi M, Ahmadipour P. Symptoms and diagnosis of dementia. Nutrition in Brain Aging and Dementia: Springer; 2024. p. 59-91.
54. Buccellato FR, D'Anca M, Tartaglia GM, Del Fabbro M, Scarpini E, Galimberti D. Treatment of Alzheimer's disease: beyond symptomatic therapies. International Journal of Molecular Sciences. 2023;24(18):13900.
55. Shukla D, Suryavanshi A, Bharti SK, Asati V, Mahapatra DK. Recent Advances in the Treatment and Management of Alzheimer's Disease: A Precision Medicine Perspective. Current Topics in Medicinal Chemistry. 2024;24(19):1699-737.
56. Kumar R, Johar R, Caruso G, Singh M, Chandra M, Igwegbe CA, et al. Pathophysiology of Alzheimer's disease: advances in drug development and therapeutic innovations. Chemical Biology Letters. 2025;12(2):1264-.
57. Smallfield S, Metzger L, Green M, Henley L, Rhodus EK. Occupational therapy practice guidelines for adults living with Alzheimer's disease and related neurocognitive disorders. The American Journal of Occupational Therapy. 2024;78(1):7801397010.
58. Sree RR, Kalyan M, Anand N, Mani S, Gorantla VR, Sakharkar MK, et al. Newer Therapeutic Approaches in Treating Alzheimer's Disease: A Comprehensive Review. ACS omega. 2025;10(6):5148.
59. Hussain MS, Mishra AK. Advancements in understanding and addressing Alzheimer's disease: a comprehensive review. International Journal of Research in Medical Sciences. 2024;12(5):1789.
60. Khalefa EMM, Altumi SA, Eldawi NS. Targeting Alzheimer's Disease: Current Pharmacological Strategies and Emerging Therapies. Libyan Journal of Medical and Applied Sciences. 2024:45-50.
61. Iqbal I, Saqib F, Mubarak Z, Latif MF, Wahid M, Nasir B, et al. Alzheimer's disease and drug delivery across the blood–brain barrier: approaches and challenges. European journal of medical research. 2024;29(1):313.
62. Thawabteh AM, Ghanem AW, AbuMadi S, Thaher D, Jaghama W, Karaman D, et al. Recent Advances in Therapeutics for the Treatment of Alzheimer's Disease. Molecules. 2024;29(21):5131.
63. Pernet F, Gazeau F. Ocean acidification: Understanding the effects, exploring the solutions. éditions Quæ; 2025.
64. Suparmaniam U. Seaweed Bioactives: Transforming Bakery Production Sustainably. Biological Outlook to Improve the Nutritive Quality of Bakery Products: Springer; 2025. p. 141-61.
65. Paranthaman S, Palraj P. Bioactive Compounds of Algae: Potential Neuroprotective Agents in Neurodegenerative Disorders. Neuroprotective Effects of Phytochemicals in Brain Ageing: Springer; 2024. p. 257-88.
66. Anburaj R, Kathiresan K, Prasannakumar C. Exploring the depths: A comprehensive review of marine algae. RECENT TRENDS IN. 2024;176.
67. Lee JY, Wong CY, Koh RY, Lim CL, Kok YY, Chye SM. Natural bioactive compounds from macroalgae and microalgae for the treatment of Alzheimer's disease: A review. The Yale Journal of Biology and Medicine. 2024;97(2):205.
68. Silva A, Cassani L, Grosso C, Garcia-Oliveira P, Morais SL, Echave J, et al. Recent advances in biological properties of brown algae-derived compounds for nutraceutical applications. Critical Reviews in Food Science and Nutrition. 2024;64(5):1283-311.
69. Jegadeshwari B, Rajaram R. A critical review on pharmacological properties of sulfated polysaccharides from marine macroalgae. Carbohydrate Polymers. 2024;344:122488.
70. Pereira L, Valado A. The seaweed diet in prevention and treatment of the neurodegenerative diseases. Marine drugs. 2021;19(3):128.
71. Kumari M, Sadhu P, Shah N, Talele C. Marine Pharmacognosy. Pharmacognosy and Phytochemistry: Principles, Techniques, and Clinical Applications. 2025:371-94.
72. Nayak S, Paul A, Gouda S, Das G, Patra JK. Bioactive Compounds Extraction from Seaweed by Biotechnology Process. Bioactive Compounds Extraction from Marine Resources and Wastes: Springer; 2025. p. 125-49.
73. Sah AN, Pathak M, Rawal P, Tewari D. Natural Bioactives used for Anti-stress. Natural Scaffolds for Prevention and Treatment of Neurodegenerative Disorders: CRC Press; 2025. p. 81-96.
74. Giuliani M, Uboldi C, Dellatorre FG, Latour E, Ponce NMA, Stortz CA, et al. Undaria pinnatifida fucoidan extract inhibits activation of the NF-κB signaling pathway by herpes simplex virus type 1 and prevents amyloid-β peptide synthesis in retinal pigment epithelium cells. Archives of Virology. 2025;170(2):27.
75. MARASINGHE MS. DERMATOLOGICAL AND WOUND HEALING APPLICATIONS OF SEAWEEDS MP THEJA VIRAJINI 1. Seaweeds as Silent Healers: Insight into the Pharmacological Potential of Marine Algal Metabolites. 2025:404.
76. Cokdinleyen M, Dos Santos LC, de Andrade CJ, Kara H, Colás-Ruiz NR, Ibañez E, et al. A Narrative Review on the Neuroprotective Potential of Brown Macroalgae in Alzheimer's Disease. Nutrients. 2024;16(24):4394.
77. Goya L, Mateos R. Antioxidant and anti-inflammatory effects of marine phlorotannins and bromophenols supportive of their anticancer potential. Nutrition Reviews. 2025;83(3):e1225-e42.
78. Mayer AM, Mayer VA, Swanson-Mungerson M, Pierce ML, Rodríguez AD, Nakamura F, et al. Marine Pharmacology in 2019–2021: Marine Compounds with Antibacterial, Antidiabetic, Antifungal, Anti-Inflammatory, Antiprotozoal,

Antituberculosis and Antiviral Activities; Affecting the Immune and Nervous Systems, and Other Miscellaneous Mechanisms of Action. Marine Drugs. 2024;22(7):309.
79. Shah MD, Fui CF, Zuldin WH, Khodzori FA, Chong WS, Mazlan N, et al. Caulerpa lentillifera Sea Grape: A Promising Source of Bioactive Metabolites for Aquaculture and Health. Essentials of Aquaculture Practices: Springer; 2024. p. 197-216.
80. Korkmaz N. Extract optimization of Ulva lactuca L. and biological activities of optimized extracts. BMC biotechnology. 2025;25(1):21.
81. Osotprasit S, Samrit T, Savedvanich G, Chaiwichien A, Changklungmoa N, Kueakhai P, et al. Evaluation of Toxicity and Antioxidant Activity of the Ethanolic Extract from Ulva Lactuca. Trends in Sciences. 2025;22(2):8812-.
82. Bauer S, Jin W, Zhang F, Linhardt RJ. The application of seaweed polysaccharides and their derived products with potential for the treatment of Alzheimer's disease. Marine drugs. 2021;19(2):89.
83. Malan A, Choudhary M, Kaur Bamrah P, Kumari D. Potential benefits of marine-derived compounds for slowing the advancement of Alzheimer's disease. Journal of Asian Natural Products Research. 2025;27(4):479-504.
84. Lomartire S, Gonçalves AM. Marine macroalgae polyphenols as potential neuroprotective antioxidants in neurodegenerative diseases. Marine drugs. 2023;21(5):261.
85. Elbandy M. Anti-inflammatory effects of marine bioactive compounds and their potential as functional food ingredients in the prevention and treatment of neuroinflammatory disorders. Molecules. 2022;28(1):2.
86. Hu D, Jin Y, Hou X, Zhu Y, Chen D, Tai J, et al. Application of marine natural products against Alzheimer's disease: past, present and future. Marine Drugs. 2023;21(1):43.
87. Yang J, Zhao H, Qu S. Therapeutic potential of fucoidan in central nervous system disorders: A systematic review. International Journal of Biological Macromolecules. 2024:134397.
88. Zhang T, Wu X, Yuan H, Huang S, Park S. Mitigation of memory impairment with fermented fucoidan and λ-carrageenan supplementation through modulating the gut microbiota and their metagenome function in hippocampal amyloid-β infused rats. Cells. 2022;11(15):2301.
89. Ye S, Xie C, Agar OT, Barrow CJ, Dunshea FR, Suleria HA. Alginates from brown seaweeds as a promising natural source: A review of its properties and health benefits. Food Reviews International. 2024;40(9):2682-710.
90. Agrawal M, Prathyusha E, Ahmed H, Dubey SK, Kesharwani P, Singhvi G, et al. Biomaterials in treatment of Alzheimer's disease. Neurochemistry International. 2021;145:105008.
91. Pritam P, Deka R, Bhardwaj A, Srivastava R, Kumar D, Jha AK, et al. Antioxidants in Alzheimer's disease: Current therapeutic significance and future prospects. Biology. 2022;11(2):212.
92. Bivona G, Iemmolo M, Agnello L, Lo Sasso B, Gambino CM, Giglio RV, et al. Microglial activation and priming in Alzheimer's disease: state of the art and future perspectives. International Journal of Molecular Sciences. 2023;24(1):884.
93. Menaa F, Wijesinghe U, Thiripuranathar G, Althobaiti NA, Albalawi AE, Khan BA, et al. Marine algae-derived bioactive compounds: a new wave of nanodrugs? Marine drugs. 2021;19(9):484.
94. Fleurence J. The Use of Algae in Human Health: From Traditional Medicine to Molecules with Therapeutic Interest: John Wiley & Sons; 2025.
95. Zhou Q-L, Wang Z, Chen W-T, Liu X-F, Cheong K-L, Zou Y-X, et al. The structural characteristics, biological activities and mechanisms of bioactive brown seaweed polysaccharides: A review. Journal of Functional Foods. 2024;119:106303.
96. Yang S, Wang J, Cao Y, Zhang Y, Sun Z, Wan P, et al. Clec7a Signaling in Microglia Promotes Synapse Loss Associated with Tauopathy. International Journal of Molecular Sciences. 2025;26(7):2888.
97. Daraban BS, Popa AS, Stan MS. Latest Perspectives on Alzheimer's Disease Treatment: The Role of Blood-Brain Barrier and Antioxidant-Based Drug Delivery Systems. Molecules. 2024;29(17):4056.
98. Ferdous KA, Jansen J, Amjad E, Pray E, Bloch R, Benoit A, et al. Mitochondrial protective potential of fucoxanthin in brain disorders. Journal of Nutritional Science. 2024;13:e21.
99. Mandal AK, Parida S, Behera AK, Adhikary SP, Lukatkin AA, Lukatkin AS, et al. Seaweed in the Diet as a Source of Bioactive Metabolites and a Potential Natural Immunity Booster: A Comprehensive Review. Pharmaceuticals. 2025;18(3):367.
100. Mishra AK, Srivastava A, Raj V, Saini V, Khan G, Singh H, et al. Recent Updates on Alzheimer's Disease: Pathogenesis, Pathophysiology, Molecular Approaches and Natural Bioactive Compounds Used in Contemporary Time to Alleviate Disease. Current Alzheimer Research. 2024.
101. Zhang Y, Hawboldt K, MacQuarrie S. Extraction of bioactive compounds from beach-cast brown algae: a review on accelerated solvent extraction and subcritical water extraction. RSC Sustainability. 2024.
102. Cotas J, Lomartire S, Gonçalves AM, Pereira L. From ocean to medicine: Harnessing seaweed's potential for drug development. International Journal of Molecular Sciences. 2024;25(2):797.
103. Duan X, Agar OT, Barrow CJ, Dunshea FR, Suleria HA. Improving potential strategies for biological activities of phlorotannins derived from seaweeds. Critical Reviews in Food Science and Nutrition. 2025;65(5):833-55.
104. Pereira L, Valado A. Red Algae Compounds: Potential Neuroprotective Agents for Neurodegenerative Disorders. OBM Neurobiology. 2024;8(2):1-27.