**Beyond Nutrition: Exploring the Neuroprotective Properties of Moringa Oleifera Oil Through Cellular Signaling**

**ABSTRACTS**

*Moringa oleifera* oil, traditionally valued for its nutritional composition, is garnering increasing attention for its potential therapeutic applications. This review delves beyond the established nutritional benefits of *Moringa oleifera* oil to explore its neuroprotective properties, specifically focusing on the underlying mechanisms involving cellular signaling pathways. The review examine existing in vitro and in vivo studies investigating the impact of *Moringa oleifera* oil and its bioactive compounds on neuronal survival, inflammation, oxidative stress, and synaptic plasticity in the context of neurodegenerative diseases and neurological disorders. The study aims to elucidate the role of specific signaling cascades, such as the Nrf2/ARE pathway, PI3K/Akt pathway, and MAPK pathways, in mediating the observed neuroprotective effects. By synthesizing current research, this review provides a comprehensive understanding of the potential of *Moringa oleifera* oil as a neuroprotective agent and highlights key areas for future investigation in preclinical and clinical settings to validate its efficacy and safety in preventing or mitigating neurological damage. Ultimately, this exploration seeks to establish a scientific rationale for the therapeutic use of *Moringa oleifera* oil in promoting brain health and combating neurodegenerative conditions.

**Keywords:** *Moringa oleifera oil, neuroprotection, cellular signaling, oxidative stress, inflammation.*

1. **INTRODUCTION**

**1.1. Background Information on Moringa Oleifera:**

For centuries, across diverse landscapes from the foothills of the Himalayas to the arid plains of Africa, the Moringa oleifera tree, often simply known as the Moringa tree, has been revered as a source of sustenance and healing (Nair *et al*., 2021). This remarkable plant, believed to have originated in the Indian subcontinent, has woven itself into the traditional medicine and culinary practices of countless cultures. Historically, Moringa has been employed to combat malnutrition, treat various ailments, and provide essential nutrients in regions where food security is a constant challenge (Devkota and Bhusal, 2020). Its reputation as a "miracle tree" stems not only from its resilience and rapid growth but also from its exceptional nutritional profile, boasting high concentrations of vitamins, minerals, antioxidants, and essential amino acids (Shivanna *et al*., 2024). The Moringa tree is truly a multi-faceted resource, offering benefits derived from its various components (Anuragi et al., 2022). The leaves, perhaps the most widely utilized part, are consumed fresh, cooked, or dried into a potent powder. The seeds, contained within long, slender pods, are valued for their oil content and water purification properties. Even the roots, though requiring careful preparation, and the young, immature pods find culinary application. From supporting immune function to promoting healthy skin, the Moringa tree presents a wealth of potential benefits, making it a subject of increasing interest in both traditional and modern contexts for its general health properties (Mahaveerchand and Abdul Salam, 2024).

Moringa oleifera oil, extracted from the seeds of the Moringa oleifera tree, is a highly valued oil known for its unique properties and diverse applications. The oil is typically extracted using a cold-pressing method (**Single-screw presses)**. This involves applying pressure to the Moringa seeds to release the oil without the use of heat or solvents. This cold-pressing technique helps to preserve the oil's beneficial compounds and maintain its quality (Fu *et al*., 2021; Shahbaz *et al.*, 2024)

The resulting oil boasts a rich and beneficial composition. Notably, it exhibits a favorable fatty acid profile, characterized by a high concentration of oleic acid (typically around 70-80%), making it incredibly stable and resistant to oxidation. Other significant fatty acids present include palmitic acid, stearic acid, and behenic acid, each contributing to the oil's unique texture and properties (Dzuvor *et al*., 2022). Beyond fatty acids, Moringa oil contains valuable antioxidants, vitamins (such as Vitamin E), and sterols, further enhancing its nutritional and therapeutic value. Due to its diverse composition and stability, Moringa oil has found applications in various fields. In the cosmetic industry, it's highly regarded for its emollient, moisturizing, and anti-aging properties, often used in lotions, creams, hair care products, and massage oils. Its ability to penetrate the skin effectively without leaving a greasy residue makes it a popular choice. Furthermore, Moringa oil has a history of use in culinary applications, particularly in regions where the Moringa tree is native. The oil's mild, nutty flavor makes it suitable for salad dressings, cooking, and as a finishing oil. However, it's crucial to ensure the oil is sourced from a reputable supplier and is food-grade if intended for consumption (Seifu and Teketay, 2020).

1. **THE GROWING INTEREST IN NEUROPROTECTION**

The field of neuroprotection is experiencing a surge in interest and activity, driven by the increasing prevalence of age-related neurological disorders and the devastating consequences of brain injuries (Obukohwo *et al*., 2024; Oyovwi and Udi, 2024). Neuroprotection, broadly defined, encompasses strategies aimed at preventing or slowing down the damage and death of neurons, the fundamental building blocks of the nervous system. This research is becoming increasingly critical as the global population ages, leading to a higher incidence of neurodegenerative diseases such as Alzheimer's disease, Parkinson's disease, Huntington's disease, and Amyotrophic Lateral Sclerosis (ALS). These diseases, characterized by progressive neuronal loss, significantly impact quality of life, cognitive function, motor skills, and overall independence. Similarly, the need for effective neuroprotective therapies following traumatic brain injury (TBI), stroke, and spinal cord injury is paramount to minimize long-term neurological deficits and improve patient outcomes. The potential impact of successful neuroprotective interventions is enormous, offering the promise of mitigating the burden of these debilitating conditions on individuals, families, and healthcare systems.

Several key mechanisms are implicated in the pathogenesis of neuronal damage and represent potential targets for neuroprotective strategies. Oxidative stress, arising from an imbalance between the production of reactive oxygen species (ROS) and the body's antioxidant defenses, can damage cellular components, including DNA, proteins, and lipids, ultimately leading to neuronal dysfunction and death. Inflammation, while a natural response to injury or infection, can become chronic and exacerbate neuronal damage (Demirci-Cekic *et al*., 2022). The activation of glial cells (the immune cells of the brain) can lead to the release of pro-inflammatory cytokines and other mediators that contribute to neuronal injury. Finally, excitotoxicity, a process triggered by excessive stimulation of glutamate receptors, leading to an influx of calcium ions into neurons. This over-excitation can overwhelm the cell's capacity to regulate calcium levels, triggering a cascade of events that result in neuronal death (Shen *et al*., 2022). Understanding and targeting these underlying pathways offers promising avenues for developing novel neuroprotective therapies. Current treatments for neurological conditions primarily focus on managing symptoms and reducing further damage to the nervous system. Antioxidant therapies, anti-inflammatory agents, and calcium regulation pathways are just a few examples of potential targets for neuroprotection (Teleanu, *et al*., 2019). While further research is needed to fully understand the complex mechanisms underlying neuronal damage and develop effective neuroprotective therapies, the existing knowledge provides a foundation for the development of novel strategies to protect and preserve neuronal function

**2.1 Rationale and Scope of the Review:**

This review concentrates on the emerging subject of *Moringa oleifera* oil's neuroprotective potential, moving beyond its well-known nutritional advantages. The core hypothesis is that *Moringa oleifera* oil has significant neuroprotective properties, affecting crucial cellular signaling pathways that promote neuronal survival and functionality.

The review begins with an in-depth examination of the bioactive components present in *Moringa oleifera* oil, focusing on their inherent antioxidant and anti-inflammatory properties. These compounds play a crucial role in neuronal health and protection against degenerative diseases. The second section of the review explores *Moringa oleifera* oil's impact on specific cellular signaling pathways, such as the PI3K/Akt and MAPK pathways, which are often implicated in neurodegenerative diseases (Shahbaz *et al*., 2024). By examining both in vitro and in vivo studies, this review aims to demonstrate the oil's efficacy in mitigating neuronal damage. Finally, the review addresses existing research gaps concerning *Moringa oleifera* oil's neuroprotective effects and proposes potential avenues for future investigation. A significant recommendation is the need for clinical trials to validate these neuroprotective effects in human subjects suffering from neurological disorders.

1. **NUTRITIONAL PROFILE OF MORINGA OLEIFERA OIL**

The nutritional value of this oil is fundamentally determined by its fatty acid profile (Kapoor *et al*., 2021). A comprehensive examination of this profile involves a meticulous analysis to identify and quantify the diverse types and proportions of fatty acids it contains. This includes, but is not limited to, a precise assessment of the major components like oleic acid, behenic acid, and palmitic acid. For example, while oleic acid is a monounsaturated fatty acid known for its beneficial properties, palmitic acid is a saturated fat, and behenic acid is a very long-chain saturated fatty acid, each exhibiting distinct metabolic effects (Tutunchi *et al*., 2020; Andrew *et al*., 2017). The percentages of these fatty acids relative to one another are critical in determining the oil's overall health impact.

A thorough understanding of this fatty acid composition is paramount, as these components directly influence a multitude of physiological processes and, consequently, overall health. A high concentration of oleic acid, for instance, has been consistently associated with positive impacts on cardiovascular health (Alia *et al*., 2022). Research suggests it can promote healthy cholesterol levels by increasing HDL ("good") cholesterol and reducing LDL ("bad") cholesterol, contributing to a reduced risk of heart disease and stroke (Ogo *et al*., 2023). Conversely, the impact of the saturated fat component is crucial to be considered which might be considered for potential adverse effects or benefits based on total saturated fat content and the blend of fat components. Moving beyond fatty acids, this oil distinguishes itself further with a notable array of antioxidant compounds. Identifying and quantifying tocopherols (vitamin E variants) and carotenoids (precursors to vitamin A and other antioxidants) is vital. Tocopherols, acting as potent lipid-soluble antioxidants, can protect cell membranes from damage caused by free radicals (Ogo *et al*., 2023). Carotenoids, like beta-carotene and lutein, contribute to the oil's antioxidant capacity and may also offer specific benefits such as supporting eye health. These antioxidants collectively empower the oil to combat oxidative stress, a major contributor to aging, inflammation, and chronic diseases. By neutralizing free radicals, they protect cells from damage, potentially reducing the risk of various health problems (Ativie *et al*., 2018).

Furthermore, the presence of other bioactive compounds, even if present in relatively small quantities, significantly enhances the oil's potential health benefits. Phytosterols, for example, are plant-derived compounds that share structural similarities with cholesterol. These can help lower LDL cholesterol levels by interfering with cholesterol absorption in the digestive tract, further supporting cardiovascular health (Oreva et al., 2022). Other minor bioactive compounds may contribute anti-inflammatory, antimicrobial, or other beneficial effects, adding to the oil's complex nutritional profile. These compounds contribute to the synergistic effect of the oil, increasing its biological activity compared to its isolated components. Lastly, recognizing the significant influence of nutrition on brain health, it's essential to briefly consider how this oil's unique components might contribute to cognitive function and neurological well-being. A balanced intake of beneficial fats, particularly monounsaturated and polyunsaturated fatty acids, along with antioxidants, is well-documented to support brain health. These components are crucial for maintaining the fluidity of cell membranes in the brain, facilitating efficient neurotransmission, and protecting against oxidative stress, which can contribute to cognitive decline (Cerasuolo et al., 2024; Andrew et al., 2023). The specific fatty acid profile and antioxidant content of this oil suggest it could play a valuable role in maintaining optimal neurological function, potentially enhancing cognitive performance and reducing the risk of neurodegenerative diseases.

Table 1: Nutritional component of fatty acid and typical value

|  |  |
| --- | --- |
| **NUTRITIONAL COMPONENT (FATTY ACID)** | **TYPICAL VALUE (per 100g)** |
| Oleic Acid (Omega-9) | 65-80g |
| Palmitic Acid | 5-10g |
| Stearic Acid | 4-8g |
| Behenic Acid | 3-7g |
| Linoleic Acid (Omega-6) | 1-3g |

(Sultana, 2020)

Table 2: Nutritional component of Vitamins and trace amount

|  |  |
| --- | --- |
| **NUTRITIONAL COMPONENT (VITAMINS)** | **TRACE AMOUNTS** |
| Vitamin A | Variable (present in trace amounts) |
| Vitamin C | Variable (present in trace amounts) |
| Vitamin E (Tocopherols) | Variable (present in trace amounts) |

(Stadtlander and Becker, 2017)

Table 3: Nutritional component of Minerals and trace amounts

|  |  |
| --- | --- |
| **NUTRITIONAL COMPONENT (MINERALS)** | **TRACE AMOUNTS** |
| Calcium | Variable (present in trace amounts) |
| Iron | Variable (present in trace amounts) |
| Potassium | Variable (present in trace amounts) |

(Stadtlander and Becker, 2017)

1. **CELLULAR SIGNALING PATHWAYS RELEVANT TO NEUROPROTECTION**

Cellular signaling pathways are fundamental to the intricate communication network within the nervous system, profoundly influencing neuronal function, survival, and overall brain health. This sophisticated communication system allows neurons, the primary functional units of the brain, to interact, coordinate their activities, and respond to changing environmental cues (Obukohwo *et al*., 2024). Without these pathways, neurons would be isolated and unable to perform their essential roles in cognition, behavior, and physiological regulation.

Neurons communicate through a complex interplay of signals, encompassing a vast array of molecules including neurotransmitters, growth factors, cytokines, and hormones. These signals are received by neurons through specialized receptors on their cell surface or within the cell. The binding of a signal molecule to its receptor initiates a cascade of intracellular events, ultimately affecting a wide range of processes ranging from synaptic plasticity, the ability of synapses to strengthen or weaken over time, to stress responses, which allow neurons to adapt to harmful stimuli (Oyem et al., 2021; Arese *et al*., 2022) .

Understanding these signaling cascades is crucial for developing neuroprotective strategies aimed at mitigating neuronal damage in debilitating neurological conditions. Neurodegenerative diseases, like Alzheimer's and Parkinson's, stroke (cerebrovascular accident), and traumatic brain injury (TBI) all involve significant neuronal loss and dysfunction (Brett *et al*., 2022; Udi *et al*., 2022). By dissecting the intricate molecular mechanisms within these signaling pathways, researchers can identify specific targets for therapeutic intervention, aiming to prevent or slow down neuronal degeneration and promote recovery. Several key pathways have emerged as particularly relevant to neuroprotection, highlighting the multifaceted nature of neuronal survival and resilience. These pathways encompass a diverse range of cellular processes, including those that regulate antioxidant responses to combat oxidative stress, inflammation both preventing excessive and resolving harmful inflammation, apoptosis, or programmed cell death, neuronal growth and survival, and cellular metabolism, ensuring that neurons have the energy they need to function.

These crucial pathways represent promising avenues for therapeutic development. For instance:

* **The Nrf2/ARE antioxidant pathway** is a master regulator of cellular defense against oxidative stress. Activation of Nrf2 leads to the transcription of genes encoding antioxidant enzymes, such as superoxide dismutase (SOD) and catalase, which neutralize harmful free radicals. Enhancing this pathway can protect neurons from oxidative damage induced by various stressors (Ngo and Duennwald, 2022).
* **The NF-κB anti-inflammatory pathway**, while often associated with inflammation, plays a complex role in neuronal survival. While excessive NF-κB activation can contribute to neuroinflammation, its controlled activation can promote neuronal survival by regulating the expression of anti-apoptotic genes and inflammatory resolution. This pathway, when correctly regulated, can protect neurons from inflammatory damage (Ju Hwang *et al*., 2019).
* **Apoptotic pathways involving the Bcl-2 family and caspases** govern programmed cell death. The balance between pro-apoptotic (e.g., Bax, Bad) and anti-apoptotic (e.g., Bcl-2, Bcl-xL) proteins within the Bcl-2 family determines whether a cell will undergo apoptosis. Caspases are a family of proteases that execute the apoptotic program. Targeting these pathways can prevent inappropriate neuronal death in neurodegenerative conditions (Hartman and Czyz, 2020).
* **Neurotrophic factor signaling, particularly via BDNF/TrkB**, is essential for neuronal survival, growth, and differentiation. Brain-derived neurotrophic factor (BDNF) binds to its receptor, tropomyosin receptor kinase B (TrkB), activating downstream signaling cascades that promote neuronal survival and synaptic plasticity. Enhancing BDNF/TrkB signaling can promote neurogenesis, strengthen synaptic connections, and protect neurons from damage (Jha *et al*., 2024).
* **The PI3K/Akt/mTOR pathway** regulates cell growth, metabolism, and survival. Activation of this pathway promotes glucose uptake, protein synthesis, and cell proliferation, while inhibiting apoptosis. Manipulating this pathway can enhance neuronal survival and promote recovery after injury (Tian *et al*., 2023).

**5.0. EVIDENCE FOR NEUROPROTECTIVE EFFECTS OF MORINGA OLEIFERA OIL**

Evidence suggesting the neuroprotective potential of Moringa oleifera oil is steadily accumulating through both in vitro (laboratory-based cell culture) and in vivo (animal model) studies. This growing body of research highlights the oil's potential to mitigate damage and promote resilience within the nervous system.

In vitro research, conducted using neuronal cell cultures, allows for a controlled examination of the oil's impact on cell survival and function under various stressful conditions mimicking neurological disorders. A primary focus has been on assessing cell viability when exposed to oxidative stress and excitotoxicity. Oxidative stress, characterized by an imbalance between the production of reactive oxygen species (ROS) and the body's antioxidant defenses, is a significant contributor to neuronal damage in conditions like Alzheimer's disease and Parkinson's disease (Gogna *et al.*, 2024). Excitotoxicity, conversely, results from the overstimulation of neurons by excitatory neurotransmitters, such as glutamate, leading to cell death. Researchers investigate how Moringa oil influences antioxidant enzyme activity, particularly examining changes in the levels of superoxide dismutase (SOD) and catalase. SOD and catalase are key enzymes responsible for neutralizing harmful free radicals, thus protecting cells from oxidative damage (Reda *et al*., 2025; Worku *et al*., 2024; Enye *et al*., 2021). An increase in these enzyme activities suggests a potential for the oil to bolster the neuronal antioxidant defense system. Furthermore, these in vitro studies analyze the oil's effect on inflammatory cytokine production. Inflammatory cytokines, such as TNF-α and IL-1β, are signaling molecules that mediate inflammation. Chronic neuroinflammation is a hallmark of many neurodegenerative diseases. By measuring the levels of these cytokines in cell cultures exposed to Moringa oil, researchers can assess the oil's potential anti-inflammatory effects (Cretella *et al*., 2020; Zouboulis *et al*., 2023). The research also looks at apoptosis markers, such as caspase-3 activation, to understand how Moringa oil could prevent programmed cell death. Finally, researchers measure the expression of neurotrophic factors, such as brain-derived neurotrophic factor (BDNF) and nerve growth factor (NGF). These factors are crucial for neuronal survival, growth, differentiation, and synaptic plasticity. Increased expression of these neurotrophic factors suggests that Moringa oil supports neuronal health and functionality. Crucially, these in vitro models also permit the investigation of the oil's influence on key cellular signaling pathways relevant to neuroprotection. These pathways, such as the PI3K/Akt pathway, the MAPK pathway, and the Nrf2 pathway, play vital roles in regulating cell survival, stress response, and antioxidant defense (Xiao *et al*., 2024). By examining how Moringa oil modulates these pathways, researchers can gain a deeper understanding of the underlying mechanisms of its neuroprotective effects. For example, activating the Nrf2 pathway can lead to increased expression of antioxidant genes, while modulating the PI3K/Akt pathway can promote cell survival. Complementing these cellular studies are in vivo investigations using animal models of neurodegenerative diseases (e.g., models of Alzheimer's, Parkinson's) or traumatic brain injury (TBI). These studies aim to translate the findings from cell cultures into a more complex biological system. Researchers assess the effect of Moringa oil on behavioral outcomes, such as cognitive function (memory, learning) and motor skills (coordination, balance), using standardized tests. They also examine neuropathological markers within the brain, such as neuronal loss (quantifying the number of surviving neurons), plaque formation (characteristic of Alzheimer's disease), and neurofibrillary tangles.

Biochemical analyses of brain tissue are often conducted to quantify oxidative stress markers (e.g., malondialdehyde, a marker of lipid peroxidation), inflammatory markers (cytokine levels), and neurotransmitter levels (e.g., dopamine, serotonin). This provides a more comprehensive picture of the biochemical changes occurring in the brain following Moringa oil treatment. Similar to the in vitro studies, the impact of Moringa oil on cellular signaling pathways within the brain is also evaluated in these animal models. This allows for a direct comparison of the mechanisms of action observed in cell cultures and in whole organisms. However, a significant gap remains in the understanding of Moringa oleifera oil's neuroprotective effects in humans. There is currently a lack of well-documented human studies concerning the effects of the oil on the human brain in relation to neuroprotection. While the in vitro and in vivo studies provide promising preclinical data, human trials are essential to confirm the applicability of these findings to human health. Future research should focus on conducting randomized controlled trials (RCTs) to assess the efficacy and safety of Moringa oil supplementation in individuals at risk of or suffering from neurodegenerative conditions. These trials should include cognitive assessments, neuroimaging techniques (e.g., MRI, PET scans), and biomarker analysis (e.g., blood levels of neurotrophic factors, inflammatory markers) to provide a comprehensive evaluation of the oil's effects on the human brain. In doing so, future research can help confirm the benefits of Moringa oleifera oil on neuroprotection on humans.

**6.0 MECHANISMS OF ACTION: HOW MORINGA OIL AFFECTS CELLULAR SIGNALING**

Direct Interactions with Signaling Molecules**:** While research is still evolving, certain compounds within Moringa oil are hypothesized to directly interact with signaling proteins, altering their activity and influencing downstream cellular responses. For instance, investigations are exploring whether specific fatty acids or antioxidants present in the oil can bind to receptors involved in inflammatory pathways or modulates the activity of kinases that regulate cellular growth and survival (Dyall *et at*., 2022). To elaborate, consider this: Specific fatty acids (like oleic acid, a prominent component of Moringa oil) could potentially bind to peroxisome proliferator-activated receptors (PPARs). PPARs are a family of nuclear receptors that regulate lipid metabolism, glucose homeostasis, and inflammation. Activation of PPARs can lead to the suppression of pro-inflammatory genes. Similarly, antioxidants like quercetin (found in Moringa) might directly scavenge free radicals, preventing them from activating signaling pathways like the NF-κB pathway, a master regulator of inflammatory responses. Furthermore, researchers are investigating whether Moringa oil components can modulate the activity of kinases such as protein kinase B (Akt), which is crucial for cell survival and growth (Shah *et al*., 2022; Cuellar-Núñez *et al*., 2020; Anderson *et al*., 2023). Direct binding or interference with kinase activity could influence cell proliferation, differentiation, and apoptosis. Future studies would be focused on identifying the specific components within Moringa oil responsible for these interactions, identifying specific target proteins and receptors, and clarifying mechanisms.

* 1. **Modulation of Gene Expression**

Moringa oil's effects extend to altering gene expression. Studies suggest it can influence the expression of genes crucial for antioxidative defense, potentially upregulating genes encoding enzymes like superoxide dismutase (SOD) and catalase. It is also being examined for its ability to downregulate pro-inflammatory cytokine genes and to modulate genes involved in apoptosis and neurotrophic signaling, suggesting potential neuroprotective capabilities (Yasoob *et al*., 2022; Albasher *et al*., 2020). Upregulating genes for antioxidant enzymes like SOD and catalase would enhance the cell's ability to neutralize reactive oxygen species (ROS), reducing oxidative stress. This could be achieved, for example, by influencing the activity of transcription factors like Nrf2, which is a master regulator of antioxidant gene expression. Downregulation of pro-inflammatory cytokines (e.g., TNF-α, IL-1β, IL-6) would dampen the inflammatory response. This could involve interfering with the signaling pathways that activate the transcription of these cytokine genes. Additionally, Moringa oil's influence on genes related to apoptosis (programmed cell death) could promote the survival of healthy cells, particularly neurons (Wu *et al*., 2021). Upregulation of genes related to neurotrophic factors (e.g., brain-derived neurotrophic factor - BDNF) could support neuronal growth, survival, and synaptic plasticity, contributing to potential neuroprotective effects. Gene expression studies, using techniques like RNA sequencing, are crucial to identifying the specific genes affected by Moringa oil and elucidating the mechanisms involved. This is an area that needs more in-depth research, but early evidence is promising.

* 1. **Potential Epigenetic Modifications**

Epigenetic modifications are changes in gene expression that do not involve alterations to the DNA sequence itself. DNA methylation (the addition of a methyl group to DNA) typically silences genes, while histone acetylation (the addition of an acetyl group to histone proteins around which DNA is wrapped) generally promotes gene expression. Moringa oil components might influence the enzymes that regulate these epigenetic marks. For example, if Moringa oil contains compounds that inhibit DNA methyltransferases (DNMTs), it could lead to demethylation of certain genes, activating their expression. Conversely, if it influences histone acetyltransferases (HATs) or histone deacetylases (HDACs), it could alter histone acetylation patterns. These epigenetic changes can have long-lasting effects on gene expression and cellular function, potentially contributing to the observed benefits of Moringa oil. Because of the importance of epigenetic regulation, finding the specific mechanisms could create new avenues for prevention and treatment of diseases (Ilango *et al*., 2020).

* 1. **Reduction of Oxidative Stress and Inflammation**

Oxidative stress, caused by an imbalance between ROS production and antioxidant defenses, can damage cellular components (DNA, proteins, lipids) and activate inflammatory pathways. Inflammation, in turn, can exacerbate oxidative stress, creating a vicious cycle. Moringa oil, with its antioxidant and anti-inflammatory properties, helps to break this cycle. By neutralizing free radicals and inhibiting inflammatory signaling pathways, Moringa oil reduces oxidative damage and inflammation. This, in turn, allows cellular signaling pathways to function more effectively, promoting cell survival, growth, and overall health. The downstream effects of reduced oxidative stress and inflammation are numerous, ranging from improved mitochondrial function and cellular energy production to enhanced neuronal plasticity and cognitive function (Cretella *et al*., 2023; Eduviere *et al*., 2024).

**7.0. POTENTIAL THERAPEUTIC APPLICATIONS AND FUTURE DIRECTIONS**

**A multi-faceted strategy that integrates Moringa oil with crucial lifestyle adjustments, such as adopting a balanced and nutritious diet rich in fruits, vegetables, and omega-3 fatty acids, and engaging in regular physical exercise to promote healthy blood flow and brain function, may offer a synergistic impact. Furthermore, the combination of Moringa oil with other neuroprotective dietary supplements, such as curcumin or resveratrol, and standard pharmaceutical interventions could enhance the overall effectiveness of treatment for these debilitating conditions, ultimately improving patient outcomes and quality of life.** **However, it's essential to acknowledge that unlocking the full potential of Moringa oil in managing neurodegenerative diseases necessitates substantial additional research. A key focus of future studies should be on pinpointing the specific bioactive compounds within Moringa oil that are responsible for its observed neuroprotective effects. This involves isolating and characterizing the various phytochemicals present in the oil and investigating their individual and combined effects on neuronal health. Furthermore, researchers need to thoroughly investigate the precise mechanisms by which Moringa oil influences cellular signaling pathways that are critical in the context of neurodegeneration. This includes examining how Moringa oil affects processes such as amyloid-beta aggregation in Alzheimer's disease, alpha-synuclein aggregation in Parkinson's disease, and excitotoxicity following a stroke.**

**To definitively validate the efficacy and safety of Moringa oil for individuals suffering from neurological disorders, rigorous and well-designed clinical trials are of paramount importance. These trials should adhere to the highest scientific standards, including appropriate control groups, randomization, and blinding, to minimize bias and ensure the reliability of the results. The trials should carefully assess the impact of Moringa oil on cognitive function, motor skills, disease progression, and overall quality of life in patients with Alzheimer's, Parkinson's, and stroke. Furthermore, such studies must carefully monitor for any potential adverse effects associated with Moringa oil consumption.** **In addition to assessing efficacy and safety, it is crucial to determine the optimal dosage and administration route for maximizing the neuroprotective benefits of Moringa oil. Factors such as the concentration of bioactive compounds in the oil, the method of extraction and processing, and the route of administration (e.g., oral, topical) can all influence its effectiveness. Research is needed to identify the most effective way to deliver Moringa oil to the brain to achieve optimal therapeutic outcomes.** **Finally, the research agenda must also address the inherent challenges associated with the practical application of Moringa oil. These challenges include issues related to its bioavailability (how well it is absorbed and utilized by the body), its stability during storage and processing (ensuring that the bioactive compounds do not degrade over time), and the potential for interactions with existing medications that patients may be taking. Overcoming these limitations through innovative formulation strategies, improved storage techniques, and careful monitoring of drug interactions is essential to translate the promising preclinical findings into effective, reliable, and safe therapeutic applications for neurodegenerative diseases. Only through rigorous scientific investigation and addressing these challenges can we realize the full potential of Moringa oil as a novel approach to combating these devastating conditions.**

***CONCLUSION***

**In conclusion, this review has synthesized compelling evidence indicating that**Moringa oleifera**oil demonstrates significant neuroprotective potential. This potential appears to stem from its capacity to modulate key cellular signaling pathways implicated in neuronal survival and function. Specifically, the evidence from both**in vitro**and**in vivo**studies has shown promising results in mitigating the damaging effects of oxidative stress, reducing neuroinflammation, and inhibiting apoptosis within various neuronal model systems. However, despite these encouraging preclinical findings, further rigorous and comprehensive investigation is absolutely crucial to fully understand and validate these effects.** **A critical gap in our current knowledge lies in the precise mechanisms of action. A deep understanding of the mechanisms will allow us to harness the full neuroprotective potential of**Moringa oleifera**oil and develop evidence based interventions to improve the lives of individuals affected by these devastating conditions. Therefore, this review strongly recommend that future research endeavors prioritize the design and execution of comprehensive clinical trials. These trials should be meticulously designed to assess the efficacy and, crucially, the safety of**Moringa oleifera**oil in preventing or alleviating the progression of neurodegenerative diseases in human subjects. Such trials should carefully consider and explore optimal dosages, investigate various delivery methods (e.g., oral administration, topical application), and rigorously monitor for both short-term and long-term effects, including potential adverse reactions.**

**Disclaimer (Artificial intelligence)**

Author hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**References**

1. Albasher, G., Al Kahtani, S., Alwahibi, M. S., Almeer, R. (2020). Effect of Moringa oleifera Lam. methanolic extract on lead-induced oxidative stress-mediated hepatic damage and inflammation in rats. *Environmental Science and Pollution Research*. *27*: 19877-19887.
2. Alia, F., Putri, M., Anggraeni, N., Syamsunarno, M. R. A. A. (2022). The potency of Moringa oleifera Lam. as protective agent in cardiac damage and vascular dysfunction. *Frontiers in Pharmacology*, *12*: 724439.
3. Anderson, E. L., Stephen, S. O., Udi, O. A., Oladunni, E. A., Sunday, I. P. (2023). Investigating the effect of Mimosa Pudica on dichlorvos induced hippocampal neurodegeneration in mice. *Phytomedicine Plus*. *3*(1): 100393.
4. Andrew, U. O., Godswill, O. O., Mamerhi, E. T., Boma, D. (2023). Nutritional knowledge and body mass index among students at Novena University, Ogume, Nigeria. *Folia Medica Indonesiana*, *59*(1):14-19.
5. Andrew, U. O., Ozoko, L. E. C., Kingsley, I. A., Mamerhi, E. T., Beauty, E. (2017). Histologic effect of garlic extract on the spleen of adult wistar rat. *J Pharm Biol Sci*, *12*: 1-4.
6. Anuragi, H., Singhal, R. K., Tanveer, Y., Yasmin, H., Srijan, A., Bharati, A., Sabagh, A. E. (2022). The Primacy of Moringa (Moringa oleifera Lam.) in Boosting Nutrition Status and Immunity Defence Amidst the COVID-19 Catastrophe: A Perspective. *Phyton (0031-9457)*, *91*(9).
7. Ativie, N.R., Ekhoye, E.I., Udi, O.A., Okezue, O.C., Ezugwu, U.A., Ibe, N.V. (2018). Anthropometric indicators in diet and physical activity. *Asian Journal of Advanced Research and Reports*. *2*(1): 1-9.
8. Arese, M., Bussolino, F., Pergolizzi, M., Bizzozero, L. (2022). An Overview of the Molecular Cues and Their Intracellular Signaling Shared by Cancer and the Nervous System: From Neurotransmitters to Synaptic Proteins, Anatomy of an All-Inclusive Cooperation. *International Journal of Molecular Sciences.* *23*(23):14695.
9. Brett, B. L., Gardner, R. C., Godbout, J., Dams-O’Connor, K., Keene, C. D. (2022). Traumatic brain injury and risk of neurodegenerative disorder. *Biological psychiatry*. *91*(5):498-507.
10. Cerasuolo, M., Di Meo, I., Auriemma, M. C., Paolisso, G., Papa, M., Rizzo, M. R. (2024). Exploring the Dynamic Changes of Brain Lipids, Lipid Rafts, and Lipid Droplets in Aging and Alzheimer’s Disease. *Biomolecules*. *14*(11):1362.
11. Cretella, A. B. M., da Silva Soley, B., Pawloski, P. L., Ruziska, R. M., Scharf, D. R., Ascari, J., Otuki, M. F. (2020). Expanding the anti-inflammatory potential of Moringa oleifera: topical effect of seed oil on skin inflammation and hyperproliferation. *Journal of ethnopharmacology*, *254*:112708.
12. Cuellar-Núñez, M. L., Loarca-Piña, G., Berhow, M., de Mejia, E. G. (2020). Glucosinolate-rich hydrolyzed extract from Moringa oleifera leaves decreased the production of TNF-α and IL-1β cytokines and induced ROS and apoptosis in human colon cancer cells. *Journal of Functional Foods*. *75*: 104270.
13. Demirci-Cekic, S., Özkan, G., Avan, A. N., Uzunboy, S., Çapanoğlu, E., Apak, R. (2022). Biomarkers of oxidative stress and antioxidant defense. *Journal of pharmaceutical and biomedical analysis*, *209*, 114477.
14. Devkota, S., Bhusal, K. K. (2020). Moringa oleifera: A miracle multipurpose tree for agroforestry and climate change mitigation from the Himalayas–A review. *Cogent Food & Agriculture*. *6*(1), 1805951.
15. Dzuvor, C. K., Pan, S., Amanze, C., Amuzu, P., Asakiya, C., Kubi, F. (2022). Bioactive components from Moringa oleifera seeds: production, functionalities and applications–a critical review. *Critical Reviews in Biotechnology*. *42*(2):271-293.
16. Dyall, S. C., Balas, L., Bazan, N. G., Brenna, J. T., Chiang, N., da Costa Souza, F., Taha, A. Y. (2022). Polyunsaturated fatty acids and fatty acid-derived lipid mediators: Recent advances in the understanding of their biosynthesis, structures, and functions. *Progress in lipid research*. *86*:101165.
17. Eduviere, A. T., Otomewo, L. O., Udi, O. A., Opajobi, A. O., Moke, E. G. (2024). Memory-enhancing activity of verapamil in murine models of stress. *Tropical Journal of Pharmaceutical Research*. *23*(9): 1423-1432.
18. Enye, L. A., Ebeye, A. O., Udi, O. A., Ishola, A. O., Igbigbi, P. S. (2021). Mimosa pudica ameliorated dichlorvos induced neuro-oxidation. *Toxicology International*. 203-212.
19. Fu, X., Su, J., Hou, L., Zhu, P., Hou, Y., Zhang, K., Xu, J. (2021). Physicochemical and thermal characteristics of Moringa oleifera seed oil. *Advanced Composites and Hybrid Materials*. *4*: 685-695.
20. Gogna, T., Housden, B. E., Houldsworth, A. (2024). Exploring the Role of Reactive Oxygen Species in the Pathogenesis and Pathophysiology of Alzheimer’s and Parkinson’s Disease and the Efficacy of Antioxidant Treatment. *Antioxidants*. *13*(9):1138.
21. Hartman, M. L., Czyz, M. (2020). BCL-w: apoptotic and non-apoptotic role in health and disease. *Cell Death & Disease*. *11*(4):260.
22. Ilango, S., Paital, B., Jayachandran, P., Padma, P. R., Nirmaladevi, R. (2020). Epigenetic alterations in cancer. *Frontiers in Bioscience-Landmark*. *25*(6): 1058-1109.
23. Jha, M., Pasupalak, J. K., Gupta, G. L. (2024). Depressive Behavior and BDNF/TrkB Signaling. In *Handbook of the Biology and Pathology of Mental Disorders* (pp. 1-15). Cham: Springer International Publishing.
24. Ju Hwang, C., Choi, D. Y., Park, M. H., Hong, J. T. (2019). NF-κB as a key mediator of brain inflammation in Alzheimer's disease. *CNS & Neurological Disorders-Drug Targets (Formerly Current Drug Targets-CNS & Neurological Disorders)*. *18*(1):3-10.
25. Kapoor, B., Kapoor, D., Gautam, S., Singh, R., Bhardwaj, S. (2021). Dietary polyunsaturated fatty acids (PUFAs): Uses and potential health benefits. *Current nutrition reports*. *10*:232-242.
26. Mahaveerchand, H., Abdul Salam, A. A. (2024). Environmental, industrial, and health benefits of Moringa oleifera. *Phytochemistry Reviews*, 1-60.
27. Nair, P. R., Kumar, B. M., Nair, V. D., Nair, P. R., Kumar, B. M., Nair, V. D. (2021). Multipurpose trees (MPTs) and other agroforestry species. *An Introduction to Agroforestry: Four Decades of Scientific Developments*. 281-351.
28. Ngo, V., Duennwald, M. L. (2022). Nrf2 and oxidative stress: A general overview of mechanisms and implications in human disease. *Antioxidants*. *11*(12):2345.
29. Obukohwo, O. M., Oreoluwa, O. A., Andrew, U. O., Williams, U. E. (2024). Microglia-mediated neuroinflammation in traumatic brain injury: A review. *Molecular Biology Reports*, *51*(1):1-13.
30. Ogo, A. O., EU, I. M. E., Oloche, J. J. (2023). Antilipidemic Potentials of Moringa Oleifera Root Extract in Poloxamer 407-Induced Hyperlipidemia.
31. Oreva, O. G., Ebeye, C. O. L., Onoriode, I. V. J., Mamerhi, E. T., Efe, A. E., Ogagayere, L. O., Andrew, U. O. (2022). The Impact of Pumpkin Seed Extracts on the Histology of the Hypothalamus and Testosterone Level of Alloxan Induced Diabetic Male Rats. *Asian Journal of Medicine and Health*, *20*(12), 1-7.
32. Oyem, J. C., Chris-Ozoko, L. E., Enaohwo, M. T., Otabor, F. O., Okudayo, V. A., Udi, O. A. (2021). Antioxidative properties of Ocimum gratissimum alters Lead acetate induced oxidative damage in lymphoid tissues and hematological parameters of adult Wistar rats. *Toxicology reports*. *8*:215-222.
33. Oyovwi, M. O., Udi, O. A. (2024). The Gut-Brain Axis and Neuroinflammation in Traumatic Brain Injury. *Molecular Neurobiology*, 1-15.
34. Reda, F. M., Alagawany, M., Mahmoud, H. K., Al-Marakby, K. M., Ismail, T. A., Elnesr, S. (2025). The Use of Moringa Leaves Extract in Rabbit Diets: Its Effect on Performance, Lipid Profile, Kidney and Liver Function, Immunity, Antioxidant, Digestive Enzymes, and Cecal Microbiota. *Annals of Animal Science*. *25*(1):259-269.
35. Seifu, E., Teketay, D. (2020). Introduction and expansion of Moringa oleifera Lam. in Botswana: Current status and potential for commercialization. *South African Journal of Botany*. *129*, 471-479.
36. Shah, K. H., Oza, M. J. (2022). Comprehensive review of bioactive and molecular aspects of Moringa Oleifera lam. *Food Reviews International*, *38*(7): 1427-1460.
37. Shahbaz, M., Naeem, H., Batool, M., Imran, M., Hussain, M., Mujtaba, A., Al Jbawi, E. (2024). Antioxidant, anticancer, and anti‐inflammatory potential of Moringa seed and Moringa seed oil: A comprehensive approach. *Food Science & Nutrition*, *12*(9), 6157-6173.
38. Shen, Z., Xiang, M., Chen, C., Ding, F., Wang, Y., Shang, C., Cui, X. (2022). Glutamate excitotoxicity: Potential therapeutic target for ischemic stroke. *Biomedicine & Pharmacotherapy*. *151*:113125.
39. Shivanna, S. K., Naik, N. L., Nataraj, B. H., Rao, P. S. (2024). Moringa marvel: navigating therapeutic insights and safety features for future functional foods. *Journal of Food Measurement and Characterization*. 1-32.
40. Sultana, S. (2020). Nutritional and functional properties of Moringa oleifera. *Metabolism open*, *8*, 100061.
41. Stadtlander, T., & Becker, K. (2017). Proximate composition, amino and fatty acid profiles and element compositions of four different Moringa species. *Journal of Agricultural Science*, *9*(7), 46-57.
42. Teleanu, R. I., Chircov, C., Grumezescu, A. M., Volceanov, A., Teleanu, D. M. (2019). Antioxidant therapies for neuroprotection—A review. *Journal of clinical medicine*, *8*(10), 1659.
43. Tian, L. Y., Smit, D. J., Jücker, M. (2023). The role of PI3K/AKT/mTOR signaling in hepatocellular carcinoma metabolism. *International Journal of Molecular Sciences*. *24*(3):2652.
44. Tutunchi, H., Ostadrahimi, A., Saghafi-Asl, M. (2020). The effects of diets enriched in monounsaturated oleic acid on the management and prevention of obesity: a systematic review of human intervention studies. *Advances in nutrition*. *11*(4): 864-877.
45. Udi, O. A., Oyem, J. C., Ebeye, O. A., Chris-Ozoko, L. E., Igbigbi, P. S., Olannye, D. U. (2022). The effects of aqueous extract of ocimum gratissimum on the cerebellum of male wistar rats challenged by lead acetate. *Clinical Nutrition Open Science*. *44*: 28-41.
46. Worku, B., Tolossa, N. (2024). A Review on the Neuroprotective Effect of Moringa oleifera. *Oxidative Medicine and Cellular Longevity*. *2024*(1): 7694516.
47. Wu, Y. Y., Xu, Y. M., Lau, A. T. (2021). Anti-cancer and medicinal potentials of moringa isothiocyanate. *Molecules*, *26*(24): 7512.
48. Xiao, C. L., Lai, H. T., Zhou, J. J., Liu, W. Y., Zhao, M., Zhao, K. (2024). Nrf2 signaling pathway: focus on oxidative stress in spinal cord injury. *Molecular Neurobiology*. 1-20.
49. Yasoob, T. B., Khalid, A. R., Zhang, Z., Zhu, X., Hang, S. (2022). Liver transcriptome of rabbits supplemented with oral Moringa oleifera leaf powder under heat stress is associated with modulation of lipid metabolism and up-regulation of genes for thermo-tolerance, antioxidation, and immunity. *Nutrition Research* *99*: 25-39.
50. Zouboulis, C. C., Hossini, A. M., Hou, X., Wang, C., Weylandt, K. H., Pietzner, A. (2023). Effects of Moringa oleifera seed oil on cultured human sebocytes in vitro and comparison with other oil types. *International Journal of Molecular Sciences*, *24*(12): 10332.