



Original Research Paper

Integrated Molecular Profiling of Vascular Disorders for Biomarker Discovery and Therapeutic Target Discovery

Thirumurugan A^{1*}, Priya K², Shanthakumari N³, Ajith T⁴

^{1*}Department of Research, Saveetha College of Nursing Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Thandalam Chennai-602105, Tamil Nadu, India.

²Department of Microbiology, Thanthai Hans Roever College (Autonomous) (Affiliated to Bharathidasan University, Tiruchirappalli), Perambalur - 621 220, Tamil Nadu, India.

³Ph.D Research Scholar, Saveetha College of Nursing, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamilnadu, India

⁴Department of Botany, Bharathidasan University, Tiruchirappalli, Tamil Nadu, India.

Key Words	Abstract
Alzheimer's, Omis, Proteomics, Lipidomics, Culture and Glycomics	The disease is predominantly associated with pathological features, including the deposition of extracellular amyloid- β plaques, the formation of intracellular neurofibrillary tangles composed of hyperphosphorylated tau protein, synaptic dysfunction, and progressive neuronal loss. In addition to these classical hallmarks, the progression of the disease is significantly influenced by processes such as neuroinflammation, oxidative stress, metabolic imbalance, and lipid dysregulation. The necessity for more sensitive molecular approaches for early diagnosis is underscored by the fact that traditional diagnostic methods, such as clinical assessment, neuroimaging, and cerebrospinal fluid biomarkers, frequently detect the disease at relatively advanced stages. In the past few years, omics technologies, such as proteomics, lipidomic, glycemic, and integrated multi-omics approaches, have become potent instruments for comprehending the intricate molecular mechanisms that underlie Alzheimer's disease. These technologies facilitate the identification of disease-specific molecular signatures and potential biomarkers by enabling the large-scale analysis of proteins, lipids, and glycans. These integrative strategies have the potential to identify therapeutic targets for drug development and discover novel biomarkers for early diagnosis. Additionally, the implementation of precision medicine methodologies that are predicated on multi-omics data may facilitate the development of personalized treatment strategies for patients. This review provides a concise summary of the current state of knowledge regarding the pathophysiology of Alzheimer's disease and emphasizes the importance of proteomics, lipidomic, glycemic, and integrated multi-omics approaches in the exploration of biomarkers, the enhancement of early diagnosis, and the support of the development of targeted therapeutic strategies for Alzheimer's disease.

* Corresponding Author's email: anubot373@gmail.com

Received: 11th August, 2026; Revised: 26th August, 2026; Accepted: 31st August, 2026

(DOI): 10.70102/AEJ.2026.18.4s.106

1. Introduction

Alzheimer's disease is the most prevalent cause of dementia worldwide and is a progressive neurodegenerative disorder. It is distinguished by a progressive deterioration in cognitive function, which encompasses memory loss, impaired reasoning, language difficulties, and behavioral changes that ultimately disrupt daily living activities. In 1906, the German neurologist Alois Alzheimer first described the disease while investigating the brain of a patient who exhibited severe memory impairment and unusual behavioral symptoms. Alzheimer's disease has emerged as one of the most significant health challenges associated with elderly populations worldwide since that time. Alzheimer's disease is responsible for approximately 60–70% of the approximately 55 million individuals who are presently living with dementia, according to recent global estimates. By 2050, the number of individuals affected by dementia is anticipated to reach nearly 139 million, a significant public health concern on a global scale, as a result of the accelerated increase in life expectancy and aging populations (Tenchov et al., 2024; Safiri et al., 2024; Ayyadurai et al., 2026; Anbazhagan et al., 2026; Ayyadurai et al., 2026). Alzheimer's disease is predominantly a condition that affects older adults and is distinguished by the progressive deterioration of brain structure and function. Mild cognitive impairment, notably in the context of short-term memory and learning ability, is frequently observed during the initial stages of the disease. Confusion, disorientation, impaired judgment, personality changes, and difficulty conducting routine tasks are among the more severe symptoms that patients experience as the disease advances. Individuals become entirely reliant on caregivers for the most fundamental activities of daily life and lose the capacity to communicate effectively in the advanced stages. Alzheimer's disease is neuropathologically associated with extensive neuronal loss, synaptic dysfunction, and brain atrophy, particularly in the hippocampus and cerebral cortex, which are regions responsible for cognitive processing and memory formation (Gholami, 2023). The accumulation of extracellular amyloid-beta ($A\beta$) plaques and intracellular neurofibrillary tangles, which are composed of hyperphosphorylated tau protein, are among the

pathological hallmarks of Alzheimer's disease. The abnormal digestion of amyloid precursor protein (APP) leads to the formation of amyloid plaques, which are composed of beta-amyloid peptides that accumulate and deposit between neurons. Neuronal injury is exacerbated by the activation of inflammatory responses and the disruption of neuronal communication by these plaques. In contrast, neurofibrillary tangles are the result of the aberrant phosphorylation of tau protein, which is typically responsible for stabilizing microtubules in neuronal cells. Tau detaches from microtubules and forms contorted filamentous structures within neurons when it becomes hyperphosphorylated, resulting in impaired intracellular transport and eventual neuronal degeneration (Kamila et al., 2025). The cognitive decline observed in Alzheimer's disease patients is strongly correlated with the accumulation of these pathological structures, which ultimately leads to synaptic loss and pervasive brain atrophy. The precise mechanisms that underlie Alzheimer's disease are still not fully understood, despite the significant progress that has been made in neuroscience research. The amyloid cascade hypothesis, tau hypothesis, oxidative stress hypothesis, and neuroinflammation hypothesis are among the numerous hypotheses that have been proposed to elucidate the disease's pathogenesis. The amyloid cascade hypothesis has garnered significant attention due to its hypothesis that the aberrant accumulation of amyloid-beta peptides triggers a sequence of downstream pathological events, such as tau hyperphosphorylation, synaptic dysfunction, and neuronal death (Wang et al., 2025; Sakthivel et al., 2026; Jancyhelan et al., 2026). Nevertheless, recent research indicates that Alzheimer's disease is a multifactorial disorder that is influenced by a multifaceted interplay of genetic, environmental, metabolic, and lifestyle factors. Alzheimer's disease has been linked to an elevated susceptibility to risk factors such as advanced age, genetic predisposition, cardiovascular diseases, diabetes, obesity, and limited physical activity (Liu et al., 2025). The early and precise diagnosis of Alzheimer's disease continues to be a significant obstacle in clinical practice. Clinical evaluation, cognitive assessment, and neuroimaging techniques, including positron emission

tomography (PET) and magnetic resonance imaging (MRI), are the primary components of conventional diagnostic methods. Furthermore, cerebrospinal fluid (CSF) biomarkers, such as amyloid-beta, total tau, and phosphorylated tau, have been extensively employed to facilitate diagnosis. Nevertheless, these diagnostic techniques are subject to a number of constraints. Early detection is typically challenging due to the fact that clinical symptoms typically manifest only after substantial neuronal injury has already occurred. Furthermore, sophisticated neuroimaging techniques and CSF biomarker analyses can be expensive, invasive, and not easily accessible in numerous healthcare environments (Xiong et al., 2023). Consequently, it is imperative to create biomarkers that are more sensitive, reliable, and non-invasive in order to detect Alzheimer's disease at an earlier stage and enhance disease management. Biomedical research has been transformed by recent developments in high-throughput molecular technologies, which have opened up new avenues for the comprehension of intricate diseases like Alzheimer's disease. Genomics, transcriptomics, proteomics, metabolomics, and epigenomics are among the various omics technologies that facilitate the comprehensive analysis of biological molecules at various levels within a biological system. These technologies enable researchers to investigate the extensive modifications in genes, RNA transcripts, proteins, and metabolites that transpire during the development and progression of diseases (Sehar et al., 2022). Numerous genes have been identified as being associated with the risk of Alzheimer's disease through genomic studies, such as APP, PSEN1, PSEN2, and the apolipoprotein E (APOE) ϵ 4 allele, which is regarded as the most prominent genetic risk factor for late-onset Alzheimer's disease. In the same vein, transcriptomic and proteomic investigations have disclosed modifications in protein signaling pathways and gene expression that are associated with neuronal survival, synaptic dysfunction, and inflammation. Additionally, metabolomics has become a critical method for detecting metabolic mutations that are linked to neurodegeneration, such as disruptions in oxidative stress pathways, energy metabolism, and lipid metabolism. Furthermore, the integration of multiple omics datasets through multi-omics

approaches has enabled a more comprehensive comprehension of disease mechanisms by connecting genetic variations with downstream molecular and

biochemical changes. These integrative strategies have the potential to identify novel biomarkers for early diagnosis and to identify therapeutic targets that may result in more effective treatment strategies (Santos et al., 2023). The application of omics technologies has become increasingly significant in neurodegenerative disease research due to the complexity and multifactorial character of Alzheimer's disease. These methods provide valuable insights into the molecular pathways that are involved in the progression of diseases and may aid in the development of personalized medicine strategies for early diagnosis, prevention, and treatment. Consequently, the objective of this review is to provide a comprehensive overview of the current state of knowledge concerning the molecular mechanisms of Alzheimer's disease and to underscore the significance of omics technologies in the advancement of research on neurodegenerative disorders. This review offers a comprehensive perspective on the newly emerging role of multi-omics approaches in the comprehension of Alzheimer's disease and the enhancement of diagnostic and therapeutic strategies by incorporating findings from genomic, transcriptomic, proteomic, and metabolomic studies.

2.1 Alzheimer's Disease Pathophysiology

Behavioral alterations, memory impairment, and cognitive decline are the hallmarks of Alzheimer's disease (AD), a progressive neurodegenerative disorder. Extracellular amyloid- β (A β) plaques and intracellular neurofibrillary tangles (NFTs) comprising hyperphosphorylated tau protein are the primary pathological hallmarks. Amyloid- β is produced as a result of the anomalous cleavage of amyloid precursor protein (APP) by β - and γ -secretases, which results in the formation of plaques that disrupt synaptic signaling and initiate neuroinflammatory responses Fig.1 & Table 1. By destabilizing microtubules, neurofibrillary tangles impede axonal transport, resulting in synaptic dysfunction and neuronal mortality. Oxidative

stress and mitochondrial dysfunction further exacerbate these protein abnormalities, resulting in progressive neuronal injury and loss (Hampel et al., 2021; Dagla et al., 2026; Brezic et al., 2025; Kamatham, et al., 2024). In addition to protein aggregation, other mechanisms are essential to the pathophysiology of Alzheimer's disease. Pro-inflammatory cytokines are released by activated microglia and astrocytes around amyloid plaques, which contribute to chronic neuroinflammation and exacerbate neuronal injury. An energy deficit that accelerates neuronal dysfunction is the result of metabolic dysregulation, which includes impaired

glucose utilization and insulin signaling in the brain. Amyloid deposition, tau pathology, oxidative stress, inflammation, and metabolic disturbances collectively result in widespread neuronal loss, particularly in the hippocampus and cerebral cortex, which is consistent with the characteristic cognitive deficits observed in Alzheimer's disease patients (Zheng et al., 2025). Cholinergic Neuron Degeneration. The basal forebrain loses cholinergic neurons, which lowers the amount of acetylcholine.

Results in memory loss and a deterioration in cognitive function (Richter et al., 2022).

Table 1. Key pathophysiological mechanisms involved in Alzheimer's disease, including amyloid- β plaque formation, tau hyperphosphorylation, neuroinflammation, oxidative stress, synaptic dysfunction, and cholinergic neuronal loss.

Pathophysiological Feature	Mechanism / Description	Impact on Brain Function	References
Amyloid- β (A β) Plaque Formation	When β -secretase and γ -secretase cut amyloid precursor protein (APP) in an unusual way, they make A β peptides that come together outside of cells to make plaques.	Disrupts synaptic signaling, causes neuronal damage, and encourages neuroinflammation.	Jia & Fu,2025; Mohapatra et al., 2025
Tau Protein Hyperphosphorylation	When tau protein has too many phosphates, it can't keep microtubules stable anymore and forms neurofibrillary tangles (NFTs).	Causes the cytoskeletal collapse of neurons, problems with axonal transport, and death of neurons.	Kaur et al., 2025
Synaptic Dysfunction	A β oligomers disrupt synaptic transmission and plasticity, especially in hippocampal neurons.	Causes early cognitive impairments and memory loss.	Li et al., 2018
Neuroinflammation	Microglia and astrocytes become active when A β builds up and neurons are damaged.	Chronic inflammation speeds up the death of neurons.	Kwon et al., 2021
Oxidative Stress	Too many reactive oxygen species (ROS) are generated because the mitochondria aren't working right and A β is harmful.	Damages lipids, proteins, and DNA, which leads to the death of neurons.	Houldsworth et al., 2024
Cholinergic Neuron Degeneration	The basal forebrain loses cholinergic neurons, which lowers the amount of acetylcholine.	Results in memory loss and a deterioration in cognitive function.	Richter et al., 2022

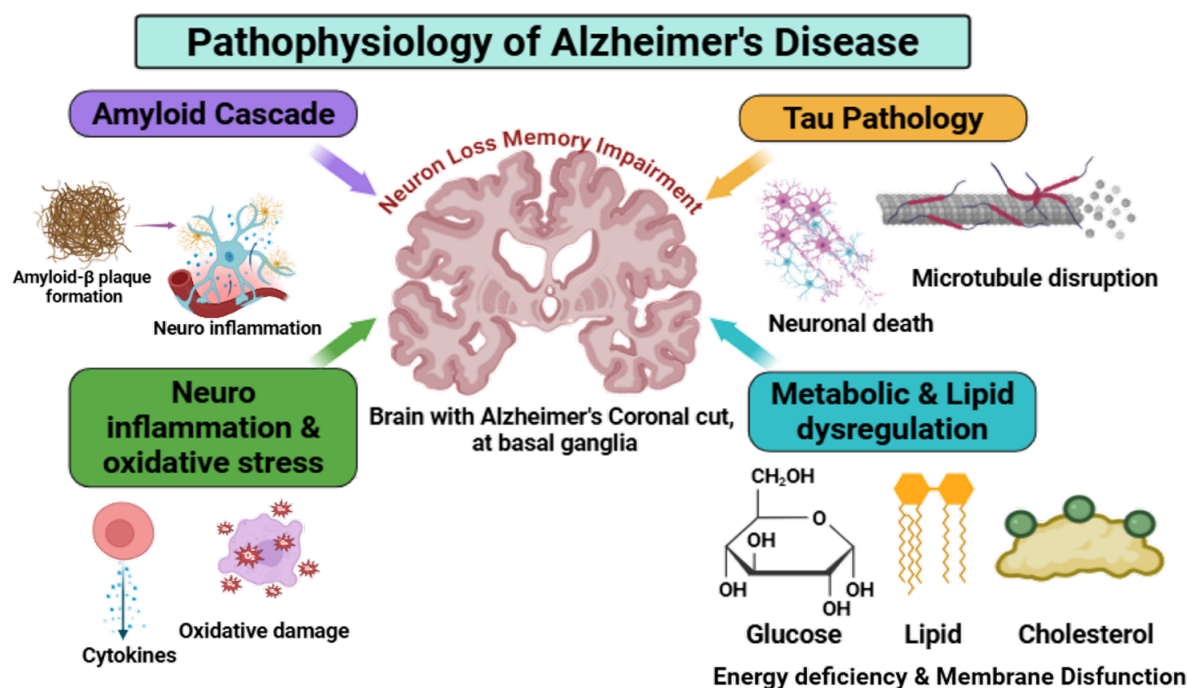


Fig.1. Schematic representation of the key mechanisms underlying Alzheimer's disease, including amyloid cascade, tau pathology, neuroinflammation, oxidative stress, and metabolic dysregulation leading to neuronal loss and memory impairment (created with biorender.com).

2.2 The Amyloid Cascade Hypothesis

The Amyloid Cascade Hypothesis posits that the aberrant accumulation of amyloid- β ($A\beta$) peptides in the brain is the primary factor driving the onset of Alzheimer's disease (AD). These peptides are produced by the sequential cleavage of the amyloid precursor protein (APP) by β - and γ -secretases. In AD, the aggregation of $A\beta$ into extracellular amyloid plaques is a result of excessive production or impaired clearance. These plaques disrupt synaptic function and disrupt neuronal communication. Neurofibrillary tangles, synaptic loss, and neuronal mortality are believed to be initiated by this early pathological event, which in turn initiates a series of downstream

neurodegenerative processes (Zhang et al., 2024). In addition, the deposition of amyloid- β plaques activates microglia and astrocytes, resulting in the release of pro-inflammatory cytokines and the induction of chronic neuroinflammation. This inflammatory response, in conjunction with oxidative stress and mitochondrial dysfunction, exacerbates neuronal injury and contributes to the progressive decline of cognitive function. In accordance with the hypothesis, amyloid accumulation is the precipitating factor that initiates the sequence of events that results in the recognizable cognitive deficits and memory loss that are observed in Alzheimer's disease patients (Chen et al., 2020).

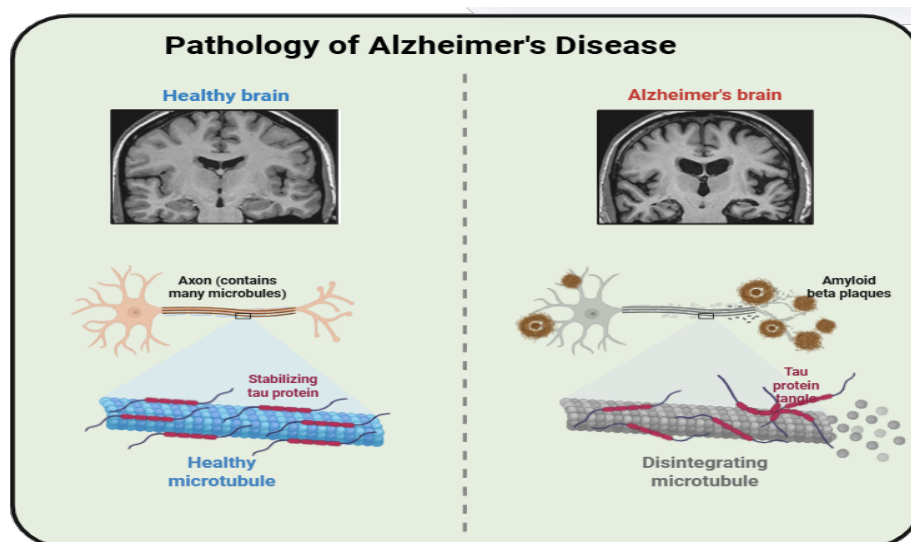


Fig.3. Comparative illustration of healthy and Alzheimer's disease brain showing amyloid- β plaque deposition, tau protein tangles, and microtubule disintegration leading to neuronal dysfunction (created with biorender.com).

2.3 Tau Pathology

In Alzheimer's disease (AD), tau pathology is a significant factor in cognitive decline and neuronal dysfunction. Tau is a microtubule-associated protein that is responsible for the stabilization of neuronal microtubules, which is essential for the appropriate axonal transport of neurotransmitters, proteins, and organelles. In Alzheimer's disease, tau undergoes hyperphosphorylation, which results in the destabilization of microtubules and a decrease in its binding to them. Neurofibrillary tangles (NFTs) are formed within neurons when the free hyperphosphorylated tau proteins aggregate, thereby disrupting intracellular transport and impairing synaptic communication. This results in neuronal dysfunction, synaptic loss, and ultimately cell death, particularly in brain regions that are responsible for memory, such as the hippocampus and entorhinal cortex (Long et al., 2022). The deterioration of cognitive symptoms is accompanied by the spread of tau pathology from the hippocampus and entorhinal cortex to the neocortex as the disease advances. The accumulation of NFTs also interacts with other pathological processes, such as oxidative stress, neuroinflammation, and mitochondrial dysfunction, which further accelerates neuronal injury Fig.3. It is important to note that the severity of tau pathology is more closely correlated with cognitive decline than amyloid- β plaque deposition, underscoring its

critical role in the clinical manifestations of Alzheimer's disease (Gao et al., 2023).

2.4 Oxidative Stress and Neuroinflammation

In Alzheimer's disease (AD), neuroinflammation is a significant factor in the development of cognitive decline and neuronal injury. In response to amyloid- β deposits and damaged neurons, microglia, the resident immune cells of the central nervous system, become overactivated. Pro-inflammatory cytokines, including IL-1 β , TNF- α , and IL-6, are released by activated microglia, which disrupt normal synaptic function and exacerbate neuronal stress. A detrimental immune response is perpetuated by chronic neuroinflammation, which also recruits astrocytes, resulting in a cycle of ongoing neuronal injury that accelerates disease progression (Lv et al., 2025).

Oxidative stress is a critical factor in the pathology of Alzheimer's disease, in addition to inflammation. The production of reactive oxygen species (ROS) is increased by overactivated microglia and dysfunctional mitochondria, which in turn degrade lipids, proteins, and DNA within neurons. This oxidative damage exacerbates the susceptibility of neurons to degeneration, disrupts synaptic signaling, and compromises cellular metabolism. Chronic neuroinflammation and oxidative stress are central mechanisms in the progression of Alzheimer's disease, as they not only

amplify amyloid- β and tau pathology but also directly contribute to neuronal mortality and cognitive decline (Lado et al., 2025).

2.5 Metabolic and Lipid Dysregulation

The pathogenesis and progression of Alzheimer's disease (AD) are significantly influenced by metabolic and lipid dysregulation. The brain's high energy requirements are met through the efficient metabolism of glucose, while the proper synaptic function and integrity of the neuronal membrane are maintained by a balanced lipid composition. Neuronal survival and synaptic activity are compromised in AD due to impaired glucose utilization and mitochondrial dysfunction, which reduce cellular energy production. These energy deficits increase the susceptibility of neurons to injury and expedite cognitive decline (He et al., 2025). Furthermore, abnormal levels of cholesterol and phospholipids, as well as disturbances in lipid metabolism, modify the fluidity and structure of neuronal membranes. These modifications exacerbate tau hyperphosphorylation, contribute to the formation and aggregation of amyloid- β plaques, and impair synaptic signaling. Energy deficits and membrane instability are directly linked to the hallmark maladies of Alzheimer's disease by the combined effects of metabolic insufficiency and lipid dysregulation, which create a permissive environment for neuronal degeneration (Zhang et al., 2026).

3. Proteomics in the Study of Alzheimer's Disease

The comprehensive analysis of protein expression, modifications, and interactions that drive disease progression is made possible by proteomics, which has become a critical tool in Alzheimer's disease (AD) research. This method has detected anomalous proteins in both brain tissue and biological fluids that are associated with critical AD hallmarks, such as the accumulation of amyloid- β plaques and the hyperphosphorylation of tau Fig.2. Proteomic studies have facilitated the identification of potential biomarkers for early diagnosis by analyzing cerebrospinal fluid (CSF) and blood. This is particularly critical due to the fact that clinical symptoms frequently manifest after significant neuronal loss (Yarbro et al., 2025; Ryu et al., 2025). In addition to biomarker discovery, proteomics offers a comprehensive understanding of the disrupted cellular pathways in AD, including impaired synaptic signaling, chronic neuroinflammation, and mitochondrial dysfunction. These factors all contribute to cognitive decline and neuronal degeneration. The molecular mechanisms that

underlie Alzheimer's disease are not only clarified by this knowledge, but it also facilitates the identification of therapeutic targets, thereby directing the development of strategies that are designed to delay or prevent the progression of the disease. Therefore, proteomics provides a comprehensive framework for the advancement of personalized diagnostic and treatment strategies and the comprehension of AD pathology (Percy et al., 2025; Zhang et al., 2023).

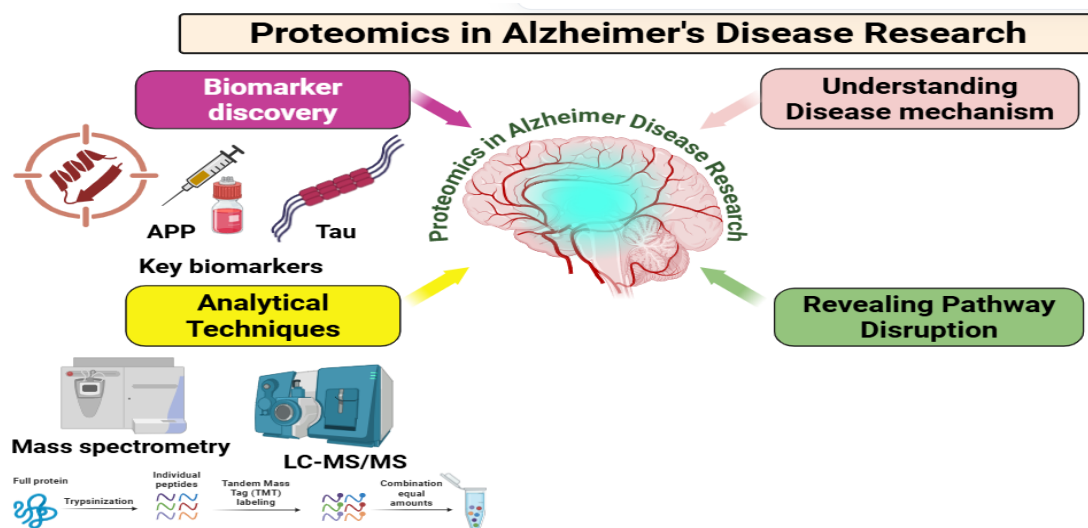


Fig.2. Overview of proteomics approaches in Alzheimer's disease research, highlighting biomarker discovery (APP, tau), analytical techniques (mass spectrometry, LC-MS/MS), and their role in understanding disease mechanisms and pathway disruptions (created with biorender.com).

3.1 Analytical Techniques and Principles

Advanced analytical techniques are employed in proteomic analysis of Alzheimer's disease (AD) to investigate the intricate protein networks that contribute to neurodegeneration Table 2. The most frequently employed methods are mass spectrometry (MS) and liquid chromatography–tandem mass spectrometry (LC–MS/MS), which enable researchers to identify and quantify thousands of proteins from biological samples, including cerebrospinal fluid, brain tissue, and blood. The detection of differential protein expression, post-translational modifications, and protein–protein interactions that are critical in AD

pathology is made possible by these techniques, which provide high sensitivity and accuracy (Bulska et al., 2022). These analytical methods assist in the mapping of molecular pathways disrupted in Alzheimer's disease, such as synaptic signaling, inflammation, and mitochondrial dysfunction, and the identification of novel protein biomarkers associated with disease progression through protein profiling. The capacity to investigate protein networks at a systems level offers valuable insights into the fundamental mechanisms of neurodegeneration and facilitates the identification of therapeutic targets for early intervention and disease-modifying strategies (Sathe et al., 2021).

Table 2 Analytical techniques commonly used in proteomic studies for Alzheimer's disease to identify, quantify, and validate proteins associated with neurodegeneration and disease progression.

Analytical Technique	Principle	Application in Alzheimer's Disease Research	Key References
Mass Spectrometry (MS)	Procedures mass-to-charge ratio of ionized peptides to identify and quantify proteins.	Identification of AD-related proteins, amyloid- β peptides, and biomarkers in brain tissue and biofluids.	Korecka & Shaw, 2021
Liquid Chromatography–Tandem Mass Spectrometry (LC–MS/MS)	Combines runny chromatography separation with tandem mass spectrometry for comprehensive peptide analysis.	Large-scale proteomic profiling and detection of discrepancy protein expression in AD samples.	Prabhakar, 2020
Two-Dimensional Gel Electrophoresis (2D-GE)	Separates proteins based on isoelectric point and molecular weight.	Comparative analysis of protein expression between AD and control samples.	Marshall et al., 2025
Western Blotting	Uses antibodies to detect specific proteins after electrophoretic separation.	Validation of AD-related proteins such as tau and amyloid precursor protein (APP).	Kulichikhin et al., 2021
Enzyme-Linked Immunosorbent Assay (ELISA)	Antibody-based quantitative detection of proteins in biological samples.	Measurement of AD biomarkers such as A β 42, total tau, and phosphorylated tau in CSF and blood.	Kareem et al., 2025
Bioinformatics & Proteomic Databases	Computational analysis of large proteomic datasets.	Identification of molecular pathways, protein networks, and biomarkers associated with AD progression.	Singh et al., 2022

3.2 Proteomic Biomarkers in Alzheimer's Disease

It is imperative to comprehend the molecular mechanisms of Alzheimer's disease (AD) and to enhance early diagnosis and disease monitoring through proteomic biomarkers. Amyloid precursor protein (APP) is a critical protein biomarker, as its aberrant processing produces amyloid- β peptides that aggregate into extracellular plaques, a characteristic of Alzheimer's disease pathology. Tau proteins are an additional significant biomarker; hyperphosphorylated tau generates intracellular neurofibrillary tangles, which disrupt microtubule stability, impede axonal transport, and contribute to neuronal mortality. In addition to APP and tau, synaptic proteins are significant biomarkers that demonstrate synaptic dysfunction and loss, which are closely correlated with cognitive decline. The identification of these protein alterations has been facilitated by proteomic analyses of brain tissue, cerebrospinal fluid (CSF), and blood. These analyses have provided valuable instruments for early detection, monitoring disease progression, and evaluating therapeutic responses. Disrupted molecular pathways, such as synaptic signaling, inflammation, and mitochondrial function, are also revealed by such studies, which provide insights into potential therapeutic targets (Do et al., 2026; Bai et al., 2021).

3.3 The Role of Proteomics in the Understanding of Disease Mechanisms.

Proteomics is a potent method for elucidating the molecular mechanisms that underlie Alzheimer's disease (AD). Proteomic studies identify critical proteins and signaling pathways involved in critical pathological processes such as neuroinflammation, synaptic dysfunction, and neuronal loss by analyzing large-scale protein expression patterns in brain tissue, cerebrospinal fluid, and blood. For instance, adjustments to the inflammatory proteins secreted by astrocytes and microglia offer a glimpse into the manner in which chronic immune activation contributes to the progression of the disease. Proteomic analyses also emphasize alterations in synaptic proteins that are crucial for neurotransmission, which may contribute to the synaptic failure observed in

Alzheimer's disease patients. Furthermore, the identification of proteins that dictate neuronal survival, apoptosis, and mitochondrial function provides insight into the mechanisms of cognitive decline and neuronal degeneration. In general, proteomics offers a comprehensive comprehension of the intricate protein networks that are disrupted in Alzheimer's disease, as well as potential biomarkers for diagnosis and therapeutic targets (Moya-Alvarado et al., 2026; Zia et al., 2026).

3.4 Therapeutic Targets Driven by Proteomics

Proteomics has emerged as an essential method for identifying potential therapeutic targets in Alzheimer's disease (AD) by exposing changes in protein expression and disrupted signaling pathways that contribute to neurodegeneration. Alterations in proteins involved in amyloid- β processing, tau phosphorylation, neuroinflammation, and synaptic dysfunction, which are critical contributors to disease progression, can be identified through large-scale proteomic analyses. The mapping of these altered protein networks facilitates the identification of molecular targets that could be exploited for therapeutic intervention and drug development (Camporesi et al., 2020; Lan et al., 2025). For example, proteins that regulate inflammatory pathways, oxidative stress responses, and synaptic function are currently being actively investigated as potential targets to mitigate or prevent neuronal injury in Alzheimer's disease. Proteomics not only helps to identify new therapeutic targets but also promotes the development of precision medicine strategies that are designed to enhance clinical outcomes and slow the progression of Alzheimer's disease by offering a comprehensive comprehension of disease-specific protein interactions and pathway disruptions. This approach emphasizes the indispensable function of proteomics in the advancement of treatment strategies for AD and the development of targeted therapies (Ali et al., 2025;

Tijms et al., 2024).

4. Alzheimer's Disease Lipidomics

The exhaustive study of lipids within biological systems and their impact on brain function, known as lipidomics, provides critical insights into Alzheimer's disease (AD) Table 3.

Lipids are crucial for the maintenance of neuronal membrane structure, the facilitation of synaptic signaling, and the support of energy metabolism. In Alzheimer's disease, disruptions in lipid metabolism can disrupt these processes, impair synaptic function, and promote neuronal degeneration (Imam et al., 2025). Abnormal levels of phospholipids, sphingolipids, and cholesterol derivatives have been detected in Alzheimer's patients through lipidomic investigations. These

lipid modifications exacerbate neuronal injury and cognitive decline by contributing to critical pathological processes, such as amyloid- β accumulation, neuroinflammation, and oxidative stress. Not only does comprehension of these lipid changes elucidate the mechanisms of AD progression, but it also offers prospective biomarkers and therapeutic targets for early detection and intervention (Magnelli et al., 2025; Plascencia-Villa et al., 2023).

Table 3 Major lipid classes and their functional roles in the brain, along with alterations observed in Alzheimer's disease and their contribution to disease pathology.

Lipid Class / Component	Role in Brain Function	Alteration in Alzheimer's Disease	Impact on AD Pathology	Key References
Phospholipids	Maintain neuronal membrane integrity and support synaptic signaling.	Reduced levels of phosphatidylcholine and phosphatidylethanolamine reported in AD brains.	Membrane instability and impaired synaptic transmission.	Zhang et al., 2025; Olešová et al., 2024
Sphingolipids	Important for cell signaling and neuronal survival.	Increased ceramide levels and altered sphingomyelin metabolism.	Promotes apoptosis and neurodegeneration.	Ge et al., 2025
Cholesterol	Regulates membrane fluidity and synaptic plasticity.	Dysregulated cholesterol metabolism associated with amyloid precursor protein processing.	Enhances amyloid- β production and plaque formation.	Zhang et al., 2026
Fatty Acids (PUFAs)	Support neuronal development and anti-inflammatory processes.	Decreased omega-3 fatty acids such as DHA in AD patients.	Increased inflammation and neuronal damage.	Giacobbe et al., 2025
Lipid Peroxidation Products	Indicators of oxidative damage to lipids.	Elevated levels of malondialdehyde and 4-hydroxynonenal.	Contributes to oxidative stress and neuronal injury.	Dham et al., 2021

4.1 The Significance of Lipids in Brain Function

Lipids are indispensable for the preservation of the brain's structure and functionality, and they are particularly important in the development and progression of Alzheimer's disease (AD). They are essential components of neuronal membranes, where they contribute to the preservation of membrane integrity, fluidity, and stability, all of which are essential for the proper functioning of cells. By enabling receptor activity, neurotransmitter release, and signal propagation across neural networks, proper lipid composition

supports synaptic transmission and neuronal signaling (Dash et al., 2025). Membrane function, synaptic efficiency, and neuronal communication can be compromised by disruptions in lipid metabolism. These lipid abnormalities may exacerbate amyloid- β accumulation, tau pathology, and oxidative stress, thereby contributing to the cognitive decline and neuronal injury observed in Alzheimer's disease. The molecular mechanisms that underlie neurodegeneration are illuminated by an understanding of the role of lipids in brain function, which also identifies potential targets for therapeutic intervention (Xiong et al., 2024; Yoon et al., 2022).

4.2 Methods of Lipidomic Profiling

Lipidomic profiling is a potent method for the analysis of lipid composition and the alterations that are associated with Alzheimer's disease (AD). Researchers can identify and quantify a variety of lipid species in intricate biological samples, such as cerebrospinal fluid, blood, and brain tissue, using advanced analytical methods like liquid chromatography–mass spectrometry (LC–MS) and gas chromatography–mass spectrometry (GC–MS). These methods are capable of separating lipid mixtures with high resolution and detecting them with high sensitivity and accuracy, thereby enabling the investigation of subtle changes in lipid

metabolism that are associated with the progression of a disease Table 4.

Lipid extraction methods, such as the Folch method or Bligh and Dyer extraction, are frequently employed to efficiently isolate lipids from biological samples prior to analysis. Researchers can identify potential lipid biomarkers and comprehend their role in neurodegeneration and cognitive decline in AD by combining these extraction and analytical techniques, which allows them to map alterations in phospholipids, sphingolipids, cholesterol derivatives, and other lipid classes (Han, 2010; Quehenberger et al., 2011).

Table 4 Major precision medicine approaches in Alzheimer’s disease integrating multi-omics technologies for biomarker discovery, risk prediction, and development of personalized therapeutic strategies.

Precision Medicine Component	Approach / Principle	Application in Alzheimer’s Disease	Clinical Significance	Key References
Genomics	Analysis of genetic variations and risk genes associated with AD.	Identification of susceptibility genes such as <i>APOE</i> , <i>APP</i> , <i>PSEN1</i> , and <i>PSEN2</i> .	Enables early risk prediction and personalized therapeutic strategies.	Kanda et al., 2025
Proteomics	Large-scale analysis of protein expression and modifications.	Detection of biomarkers such as amyloid-β, tau, and phosphorylated tau in CSF and blood.	Helps in diagnosis, disease monitoring, and therapeutic targeting.	Tao et al., 2024
Lipidomics	Study of lipid metabolism and lipid biomarkers in biological systems.	Identification of altered phospholipids, sphingolipids, and cholesterol metabolism in AD.	Provides insights into neurodegeneration and potential metabolic targets.	Cao et al., 2024
Glycomics	Analysis of glycan structures and glycosylation patterns of proteins.	Investigation of altered glycosylation in amyloid precursor protein and other neural proteins.	Contributes to biomarker discovery and understanding disease mechanisms.	Guerreiro, 2025
Multi-Omics Integration	Integration of genomics, proteomics, lipidomics, and glycomics data.	Identification of molecular networks and patient-specific disease pathways.	Supports personalized treatment and precision therapeutic development.	Ali, 2023
Biomarker-Guided Therapy	Use of molecular biomarkers to	Monitoring therapeutic	Improves treatment efficacy	Fatima et al., 2025

	guide treatment decisions.	response and disease progression in AD patients.	and enables personalized clinical management.	
--	----------------------------	--	---	--

4.3 Lipid Biomarkers in Alzheimer's Disease

Lipid biomarkers are essential for comprehending the metabolic changes that contribute to the pathogenesis of Alzheimer's disease (AD). Modifications in phospholipids, which are essential components of neuronal membranes, can compromise the integrity, fluidity, and synaptic signaling of the membrane, thereby impairing neuronal communication. Sphingolipids, such as ceramides and sphingomyelins, are crucial for cell signaling, apoptosis, and stress responses. These lipids have been linked to cognitive decline and neuronal degeneration at aberrant levels. The pathology of Alzheimer's disease is also influenced by changes in cholesterol derivatives, which promote the formation of amyloid- β plaques in the brain and influence the processing of amyloid precursor protein (APP). These lipid alterations have been identified as potential biomarkers for early diagnosis and indicators of disease progression through lipidomic analyses of brain tissue, cerebrospinal fluid, and blood. These insights are invaluable for the development of diagnostic and therapeutic strategies in Alzheimer's disease and for the comprehension of disease mechanisms (Sarkar et al., 2024; Breil et al., 2017).

4.4 Dysregulation of Lipids in Neurodegeneration

Lipid dysregulation is a critical factor contributing to neurodegeneration in Alzheimer's disease (AD). Neuronal membrane integrity can be compromised and synaptic signaling can be disrupted by abnormal lipid metabolism, which results in impaired communication between neurons. This includes phospholipids, sphingolipids, and cholesterol. The genesis and aggregation of amyloid- β peptides, a hallmark of AD pathology, are also influenced by these lipid alterations, which affect amyloid precursor protein (APP) processing (Farooqui et al., 2024). Additionally, neuroinflammation, oxidative stress, and apoptosis can be induced by elevated levels of specific lipids, such as ceramides, which further exacerbate neuronal injury. As a result, disruptions

in lipid homeostasis produce an environment that is conducive to neuronal dysfunction and degeneration, which accelerates the progression of Alzheimer's disease and cognitive decline. The comprehension of lipid dysregulation offers a window into the molecular mechanisms of neurodegeneration and may identify potential therapeutic targets to slow the progression of the disease (Cao et al., 2024).

5. Alzheimer's Disease and Glycomics

Glycomics is the exhaustive examination of glycans, which are carbohydrate molecules that are attached to proteins and lipids, and their functions in biological systems. Alterations in glycosylation patterns—the addition or modification of glycans—can disrupt protein folding, stability, and function, impair cell signaling, and modulate immune responses in the brain in Alzheimer's disease (AD). These glycan modifications have been demonstrated to affect critical pathological processes in AD, such as amyloid- β aggregation, tau hyperphosphorylation, and neuroinflammation, thereby contributing to the progression of the disease and neuronal dysfunction. The molecular mechanisms that underlie Alzheimer's pathology are illuminated by glycomics, which analyzes alterations in glycosylation in brain tissue, cerebrospinal fluid, and blood. These studies have the potential to uncover novel therapeutic targets to regulate protein aggregation, inflammation, and other pathological pathways in AD, as well as identify glycan-based biomarkers for early diagnosis (Ahmed et al., 2024).

5.1 Glycosylation in Brain Biology

Glycosylation is a critical biological process that involves the covalent attachment of glycans (carbohydrate chains) to proteins and lipids, thereby influencing their structure, stability, and function. Cell signaling, protein folding, and protein stability are all dependent on glycans in the brain, which are essential for effective neuronal communication and synaptic function. The complex network necessary for cognitive processes is supported by the correct glycosylation of proteins, which ensures that they

adopt their proper three-dimensional conformation and facilitates interactions between neurons and glial cells. These processes can be impaired by glycosylation disruptions, which can result in compromised cell signaling, altered receptor function, and defective protein folding. These abnormalities are associated with neurodegenerative diseases, such as Alzheimer's disease, where altered glycosylation can affect amyloid- β aggregation, tau pathology, and neuroinflammation, thereby contributing to neuronal dysfunction and cognitive decline (Ou et al., 2025).

5.2 Glycomic Analytical Methods

Glycomic analytical methodologies are indispensable for investigating the structure, composition, and functionality of glycans in biological systems. Glycan profiling allows researchers to identify and characterize the diverse glycan structures that are attached to proteins and lipids, thereby providing insight into their biological functions. The study of subtle changes in glycosylation associated with diseases like Alzheimer's is now possible due to the highly sensitive and precise detection of glycan composition, branching patterns, and post-translational modifications through advanced techniques such as mass spectrometry (MS). In addition to MS, lectin arrays are frequently implemented to identify particular glycan patterns. Lectins are proteins that bind carbohydrates and selectively identify specific glycan motifs. This allows for the high-throughput analysis of glycosylation variations across multiple samples. Glycomics offers comprehensive information on the structure and function of glycans, thereby facilitating the elucidation of neurodegenerative mechanisms and the identification of glycan-based biomarkers for early diagnosis and therapeutic targeting in Alzheimer's disease (embrek et al., 2015).

5.3 Glycan Biomarkers in Alzheimer's Disease

Glycan biomarkers are crucial indicators of molecular changes that are linked to Alzheimer's disease (AD). Protein folding, stability, and cellular signaling in the brain are influenced by N-glycans,

which are covalently affixed to proteins. These processes can be disrupted by altered N-glycosylation, which can lead to synaptic dysfunction and impaired neuronal communication. Glycosaminoglycans (GAGs), which are involved in cell-cell and cell-matrix interactions, have also been linked to Alzheimer's disease (AD). Modifications to their composition may facilitate the formation of plaques and the aggregation of amyloid- β . Additionally, the structure of the membrane and the transmission of signals are regulated by glycosphingolipids, which are essential components of neuronal membranes. The progression of Alzheimer's disease is linked to glycan alterations, which are associated with neuronal dysfunction and degeneration. Abnormal levels of these lipids are also implicated. Researchers can identify glycan-based biomarkers for early diagnosis and disease monitoring, as well as potential therapeutic targets to mitigate neurodegeneration, by profiling these glycans in brain tissue, cerebrospinal fluid, and blood (Onigbinde et al., 2025; Costa et al., 2023).

5.4 Glycomic Alterations in Alzheimer's Disease Pathology

The development and progression of Alzheimer's disease (AD) are increasingly recognized as being significantly influenced by glycomic alterations. Changes in glycosylation patterns, which involve the attachment or modification of glycans on proteins and lipids, can disrupt cellular signaling, protein folding, and stability in the brain. Critical AD-related processes, such as amyloid- β aggregation, tau protein hyperphosphorylation, and neuroinflammatory responses, may be influenced by these modifications, which collectively exacerbate neuronal dysfunction. Neuronal communication and synaptic function can be impaired by abnormal glycan structures, which can directly contribute to neurodegeneration and synaptic failure. Researchers can acquire a more profound understanding of the molecular mechanisms that underlie AD and identify glycan-based biomarkers for early diagnosis, disease monitoring, and potential therapeutic intervention by profiling glycomic changes in brain tissue, cerebrospinal fluid, and blood (Li et al., 2023; Conroy et al., 2021).

6. Integrated Multi-Omics Methods

Integrated multi-omics approaches integrate data from genomics, proteomics, lipidomics, and glycomics to offer a comprehensive understanding of biological systems and their regulation. These methods facilitate the identification of intricate molecular interactions and disrupted pathways that contribute to neurodegeneration in Alzheimer's disease (AD) research. Researchers can identify connections between genetic variants, protein expression, lipid metabolism, and glycosylation changes, all of which contribute to the progression of a disease, by examining multiple layers of molecular data simultaneously. These integrative analyses enable the identification of therapeutic targets that may not be evident when examining a single omics layer in isolation and facilitate the discovery of novel biomarkers for early diagnosis. Multi-omics approaches facilitate the development of precision medicine strategies that are designed to delay or prevent neurodegeneration by offering a systems-level comprehension of AD pathology (Lundstrøm et al., 2023).

6.1 Multi-Omics Integration Concept

Multi-omics integration is the process of integrating data from various biological layers, including the proteome, lipidome, and glycome, to develop a comprehensive understanding of cellular processes and disease mechanisms. Researchers can disclose the impact of changes at one molecular level on others by identifying interactions and cross-talk between proteins, lipids, and glycans through the analysis of these datasets in combination. The biological networks and pathways that are perturbed in disease can be more accurately mapped through this systems-level perspective. Multi-omics integration is particularly advantageous in the investigation of the intricate molecular pathways that underlie neurodegeneration, such as amyloid- β accumulation, tau pathology, synaptic dysfunction, and metabolic dysregulation, in Alzheimer's disease (AD) research. This method facilitates the identification of reliable biomarkers for early diagnosis and the identification of therapeutic targets by emphasizing critical nodes in disease-associated molecular networks (Huang et al., 2025).

6.2 Tools for Bioinformatics and Systems Biology

The analysis of the large-scale omics datasets produced in Alzheimer's disease (AD) research is contingent upon the use of bioinformatics and systems biology tools. These computational methods enable researchers to incorporate and interpret intricate data from genomics, proteomics, lipidomics, and glycomics, thereby offering a deeper understanding of disease mechanisms. Network analysis is frequently employed to identify interactions among genes, proteins, lipids, and glycans, thereby revealing critical nodes and pathways that contribute to neurodegeneration. Furthermore, pathway mapping serves to clarify the molecular pathways linked to AD, such as amyloid- β processing, tau pathology, synaptic dysfunction, and neuroinflammation. Researchers can enhance our comprehension of Alzheimer's disease and facilitate the development of precision medicine strategies by integrating multi-omics data with these bioinformatics approaches to identify critical biomarkers for early diagnosis and potential therapeutic targets (Schedin-Weiss et al., 2025; Powell et al., 2025).

6.3 Discovery of Multi-Omics Biomarkers

The process of multi-omics biomarker discovery entails the incorporation of data from various omics platforms to identify molecular signatures that are unique to Alzheimer's disease (AD). Researchers can identify distinctive molecular patterns that manifest during the onset and progression of a disease by integrating data from proteomics, lipidomics, and glycomics. The molecular landscape is comprehensively viewed through this integrated approach, which captures interactions and pathway disruptions that may not be apparent when analyzing a single omics layer. These molecular signatures are indispensable for the identification of dependable biomarkers that can be employed for the early diagnosis, disease prognosis, and monitoring of therapeutic responses. Multi-omics biomarker discovery improves comprehension of disease mechanisms and directs the development of targeted therapeutic strategies by disclosing the alteration of proteins, lipids, and glycans in AD (Ren et al., 2025; O'Connor et al., 2023; Tiwari et al., 2023).

7. Clinical Applications

The identification of reliable molecular biomarkers for early diagnosis is facilitated by multi-omics approaches, which have significant clinical applications in Alzheimer's disease (AD). Researchers can detect molecular changes prior to the onset of overt cognitive symptoms by integrating data from proteomics, lipidomics, glycomics, and other omics layers. This enables opportune intervention. Furthermore, the formulation of personalized treatment strategies that

are customized to the individual's distinctive molecular profile is facilitated by multi-omics analyses Fig.4. These methods also enable the monitoring of disease progression and therapeutic responses, providing dynamic insights into how patients respond to treatments and facilitating adjustments in therapy. In general, the incorporation of multi-omics improves precision medicine approaches in AD by enhancing diagnosis, prognosis, and patient-specific management strategies (Gutierrez Reyes et al., 2024).

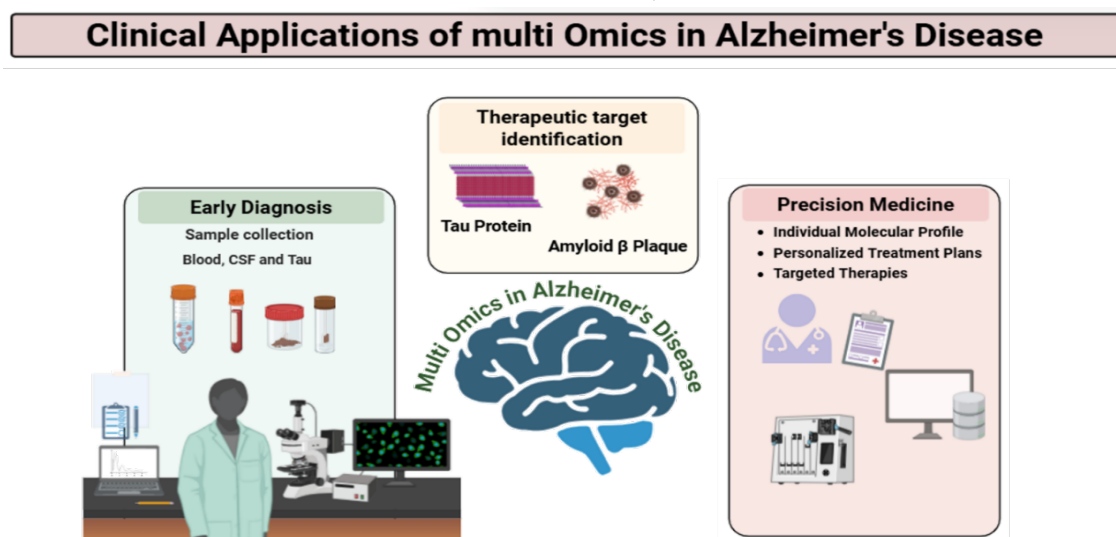


Fig.4. Clinical applications of multi-omics in Alzheimer's disease, highlighting early diagnosis, therapeutic target identification (tau and amyloid- β), and precision medicine approaches for personalized treatment (created with biorender.com).

7.1 Biomarker Development and Early Diagnosis

The identification of reliable molecular biomarkers in biological fluids, such as blood and cerebrospinal fluid (CSF), is essential for the early diagnosis of Alzheimer's disease (AD). The brain's amyloid plaque formation, tau pathology, and neuronal injury are all reflected in key biomarkers, including amyloid- β peptides, total tau (t-tau), and phosphorylated tau (p-tau). By monitoring these biomarkers, clinicians can identify AD at preclinical or mild cognitive impairment stages, which enables earlier intervention and enhanced patient management.

In recent years, the sensitivity and accuracy of biomarker detection have been improved by recent advancements in omics technologies, such as proteomics and multi-omics approaches. This has

enabled the identification of additional candidate markers and molecular signatures that are associated with disease progression. Additionally, blood-based biomarkers are being investigated as less invasive alternatives to CSF sampling, which will make the routine screening and longitudinal surveillance of Alzheimer's disease more manageable in clinical practice (Cardillo et al., 2025).

7.2 Identification of Therapeutic Targets

Omics technologies are essential for the identification of molecular targets for drug discovery in Alzheimer's disease (AD) by analyzing changes in proteins, lipids, glycans, and other biomolecules. These investigations assist in the identification of critical pathways that are involved in the hallmark AD processes, such as neuroinflammation, amyloid- β accumulation, tau

hyperphosphorylation, and synaptic dysfunction. Researchers can identify critical nodes and pathways that may be therapeutic targets for intervention by mapping these disrupted molecular networks. The identification of such targets facilitates the development of innovative treatment strategies that are designed to impede, delay, or prevent the progression of the disease. The integration of findings from multi-omics analyses enables a more precise comprehension of disease mechanisms, thereby facilitating the development of targeted therapies that target specific molecular dysfunctions in Alzheimer's disease (McGrowder et al., 2021).

7.3 The Role of Precision Medicine in Alzheimer's Disease

Alzheimer's disease (AD) precision medicine is dedicated to the creation of customized treatment strategies that are determined by an individual's genetic, molecular, and clinical profile. Researchers can identify patient-specific biomarkers and molecular mechanisms that drive disease progression by integrating data from genomics, proteomics, lipidomics, and glycomics. This method enables the development of therapies that specifically target the biological pathways that are uniquely affected in each patient, thereby enhancing the efficacy of treatment and reducing the likelihood of adverse effects. Additionally, precision medicine enables a more proactive and tailored management of AD by facilitating risk stratification, early intervention, and therapeutic response monitoring. Clinicians and researchers can develop personalized strategies that are designed to delay the progression of disease and enhance patient outcomes by utilizing multi-omics data, which transcends one-size-fits-all approaches (Yu et al., 2025).

8. Obstacles and Restrictions

Omics technologies offer profound insights into the molecular mechanisms of Alzheimer's disease (AD); however, they encounter numerous technical and practical obstacles. The accuracy, reproducibility, and accessibility of omics analyses can be restricted by high costs, complex instrumentation, and variability in sample preparation. Standardizing protocols across

laboratories and studies is a difficult task due to these factors. Significant bioinformatics and computational challenges are also presented by the integration of data from multiple omics platforms. The identification of reliable biomarkers and therapeutic targets can be complicated by the challenges

associated with data integration, interpretation, and reproducibility that can result from large, heterogeneous datasets. In addition, there are translational gaps between research and clinical practice, as numerous biomarkers and targets identified in laboratory studies necessitate extensive validation and regulatory approval prior to their implementation in routine diagnosis or treatment. These limitations underscore the necessity of rigorous clinical validation, robust computational tools, and standardized methodologies to fully realize the potential of omics technologies in AD research (Mohr et al., 2024; . Sandhiya et al., 2026; Martins et al., 2017; Gopalakrishnan et al., 2025; Jiang et al., 2025; Karthikeyan et al., 2025; Sudhakara et al., 2025; Mukherjee et al., 2025).

9. Prospects for the Future

It is anticipated that future research in Alzheimer's disease will be significantly impacted by advancements in artificial intelligence (AI) and machine learning. These technologies are capable of analyzing intricate omics datasets to more effectively identify patterns, biomarkers, and disease-related pathways. The simultaneous analysis of proteomic, lipidomic, and glycomic biomarkers may be facilitated by the development of integrated multi-omics diagnostic platforms, thereby enhancing early detection and disease monitoring. Additionally, the knowledge acquired from these technologies may facilitate the identification of new therapeutic targets and interventions, thereby facilitating the advancement of more effective Alzheimer's disease treatments

10. Conclusion

Alzheimer's disease continues to be a significant global health concern as a result of its restricted therapeutic options, complex molecular mechanisms, and progressive neurodegeneration. The molecular pathways involved in the development and progression of disease have been

considerably enhanced by advancements in omics technologies, including proteomics, lipidomics, and glycomics. These methods facilitate the identification of new biomarkers that are linked to amyloid- β accumulation, tau pathology, lipid dysregulation, and altered glycosylation patterns in the brain. The integration of these datasets through multi-omics strategies offers a comprehensive understanding of the interactions between proteins, lipids, and glycans that contribute to neurodegeneration. The identification of disease-specific molecular signatures that may enhance the early diagnosis and monitoring of Alzheimer's disease is facilitated by these integrative analyses. Furthermore, multi-omics research has the potential to identify novel therapeutic targets that are implicated in inflammation, synaptic dysfunction, metabolic imbalance, and neuronal survival. Despite the challenges that persist, such as the necessity for clinical validation, data integration issues, and technical limitations, it is anticipated that the advancement of omics technologies and bioinformatics tools will expedite the research on Alzheimer's disease. In the future, the implementation of integrated multi-omics approaches may contribute to the development of more precise diagnostic methods and personalized treatment strategies, thereby enhancing patient outcomes and disease management.

Authors' contributions

AT: Writing – Original Draft, and Writing – Review & Editing. & Formal Analysis, **PK:** Data Curation; **AT and NS** Investigation, Conceptualization and Data Curation.

Funding

Not applicable.

Declarations

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics approval

Not applicable.

Competing interest

The authors declare no competing interests.

Acknowledgements

The authors express their thanks and gratitude to Saveetha Institute of Medical and Technical Sciences, Tamil Nadu, India for the support to publish this article. The authors acknowledge the use of ChatGPT (OpenAI, San Francisco, USA) for assistance with language editing and content organization. The authors have reviewed and take full responsibility for the content.

References

- [1] 1. Tenchov, R., Sasso, J. M., & Zhou, Q. A. (2024). Alzheimer's disease: exploring the landscape of cognitive decline. *ACS Chemical Neuroscience*, 15(21), 3800-3827.
- [2] 2. Safiri, S., Ghaffari Jolfayi, A., Fazlollahi, A., Morsali, S., Sarkesh, A., Daei Sorkhabi, A., ... & Kolahi, A. A. (2024). Alzheimer's disease: a comprehensive review of epidemiology, risk factors, symptoms diagnosis, management, caregiving, advanced treatments and associated challenges. *Frontiers in Medicine*, 11, 1474043.
- [3] 3. Gholami, A. (2023). Alzheimer's disease: The role of proteins in formation, mechanisms, and new therapeutic approaches. *Neuroscience Letters*, 817, 137532.
- [4] 4. Kamila, P., Kar, K., Chowdhury, S., Chakraborty, P., Dutta, R., Singh, A., & Prajapati, B. G. (2025). Effect of neuroinflammation on the progression of Alzheimer's disease and its significant ramifications for novel anti-inflammatory treatments. *IBRO Neuroscience Reports*, 18, 771-782.
- [5] 5. Wang, R., Peng, S., Zhu, J., Xu, Y., Wang, M., Zhang, L., ... & Liu, R. (2025). Innovations in Alzheimer's disease diagnostic technologies: clinical prospects of novel biomarkers, multimodal integration, and non-invasive detection. *Frontiers in Neurology*, 16, 1651708.
- [6] 6. Liu, X., Li, F., Czosnyka, M., Czosnyka, Z., Yu, H., Tong, X., ... & Ming, D. (2025). Multi-omics and high-spatial-resolution omics: deciphering complexity in neurological disorders. *GigaScience*, g1af137.
- [7] 7. Xiong, F., Gong, K., Xu, H., Tu, Y., Lu, J., Zhou, Y., ... & Zheng, H. (2023). Optimized integration of metabolomics and lipidomics reveals brain region-specific changes of oxidative stress and neuroinflammation in type 1 diabetic mice with cognitive decline. *Journal of Advanced Research*, 43, 233-245.

- [8] 8. Sehar, U., Rawat, P., Reddy, A. P., Kopel, J., & Reddy, P. H. (2022). Amyloid beta in aging and Alzheimer's disease. *International journal of molecular sciences*, 23(21), 12924.
- [9] 9. Santos-Reboucas, C. B., Cotrin, J. C., & dos Santos Junior, G. C. (2023). Exploring the interplay between metabolomics and genetics in Parkinson's disease: Insights from ongoing research and future avenues. *Mechanisms of Ageing and Development*, 216, 111875.
- [10] 10. Hampel, H., Hardy, J., Blennow, K., Chen, C., Perry, G., Kim, S. H., ... & Vergallo, A. (2021). The amyloid- β pathway in Alzheimer's disease. *Molecular psychiatry*, 26(10), 5481-5503.
- [11] 11. Dagla, I., Gkikas, F., Gikas, E., & Tsiaropoulos, A. (2026). Targeting Amyloid Beta Aggregation and Neuroinflammation in Alzheimer's Disease: Advances and Future Directions. *Cells*, 15(3), 295.
- [12] 12. Brezic, N., Gligorevic, S., Sic, A., & Knezevic, N. N. (2025). Protein misfolding and aggregation as a mechanistic link between chronic pain and neurodegenerative diseases. *Current issues in molecular biology*, 47(4), 259.
- [13] 13. Kamatham, P. T., Shukla, R., Khatri, D. K., & Vora, L. K. (2024). Pathogenesis, diagnostics, and therapeutics for Alzheimer's disease: breaking the memory barrier. *Ageing research reviews*, 101, 102481.
- [14] 14. Chen, S. Y., Gao, Y., Sun, J. Y., Meng, X. L., Yang, D., Fan, L. H., ... & Wang, P. (2020). Traditional Chinese medicine: role in reducing β -amyloid, apoptosis, autophagy, neuroinflammation, oxidative stress, and mitochondrial dysfunction of Alzheimer's disease. *Frontiers in Pharmacology*, 11, 497.
- [15] 15. Zheng, Q., & Wang, X. (2025). Alzheimer's disease: insights into pathology, molecular mechanisms, and therapy. *Protein & cell*, 16(2), 83-120.
- [16] 16. Zhang, S., Crossley, C. A., & Yuan, Q. (2024). Neuronal vulnerability of the entorhinal cortex to tau pathology in Alzheimer's disease. *British journal of biomedical science*, 81, 13169.
- [17] 17. Long, H. Z., Zhou, Z. W., Cheng, Y., Luo, H. Y., Li, F. J., Xu, S. G., & Gao, L. C. (2022). The role of microglia in Alzheimer's disease from the perspective of immune inflammation and iron metabolism. *Frontiers in Aging Neuroscience*, 14, 888989.
- [18] 18. Gao, C., Jiang, J., Tan, Y., & Chen, S. (2023). Microglia in neurodegenerative diseases: mechanism and potential therapeutic targets. *Signal transduction and targeted therapy*, 8(1), 359.
- [19] 19. Lv, H., Liu, Y., Yang, X., Xu, X., Zhou, J., & Yu, W. (2025). Research progress on the role of oxidative stress in the pathogenesis of vascular dementia and its treatment. *Journal of Stroke and Cerebrovascular Diseases*, 108475.
- [20] 20. Lado, L., & Misir, A. (2025). The interplay of homeostasis, inflammation, and oxidative stress in neurodegenerative disorders: the role of biological markers, antioxidants, lithium, and TMS—a proposed framework for preventing neurodegenerative disorders through biomarkers and multimodal therapies. *Frontiers in Aging Neuroscience*, 17, 1607669.
- [21] 21. He, S., Xu, Z., & Han, X. (2025). Lipidome disruption in Alzheimer's disease brain: detection, pathological mechanisms, and therapeutic implications. *Molecular neurodegeneration*, 20(1), 11.
- [22] 22. Zhang, T., Yin, Y., Xia, X., Que, X., Liu, X., Zhao, G., ... & Qin, Q. (2026). Regulation of synaptic function and lipid metabolism. *Neural Regeneration Research*, 21(3), 1037-1057.
- [23] 23. Yarbro, J. M., Han, X., Dasgupta, A., Yang, K., Liu, D., Shrestha, H. K., ... & Peng, J. (2025). Human and mouse proteomics reveals the shared pathways in Alzheimer's disease and delayed protein turnover in the amyloidome. *Nature communications*, 16(1), 1533.
- [24] 24. Ryu, T., Kim, K., Asimwe, N., & Na, C. H. (2025). Proteomic Insight Into Alzheimer's Disease Pathogenesis Pathways. *Proteomics*, 25(21-22), 214-229.
- [25] 25. Percy, K. C. M., Liu, Z., & Qi, X. (2025). Mitochondrial dysfunction in Alzheimer's disease: Guiding the path to targeted therapies. *Neurotherapeutics*, 22(3), e00525.
- [26] 26. Zhang, W., Xiao, D., Mao, Q., & Xia, H. (2023). Role of neuroinflammation in neurodegeneration development. *Signal transduction and targeted therapy*, 8(1), 267.
- [27] 27. Sathe, G., Albert, M., Darrow, J., Saito, A., Troncoso, J., Pandey, A., & Moghekar, A. (2021). Quantitative proteomic analysis of the frontal cortex in Alzheimer's disease. *Journal of neurochemistry*, 156(6), 988-1002.
- [28] 28. Bulska, E., Bicka, M., Gawor, A., Karpiński, A., & Konopka, A. (2022). Mass spectrometry-based proteomic analysis in neurodegenerative disorders' research. *Handbook of Bioanalytics*, 27-48.

- [29] 29. Bai, B., Vanderwall, D., Li, Y., Wang, X., Poudel, S., Wang, H., ... & Peng, J. (2021). Proteomic landscape of Alzheimer's Disease: novel insights into pathogenesis and biomarker discovery. *Molecular neurodegeneration*, 16(1), 55.
- [30] 30. Do, A. N., Song, S., Ali, M., Timsina, J., Wang, L., Western, D., ... & Sung, Y. J. (2026). CSF proteomic profiling with amyloid and tau pathology identifies distinctive sex-specific alteration of multiple proteins involved in Alzheimer's disease. *Alzheimer's & Dementia*, 22(1), e71063.
- [31] 31. Zia Ul Haq, M., Zhao, X., Obeng Apori, S., Singh, B., & Tian, F. (2025). Molecular Biomarkers for Early Detection of Alzheimer's Disease and the Complementary Role of Engineered Nanomaterials: A Systematic Review. *International Journal of Molecular Sciences*, 26(19), 9282.
- [32] 32. Moya-Alvarado, G., Gershoni-Emek, N., Perlson, E., & Bronfman, F. C. (2016). Neurodegeneration and Alzheimer's disease (AD). What can proteomics tell us about the Alzheimer's brain?. *Molecular & Cellular Proteomics*, 15(2), 409-425.
- [33] 33. Lan, G., Li, B., Wang, M., Barve, A., Colin, M., Buée, L., ... & Guo, T. (2025). Plasma growth-associated protein 43 correlates with synaptic loss in Alzheimer's disease. *Cell Reports Medicine*, 6(12).
- [34] 34. Camporesi, E., Nilsson, J., Brinkmalm, A., Becker, B., Ashton, N. J., Blennow, K., & Zetterberg, H. (2020). Fluid biomarkers for synaptic dysfunction and loss. *Biomarker insights*, 15, 1177271920950319.
- [35] 35. Tijms, B. M., Vromen, E. M., Mjaavatten, O., Holstege, H., Reus, L. M., van der Lee, S., ... & Visser, P. J. Cerebrospinal fluid proteomics in patients with Alzheimer's disease reveals five molecular subtypes with distinct genetic risk profiles. *Nat Aging*. 2024.
- [36] 36. Ali, M., Timsina, J., Western, D., Liu, M., Beric, A., Budde, J., ... & Cruchaga, C. (2025). Multi-cohort cerebrospinal fluid proteomics identifies robust molecular signatures across the Alzheimer disease continuum. *Neuron*, 113(9), 1363-1379.
- [37] 37. Imam, F., Saloner, R., Vogel, J. W., Krish, V., Abdel-Azim, G., Ali, M., ... & Global Neurodegeneration Proteomics Consortium (GNPC). (2025). The Global Neurodegeneration Proteomics Consortium: biomarker and drug target discovery for common neurodegenerative diseases and aging. *Nature medicine*, 31(8), 2556-2566.
- [38] 38. Magnelli, V., Pagano, C. A., & Sabbatini, M. (2025). Proteome-Based Biomarkers for Alzheimer's Disease: Old Acquisitions and Innovative Proposals. *International Journal of Molecular Sciences*, 26(23), 11654.
- [39] 39. Plascencia-Villa, G., & Perry, G. (2023). Roles of oxidative stress in synaptic dysfunction and neuronal cell death in Alzheimer's disease. *Antioxidants*, 12(8), 1628.
- [40] 40. Dash, U. C., Bhol, N. K., Swain, S. K., Samal, R. R., Nayak, P. K., Raina, V., ... & Jena, A. B. (2025). Oxidative stress and inflammation in the pathogenesis of neurological disorders: Mechanisms and implications. *Acta Pharmaceutica Sinica B*, 15(1), 15-34.
- [41] 41. Yoon, J. H., Seo, Y., Jo, Y. S., Lee, S., Cho, E., Cazenave-Gassiot, A., ... & Suh, P. G. (2022). Brain lipidomics: From functional landscape to clinical significance. *Science advances*, 8(37), eadc9317.
- [42] 42. Xiong, Wei, Bing Fang, Xiaoyu Wang, Ming Zhang, Min Du, Jiazeng Sun, Juan Chen et al. "Dietary lipid intervention in the prevention of brain aging." *Engineering* 37 (2024): 128-137.
- [43] 43. Campos-Peña, V., Pichardo-Rojas, P., Sánchez-Barbosa, T., Ortiz-Islas, E., Rodríguez-Pérez, C. E., Montes, P., ... & Toral-Rios, D. (2022). Amyloid β , lipid metabolism, basal cholinergic system, and therapeutics in Alzheimer's disease. *International Journal of Molecular Sciences*, 23(20), 12092.
- [44] 44. Sarkar, S., Roy, D., Chatterjee, B., & Ghosh, R. (2024). Clinical advances in analytical profiling of signature lipids: implications for severe non-communicable and neurodegenerative diseases. *Metabolomics*, 20(2), 37.
- [45] 45. Breil, C., Abert Vian, M., Zemb, T., Kunz, W., & Chemat, F. (2017). "Bligh and Dyer" and Folch methods for solid-liquid-liquid extraction of lipids from microorganisms. Comprehension of solvation mechanisms and towards substitution with alternative solvents. *International journal of molecular sciences*, 18(4), 708.
- [46] 46. Farooqui, A. A., & Farooqui, T. (2024). Phospholipids, sphingolipids, and cholesterol-derived lipid mediators and their role in neurological disorders. *International journal of molecular sciences*, 25(19), 10672.
- [47] 47. Cao, Y., Zhao, L. W., Chen, Z. X., & Li, S. H. (2024). New insights in lipid metabolism: Potential therapeutic targets for the treatment of Alzheimer's disease. *Frontiers in Neuroscience*, 18, 1430465.
- [48] 48. Ahmed, H., Wang, Y., Griffiths, W. J., Levey, A. I., Pikuleva, I., Liang, S. H., & Haider, A. (2024). Brain cholesterol and Alzheimer's disease: challenges and opportunities in probe and drug development. *Brain*, 147(5), 1622-1635.

- [49] 49. Ou, C., Yu, H., Chen, B., & Long, H. (2025). Molecular mechanisms of lipid metabolism abnormalities driving sepsis and atrial fibrillation: A Systematic study based on bioinformatics and machine learning. *PloS one*, 20(12), e0338511.
- [50] 50. Jembrek, M. J., Hof, P. R., & Šimic, G. (2015). Ceramides in Alzheimer's disease: key mediators of neuronal apoptosis induced by oxidative stress and A accumulation. *Oxidative medicine and cellular longevity*.
- [51] 51. Costa, J., Hayes, C., & Lisacek, F. (2023). Protein glycosylation and glycoinformatics for novel biomarker discovery in neurodegenerative diseases. *Ageing research reviews*, 89, 101991.
- [52] 52. Onigbinde, S., Adeniyi, M., Daramola, O., Chukwubueze, F., Bhuiyan, M. M. A. A., Nwaiwu, J., ... & Mechref, Y. (2025). Glycomics in Human Diseases and Its Emerging Role in Biomarker Discovery. *Biomedicines*, 13(8), 2034.
- [53] 53. Li, J., Qiu, Y., Zhang, C., Wang, H., Bi, R., Wei, Y., ... & Hu, B. (2023). The role of protein glycosylation in the occurrence and outcome of acute ischemic stroke. *Pharmacological Research*, 191, 106726.
- [54] 54. Conroy, L. R., Hawkinson, T. R., Young, L. E., Gentry, M. S., & Sun, R. C. (2021). Emerging roles of N-linked glycosylation in brain physiology and disorders. *Trends in Endocrinology & Metabolism*, 32(12), 980-993.
- [55] 55. Lundstrøm, J., Urban, J., & Bojar, D. (2023). Decoding glycomics with a suite of methods for differential expression analysis. *Cell Reports Methods*, 3(12).
- [56] 56. Huang, S., Tang, J., Wu, X., Xu, H., Li, S., Li, H., ... & Yu, S. (2025). The omics techniques used in perineuronal nets research. *Experimental Neurology*, 392, 115369.
- [57] 57. Schedin-Weiss, S., Gaunitz, S., Sui, P., Chen, Q., Haslam, S. M., Blennow, K., ... & Tjernberg, L. O. (2020). Glycan biomarkers for Alzheimer disease correlate with T-tau and P-tau in cerebrospinal fluid in subjective cognitive impairment. *The FEBS journal*, 287(15), 3221-3234.
- [58] 58. Powell, W. C., Jing, R., Herlory, M., Holland, P., Poliyenko, D., Ebmeier, C. C., ... & Walczak, M. A. (2025). Chemical synthesis reveals pathogenic role of N-glycosylation in microtubule-associated protein tau. *Journal of the American Chemical Society*, 147(8), 6995-7007.
- [59] 59. Tiwari, V., & Shukla, S. (2023). Lipidomics and proteomics: An integrative approach for early diagnosis of dementia and Alzheimer's disease. *Frontiers in Genetics*, 14, 1057068.
- [60] 60. O'Connor, L. M., O'Connor, B. A., Lim, S. B., Zeng, J., & Lo, C. H. (2023). Integrative multi-omics and systems bioinformatics in translational neuroscience: A data mining perspective. *Journal of Pharmaceutical Analysis*, 13(8), 836-850.
- [61] 61. Ren, F., Wei, J., Chen, Q., Hu, M., Yu, L., Mi, J., ... & Wu, A. (2025). Artificial intelligence-driven multi-omics approaches in Alzheimer's disease: Progress, challenges, and future directions. *Acta Pharmaceutica Sinica B*.
- [62] 62. Gutierrez Reyes, C. D., Alejo-Jacuinde, G., Perez Sanchez, B., Chavez Reyes, J., Onigbinde, S., Mogut, D., ... & Mechref, Y. (2024). Multi omics applications in biological systems. *Current Issues in Molecular Biology*, 46(6), 5777-5793.
- [63] 63. Cardillo, M., Katam, K., & Suravajhala, P. (2025). Advancements in multi-omics research to address challenges in Alzheimer's disease: a systems biology approach utilizing molecular biomarkers and innovative strategies. *Frontiers in Aging Neuroscience*, 17, 1591796.
- [64] 64. McGrowder, D. A., Miller, F., Vaz, K., Nwokocha, C., Wilson-Clarke, C., Anderson-Cross, M., ... & Alexander-Lindo, R. (2021). Cerebrospinal fluid biomarkers of Alzheimer's disease: current evidence and future perspectives. *Brain sciences*, 11(2), 215.
- [65] 65. Yu, H., Chen, X., Yang, Y., Gu, M., Ren, K., & Wei, Z. (2025). Decoding glycosylation in neurodegenerative diseases: mechanistic insights and therapeutic opportunities. *The FASEB Journal*, 39(20), e71160.
- [66] 66. Martins, I. J. (2016). The role of clinical proteomics, lipidomics, and genomics in the diagnosis of Alzheimer's disease. *Proteomes*, 4(2), 14.
- [67] 67. Mohr, A. E., Ortega-Santos, C. P., Whisner, C. M., Klein-Seetharaman, J., & Jasbi, P. (2024). Navigating challenges and opportunities in multi-omics integration for personalized healthcare. *Biomedicines*, 12(7), 1496.
- [68] 68. Jiang, S., Tian, Z., Yang, Y., Li, X., Zhou, F., Cheng, J., ... & Tong, Z. (2025). New insights into translational research in Alzheimer's disease guided by artificial intelligence, computational and systems biology. *Acta Pharmaceutica Sinica B*.
- [69] 69. Gopalakrishnan, M., Kannan, D., Elumalai, K., Karunakar, K., Jayaraj, S., Devaraji, M., & Jayaprakash, N. (2025). Advanced 3D biomaterials and bioprinting strategies for in vitro modeling of

- neurodegenerative diseases. *Biomedical Technology*, 11, 100089.
- [70] 70. Jia, F., & Fu, L. (2025). Roles of ubiquitin ligases and deubiquitylases in Alzheimer's disease. *Molecular Neurobiology*, 62(6), 7747-7761.feb 2025
- [71] 71. Mohapatra, T. K., Nayak, R. R., Ganeshpurkar, A., Tiwari, P., & Kumar, D. (2025). Navigating the treatment landscape of Alzheimer's disease: Current strategies and future directions. *ibrain*, 11(2), 162-184.
- [72] 72. Kaur, P., Khera, A., Alajangi, H. K., Sharma, A., Jaiswal, P. K., Singh, G., & Barnwal, R. P. (2023). Role of tau in various tauopathies, treatment approaches, and emerging role of nanotechnology in neurodegenerative disorders. *Molecular Neurobiology*, 60(3), 1690-1720.
- [73] 73. Li, K., Wei, Q., Liu, F. F., Hu, F., Xie, A. J., Zhu, L. Q., & Liu, D. (2018). Synaptic dysfunction in Alzheimer's disease: A β , tau, and epigenetic alterations. *Molecular neurobiology*, 55(4), 3021-3032.
- [74] 74. Kwon, H. S., & Koh, S. H. (2020). Neuroinflammation in neurodegenerative disorders: the roles of microglia and astrocytes. *Translational neurodegeneration*, 9(1), 42.
- [75] 75. Houldsworth, A. (2024). Role of oxidative stress in neurodegenerative disorders: a review of reactive oxygen species and prevention by antioxidants. *Brain Communications*, 6(1), fcad356.
- [76] 76. Richter, N., David, L. S., Grothe, M. J., Teipel, S., Dietlein, M., Tittgemeyer, M., ... & Kukolja, J. (2022). Age and anterior basal forebrain volume predict the cholinergic deficit in patients with mild cognitive impairment due to Alzheimer's disease. *Journal of Alzheimer's disease*, 86(1), 425-440.
- [77] 77. Korecka, M., & Shaw, L. M. (2021). Mass spectrometry-based methods for robust measurement of Alzheimer's disease biomarkers in biological fluids. *Journal of neurochemistry*, 159(2), 211-233.
- [78] 78. Prabhakar, P. K. (2020). Liquid Chromatography-Mass Spectrometry (LCMS): An Advanced Tool for the Microbial Proteomics Analysis. In *Microbial Proteomics: Development in Technologies and Applications* (pp. 36-60). Bentham Science Publishers.
- [79] 79. Marshall, K., Twum, Y., Li, Y., & Gao, W. (2025). Spotting targets with 2D-DIGE proteomics. *Advances in Clinical Chemistry*, 125, 1-22.
- [80] 80. Kulichikhin, K. Y., Fedotov, S. A., Rubel, M. S., Zalutskaya, N. M., Zobnina, A. E., Malikova, O. A., ... & Rubel, A. A. (2021). Development of molecular tools for diagnosis of Alzheimer's disease that are based on detection of amyloidogenic proteins. *Prion*, 15(1), 56-69.
- [81] 81. Kareem, S. A., Abd, M. Y., Hammood, M. N., & Naser, M. A. (2025). Understanding the Biochemical Basis of Alzheimer's Disease: A Clinical Chemistry Approach. *Central Asian Journal of Medical and Natural Science*, 6(3), 938-953.
- [82] 82. Singh, S. K., Kumar, A., Singh, R. B., Ghosh, P., & Bajad, N. G. (2022). Recent applications of bioinformatics in target identification and drug discovery for Alzheimer's disease. *Current topics in medicinal chemistry*, 22(26), 2153-2175.
- [83] 83. Olešová, D., Dobešová, D., Majerová, P., Brumarová, R., Kvasnička, A., Kouřil, Š., ... & Kováč, A. (2024). Changes in lipid metabolism track with the progression of neurofibrillary pathology in tauopathies. *Journal of Neuroinflammation*, 21(1), 78.
- [84] 84. Zhang, W., Li, R., Lu, D., Wang, X., Wang, Q., Feng, X., ... & Zhang, X. (2025). Phospholipids and peroxisomes in ferroptosis: the therapeutic target of acupuncture regulating vascular cognitive impairment and dementia. *Frontiers in Aging Neuroscience*, 17, 1512980.
- [85] 85. Ge, Z., Hu, Y., Kan, W., Li, L., Xu, J., Zhang, Y., ... & Du, J. (2025). Lipid metabolic dysregulation-induced neuroinflammation in the pathophysiology of major depressive disorder. *Frontiers in Immunology*, 16, 1625087.
- [86] 86. Zhang, T., Yin, Y., Xia, X., Que, X., Liu, X., Zhao, G., ... & Qin, Q. (2026). Regulation of synaptic function and lipid metabolism. *Neural Regeneration Research*, 21(3), 1037-1057.
- [87] 87. Giacobbe, J., Benoiton, B., Zunszain, P., Pariante, C. M., & Borsini, A. (2020). The anti-inflammatory role of omega-3 polyunsaturated fatty acids metabolites in pre-clinical models of psychiatric, neurodegenerative, and neurological disorders. *Frontiers in Psychiatry*, 11, 450833.
- [88] 88. Dham, D., Roy, B., Gowda, A., Pan, G., Sridhar, A., Zeng, X., ... & Palaniyandi, S. S. (2021). 4-Hydroxy-2-nonenal, a lipid peroxidation product, as a biomarker in diabetes and its complications: Challenges and opportunities. *Free radical research*, 55(5), 510-524.
- [89] 89. Kanda, A., Rani, A., & Mazumder, A. (2025). Exploring precision medicine by utilizing individual genetic information for the management of Alzheimer's disease. *Pharmacogenomics*, 26(10-12), 455-474.
- [90] 90. Tao, Q. Q., Cai, X., Xue, Y. Y., Ge, W., Yue, L., Li, X. Y., ... & Wu, Z. Y. (2024). Alzheimer's

- disease early diagnostic and staging biomarkers revealed by large-scale cerebrospinal fluid and serum proteomic profiling. *The Innovation*, 5(1).
- [91] 91. Guerreiro, J. S. D. S. (2025). Profiling Cerebrospinal Fluid Protein Glycosylation in Alzheimer's Disease: Toward Novel Biomarker Discovery.
- [92] 92. Sandhiya T, Jeyabharathi S, Thirumurugan A. Exploration of Antimicrobial Drug Targets from Human Breast Milk *Lactobacillus* for the Control of Vaginal Infections. *Int J Drug Deliv Technol*. 2026;16(7s): 924- 933; DOI: 10.25258/ijddt.16.7s.98
- [93] 93. Ali, H. (2023). Artificial intelligence in multi-omics data integration: Advancing precision medicine, biomarker discovery and genomic-driven disease interventions. *Int J Sci Res Arch*, 8(1), 1012-30.
- [94] 94. Fatima, S., Tiwari, S., Siddiqi, B., Quadri, S. N., & Abdin, M. Z. (2025). Biomarkers: From early detection to treatment personalization. *Progress in Brain Research*, 297, 131-153.
- [95] 95. Karthikeyan, M., Sabarathinam, S., Mohan, H., & Usha, B. (2025). An integrated network pharmacological approach unveils the therapeutic mechanism of bonducellin, a homoisoflavonoid from *Caesalpinia bonducella*, against polycystic ovary syndrome. *Tradit Med Res*, 10(11), 65.
- [96] 96. Sudhakaran, G., Gopi, S., Priya, S., Pachaiappan, R., Soundharrajan, I., Almutairi, B. O., & Arockiaraj, J. (2025). Apigenin Regulates Bisphenol-A Induced Polycystic Ovarian Syndrome (PCOS) Symptoms In-Vivo Zebrafish. *Reproductive Sciences*, 32(6), 1912-1925.
- [97] 97. Mukherjee, A. G., Wanjari, U. R., Kannampuzha, S., Murali, R., Namachivayam, A., Ganesan, R., ... & Gopalakrishnan, A. V. (2023). The implication of mechanistic approaches and the role of the microbiome in polycystic ovary syndrome (PCOS): a review. *Metabolites*, 13(1), 129
- [98] 98. Ayyadurai, T., Mohan, P. K., Annamalai, A., Kamaraj, C., & Waheeb, M. Q. (2026). Biogenic silver nanoparticles synthesis from *Guilandina bonduc* L. seed kernel extract with antibacterial, antioxidant and anticancer potential against ovarian Cancer cells. *Results in Chemistry*, 103246.
- [99] 99. Jancyhelan, J., Thirumurugan, A., Alagumanian, S., & Vignesh, K. (2026). Eco-friendly biosynthesis of silver nanoparticles using marine algal extract and their biomedical applications. *Results in Chemistry*, 103606.
- [100] 100. Sakthivel V, Ilanthiraya S, Jeevanantham G, Aravindhan T, Priya K, Thirumurugan A, Larvicidal Activity Of Marine Macroalgae: A Comprehensive Review. *Int J Drug Deliv Technol*. 2026;16(4s): 908-917; DOI: 10.25258/ijddt.16.4s.106
- [101] 101. Ayyadurai, T., Ravi, S., & Annamalai, A. (2026). Steroidogenic Enzyme Dysregulation in Polycystic Ovary Syndrome: Mechanistic Insights and Emerging Therapeutic Strategies. *The Journal of Steroid Biochemistry and Molecular Biology*, 107088.
- [102] 102. Anbazhagan, V., Natrajan, A., Arul, J. et al. Strategic development of a buffalo farming framework and optimization of the foraging behaviour using mathematical models. *Trop Anim Health Prod* 58, 424 (2026). <https://doi.org/10.1007/s11250-026-05211-6>