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Review Article

Palm Oil Phenolic Compounds and Their Antioxidant Potential in Human Disease Models: A Systematic Literature Review

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Abstract

The increasing scientific interest in naturally derived bioactive compounds has intensified attention toward palm oil-derived phenolic constituents due to their potential roles in oxidative stress modulation and cellular antioxidant regulation. Palm oil phenolics, including caffeoylshikimic acid and protocatechuic acid derivatives, have been increasingly investigated in biomedical studies related to oxidative injury, inflammatory signalling, and disease-associated cellular dysfunction. The research sought to systematically evaluate the current body of scientific literature concerning the antioxidant activities of phenolic compounds derived from palm oil across a broad spectrum of human disease models. This research employed a Systematic Literature Review (SLR) approach based on PRISMA guidelines using secondary data retrieved exclusively from peer-reviewed articles indexed in Scopus and PubMed. Data collection involved keyword refinement, relevance screening, publication year limitation (2019–2026), full-text eligibility assessment, and duplicate removal, resulting in 32 eligible studies included in the final synthesis. Data analysis was conducted using thematic synthesis and comparative interpretation to identify recurring antioxidant-related mechanisms. The findings revealed five dominant mechanistic themes, including Reactive Oxygen Species (ROS) scavenging, enhancement of endogenous antioxidant enzymes, regulation of redox homeostasis, modulation of inflammatory signalling pathways involving NF-kB and MAPK, and preservation of mitochondrial integrity. Several studies also reported reductions in lipid peroxidation, inflammatory cytokines, and oxidative cellular injury across metabolic, cardiovascular, neurodegenerative, and cancer-related models. Overall, palm oil-derived phenolic compounds demonstrate multifaceted antioxidant-associated biological activities within contemporary biomedical research. Future studies should prioritise standardised clinical investigations and bioavailability evaluation to strengthen translational relevance.

Keywords: Palm oil phenolics, Antioxidant activity, Oxidative stress, Disease models, Systematic literature review

Introduction

Oxidative stress has become one of the most extensively discussed biological phenomena in contemporary biomedical research due to its close association with the onset and progression of diverse chronic degenerative diseases. Overproduction of ROS alongside inadequate endogenous antioxidant activity may contribute to cellular disturbances, structural biomolecular damage, inflammatory cascades, mitochondrial malfunction, and degenerative changes in multiple physiological systems [1]. The overproduction of oxidative species has been implicated in the underlying mechanisms of cardiovascular disorders, metabolic syndrome, neurodegenerative diseases, diabetes mellitus, chronic inflammatory conditions, and several forms of cancer, thereby positioning antioxidant-related interventions as an important area of scientific investigation [2]. Scientific interest has recently expanded toward naturally occurring compounds from botanical sources due to their possible effectiveness in modulating oxidative signalling pathways and preserving redox homeostasis under pathological circumstances [3]. Among various natural bioactive sources, palm oil has attracted growing scientific interest due to the presence of multiple antioxidant-associated constituents, including tocopherols, tocotrienols, carotenoids, sterols, and phenolic compounds [4]. Although palm oil is widely recognised for its economic and industrial relevance within the global agricultural sector, current biomedical research has increasingly explored its compositional diversity and potential biological significance beyond its conventional nutritional applications [5]. Particular attention has recently been directed toward palm oil-derived phenolic compounds because these metabolites possess chemical structures capable of donating hydrogen atoms, stabilising free radicals, and influencing oxidative signalling pathways involved in cellular defence mechanisms. As a result, palm phenolics have emerged as a promising area of investigation within antioxidant and disease-related biomedical studies.

The class of phenolic secondary metabolites is distinguished by hydroxylated aromatic architectures that exhibit the ability to interact with reactive oxygen species and catalytic transition metals in oxidative pathways. Within palm oil matrices, several phenolic constituents have been identified, including caffeoylshikimic acid, protocatechuic acid, hydroxybenzoic acid derivatives, p-hydroxybenzoic acid, and other phenolic acid-related metabolites that may contribute to antioxidant activity through multiple biochemical pathways [6]. Studies conducted under experimental conditions have demonstrated that these compounds possess the potential to engage in radical scavenging activities, inhibit lipid peroxidation, regulate antioxidant enzyme networks, and influence oxidative stress-related inflammatory pathways. Furthermore, several investigations have suggested that palm phenolic compounds may contribute to mitochondrial protection, preservation of membrane integrity, and attenuation of oxidative biomolecular damage under stress-related pathological conditions [7]. The growing scientific interest surrounding palm phenolics is also associated with increasing recognition that oxidative stress does not operate as an isolated biological mechanism but rather interacts dynamically with inflammatory pathways, metabolic disturbances, endothelial dysfunction, and apoptosis-related signalling [8]. Consequently, antioxidant compounds capable of influencing interconnected oxidative and inflammatory processes have become highly relevant in disease-oriented biomedical research. Previous studies involving palm oil-derived phenolics have explored their biological activities across a variety of experimental contexts, including diabetic models, cardiovascular dysfunction, neurodegenerative injury, hepatic oxidative stress, inflammatory disorders, and cancer-associated oxidative environments [9]. However, despite the increasing volume of available evidence, current findings remain dispersed across diverse experimental platforms, biological models, extraction methods, and analytical approaches, resulting in substantial heterogeneity within the literature.

The complexity of the available evidence creates several important scientific challenges. First, antioxidant outcomes reported across studies frequently differ depending on the type of phenolic extract, experimental dosage, disease model, and evaluated biomarkers, making direct comparison between studies difficult [10]. Second, some investigations focus primarily on direct radical scavenging mechanisms, whereas others emphasise intracellular signalling modulation, inflammatory regulation, or mitochondrial protection, thereby generating fragmented mechanistic interpretations. Third, although numerous experimental studies report beneficial antioxidant-associated effects, the biological pathways through which palm phenolic compounds influence oxidative stress-related diseases remain incompletely synthesised within a unified analytical framework [11]. As a result, there remains a need for a structured and evidence-based synthesis capable of integrating mechanistic findings from different disease models while identifying dominant antioxidant-related pathways consistently reported across the literature. Another important consideration involves the increasing scientific demand for evidence-based evaluation of bioactive compounds using transparent and reproducible review methodologies. In biomedical and nutritional sciences, systematic literature reviews have become increasingly important because they allow researchers to critically synthesise heterogeneous evidence while minimising subjective interpretation bias. Compared with conventional narrative reviews, the systematic literature review approach provides a more rigorous framework for study selection, data extraction, thematic synthesis, and methodological transparency [12]. Such an approach is particularly relevant for research areas characterized by rapidly expanding evidence and diverse experimental methodologies, including antioxidant studies involving natural phenolic compounds. Therefore, adopting a systematic review framework is essential to provide a clearer understanding of the current scientific landscape concerning palm oil phenolics and their antioxidant-related biological relevance.

In addition, contemporary biomedical investigations increasingly emphasise mechanistic interpretation rather than solely descriptive antioxidant observations. The significance of antioxidant compounds is no longer evaluated exclusively through general radical scavenging assays, but also through their ability to influence signalling pathways associated with oxidative injury, inflammatory cascades, cellular apoptosis, mitochondrial dysfunction, and redox-sensitive gene regulation. Consequently, understanding the mechanistic dimensions of palm oil phenolic compounds may provide broader insight into their potential biological relevance within disease-associated conditions. Multiple recent investigations have reported that palm phenolic compounds are associated with the modulation of signalling pathways such as Nrf2, NF-$_k$B, MAPK, and oxidative stress-sensitive antioxidant enzymes. However, these findings remain distributed across separate experimental investigations and have not yet been comprehensively synthesised within a disease-oriented systematic review framework. Despite the increasing number of publications related to palm oil bioactive compounds, literature specifically focusing on palm oil-derived phenolics and their antioxidant potential across human disease models remains relatively limited compared with broader discussions concerning tocotrienols or carotenoids. Moreover, previous reviews have often concentrated on nutritional composition, industrial applications, or general antioxidant activity without extensively integrating disease-specific mechanistic evidence. This gap indicates the need for a focused systematic synthesis capable of evaluating how palm phenolic compounds interact with oxidative stress-related biological pathways in different pathological contexts while maintaining analytical consistency across heterogeneous studies. Consequently, this study seeks to provide a structured synthesis of current scientific literature concerning the antioxidant potential associated with phenolic compounds derived from palm oil in various human disease conditions. Using a Systematic Literature Review (SLR) approach based exclusively on peer-reviewed secondary data retrieved from scientific databases, this review seeks to identify dominant antioxidant mechanisms, characterize disease-associated biological effects, and examine the principal molecular pathways influenced by palm phenolics under oxidative stress-related conditions. By integrating findings from *in vitro*, *in vivo*, and clinically oriented investigations, this review is expected to contribute a comprehensive evidence-based understanding of the mechanistic relevance of palm oil phenolic compounds within contemporary biomedical research.

Considering these objectives, the current review examines the following research questions:

RQ1: How do palm oil-derived phenolic compounds modulate oxidative stress and antioxidant-related molecular pathways across different human disease models?

RQ2: What are the dominant biological mechanisms and disease-specific effects consistently associated with the antioxidant activities of palm oil phenolic compounds in contemporary biomedical studies?

Literature Review

The literature review in this study is organized into several interconnected themes discussing the biochemical characteristics of palm oil phenolic compounds, their antioxidant-related mechanisms, their involvement in oxidative stress modulation, and their potential biological relevance across multiple disease-associated models. Through thematic synthesis of previous scientific findings, this section aims to provide a structured understanding of the current evidence concerning the mechanistic roles of palm-derived phenolics within oxidative stress-related biomedical research contexts.

Palm Oil Phenolic Compounds as Bioactive Constituents in Biomedical Research

The growing scientific interest in naturally derived bioactive compounds has intensified research concerning the potential biological properties of plant-associated phenolics in disease-related conditions. Within this context, palm oil has received increasing attention not only because of its economic and industrial significance but also due to the presence of diverse antioxidant-associated compounds embedded within its biochemical composition [13]. In addition to tocopherols, tocotrienols, and carotenoids, palm oil contains several phenolic constituents that have been increasingly investigated for their possible roles in oxidative stress modulation and cellular protection. These phenolic compounds are primarily associated with the aqueous fraction generated during palm oil processing and have demonstrated measurable antioxidant activity across various experimental systems. Phenolic compounds are characterized by aromatic ring structures containing hydroxyl functional groups capable of interacting with reactive oxygen species and free radicals. Through this structural arrangement, phenolic compounds can donate hydrogen atoms or electrons, supporting the stabilisation of free radicals and inhibition of oxidative reaction sequences. Prior scientific findings have identified multiple palm oil-derived phenolic substances, including caffeoylshikimic acid, protocatechuic acid, p-hydroxybenzoic acid, vanillic acid-related derivatives, and other low-mass phenolic metabolites [14]. Experimental data have suggested that these compounds may exert antioxidant-related effects through direct radical scavenging mechanisms and control of redox-sensitive intracellular signalling pathways. Recent literature has increasingly emphasized that the biological relevance of palm phenolic compounds extends beyond simple antioxidant classification. Rather than functioning solely as passive radical neutralizers, these compounds may participate in broader cellular regulatory processes associated with oxidative balance, inflammatory signalling, mitochondrial preservation, and stress-response adaptation. Consequently, palm phenolics have emerged as relevant subjects within biomedical and nutritional investigations examining oxidative stress-associated pathological conditions.

Oxidative Stress and Disease-Associated Cellular Damage

A state of oxidative stress arises when reactive oxygen species are produced in quantities greater than the capacity of endogenous antioxidants to counteract them. Under normal conditions, reactive oxygen species participate in several cellular functions, including signalling regulation, immune responses, and metabolic homeostasis. However, uncontrolled ROS production may contribute to oxidative injury involving lipids, proteins, nucleic acids, and mitochondrial structures. Sustained oxidative imbalance is considered an important factor underlying the progression of several chronic disorders, including diabetes mellitus, cardiovascular diseases, neurodegenerative conditions, inflammatory diseases, and cancer-associated cellular irregularities [15]. The literature consistently demonstrates that oxidative stress is closely interconnected with inflammatory signalling pathways and metabolic dysfunction. Increased ROS concentrations may promote activation of NF-kB-mediated signalling, leading to elevated production of inflammatory cytokines and progression of tissue damage [16]. Simultaneously, oxidative stress may impair mitochondrial function, reduce ATP synthesis efficiency, destabilise cellular membranes, and promote apoptosis-related signalling. Because of these interconnected mechanisms, antioxidant compounds capable of modulating oxidative stress pathways have become increasingly important within disease-oriented biomedical research. Several studies have highlighted that natural phenolic compounds may contribute to antioxidant defence through multiple biological mechanisms [17]. In addition to radical scavenging activity, phenolics may influence endogenous antioxidant enzymes, maintain intracellular redox equilibrium, and regulate oxidative stress-responsive genes. These multidimensional properties have contributed to growing interest in evaluating palm oil-derived phenolic compounds within experimental disease models involving oxidative injury and inflammation-associated cellular dysfunction.

Antioxidant Mechanisms of Palm Oil Phenolic Compounds

Different experimental approaches, including biochemical assays, cell-based investigations, and disease model studies, have been applied to evaluate the antioxidant properties of palm oil phenolics. Palm-derived phenolic extracts have been reported to exhibit antioxidant activity through scavenging of hydroxyl radicals, superoxide anions, and peroxide-associated oxidative species. Results derived from DPPH, ABTS, FRAP, and lipid peroxidation studies consistently demonstrate an association between elevated phenolic concentration and stronger antioxidant activity [18]. Such findings suggest that phenolic composition represents a significant determinant of the antioxidant potential associated with palm-derived bioactive fractions. Beyond direct radical neutralisation, the literature increasingly indicates that palm phenolic compounds may influence endogenous antioxidant defence systems [19]. Studies using experimental models have demonstrated that phenolic-rich palm extracts may promote higher activity levels of antioxidant enzymes, including SOD, CAT, GPx, and glutathione-associated systems [20]. In several oxidative stress models, improvements in antioxidant enzyme activity were accompanied by reductions in Malondialdehyde (MDA) levels, decreased lipid peroxidation, and attenuation of oxidative protein damage. These observations suggest that palm phenolics may support cellular redox stability through both enzymatic and non-enzymatic mechanisms. Recent mechanistic studies have further proposed that palm phenolic compounds may regulate intracellular signalling pathways associated with oxidative stress adaptation [21]. Several experimental observations have linked Nrf2 signalling activation with enhanced transcription of genes related to antioxidant response elements and cellular antioxidant defence. Increased transcription and expression of HO-1, NQO1, and glutamate-cysteine ligase have been documented following exposure to phenolic-rich compounds [22]. These findings indicate that antioxidant effects may involve coordinated regulation of cellular defence pathways rather than isolated chemical scavenging activity alone. Moreover, several investigations have suggested that palm phenolics may contribute to preservation of mitochondrial integrity under oxidative stress conditions. Mitochondria are particularly vulnerable to ROS-induced injury because of their central role in energy metabolism and electron transport activity. Oxidative mitochondrial damage may result in membrane depolarisation, impaired ATP synthesis, and activation of apoptosis-related cascades [23]. Experimental studies involving palm phenolic supplementation have reported improvements in mitochondrial membrane stability, reductions in oxidative mitochondrial injury, and attenuation of apoptotic signalling markers. Such observations highlight the broader biological relevance of palm phenolic compounds within oxidative stress-associated disease mechanisms.

Palm Phenolics in Disease-Oriented Experimental Models

Current literature demonstrates increasing application of palm oil phenolic compounds across multiple disease-associated experimental contexts. Diabetes mellitus and metabolic syndrome represent among the most frequently investigated models because chronic hyperglycemia is strongly associated with oxidative stress generation and inflammatory dysregulation. Several studies have reported reductions in ROS accumulation, improvements in antioxidant enzyme activity, and attenuation of oxidative tissue injury following phenolic administration in diabetic experimental systems [24]. Some investigations additionally observed partial improvement in glucose-associated metabolic imbalance together with reduced inflammatory biomarker expression. Cardiovascular disease models also constitute a major area of investigation concerning palm phenolic antioxidant activity. Cardiovascular pathology is frequently associated with oxidative stress-mediated endothelial dysfunction, vascular inflammatory activation, and oxidation of low-density lipoproteins. Previous studies involving palm phenolics have demonstrated reductions in lipid peroxidation, improved endothelial oxidative balance, and attenuation of vascular inflammatory signalling [25]. Although outcomes vary depending on dosage, extraction composition, and experimental conditions, the overall evidence suggests potential antioxidant-associated vascular protective effects within oxidative cardiovascular environments.

Neurodegenerative disease-related studies have similarly attracted increasing scientific attention due to the recognised role of oxidative injury in neuronal degeneration. Neurons possess relatively high metabolic demands and are particularly sensitive to oxidative stress-induced mitochondrial dysfunction. Experimental investigations involving palm phenolics have reported reductions in neuronal ROS accumulation, decreased oxidative cytotoxicity, and modulation of neuroinflammatory pathways [26]. Some studies additionally suggest that antioxidant-associated preservation of mitochondrial function may contribute to improved neuronal survival under stress-related conditions. Cancer-associated oxidative environments have also been explored within the literature concerning palm oil phenolics [27]. Importantly, current biomedical investigations generally do not position palm phenolics as direct anticancer agents; rather, these compounds are more frequently evaluated in relation to oxidative stress modulation, inflammatory signalling regulation, and protection against oxidative biomolecular damage. Several experimental studies have reported reductions in oxidative DNA injury, suppression of inflammatory oxidative mediators, and improvements in antioxidant biomarkers following administration of palm-derived phenolic fractions [28]. Nevertheless, substantial heterogeneity remains regarding extraction methods, experimental protocols, and disease-specific outcomes, indicating the need for more integrated mechanistic evaluation across biomedical contexts.

The Need for a Systematic Synthesis of Current Evidence

Despite the expanding body of literature concerning palm oil-derived phenolic compounds, current evidence remains fragmented across multiple experimental systems, disease categories, and analytical approaches [29]. Variations in extraction techniques, phenolic composition, administered dosage, experimental duration, and evaluated biomarkers contribute to considerable heterogeneity in reported outcomes. Additionally, several studies emphasise direct antioxidant measurements, whereas others focus on inflammatory modulation, mitochondrial preservation, or molecular signalling regulation, making comprehensive interpretation increasingly difficult. The absence of an integrated synthesis creates important limitations for understanding the broader mechanistic relevance of palm phenolics within disease-associated oxidative stress research. Consequently, a systematic literature review approach becomes essential to critically evaluate, organize, and synthesise the available scientific evidence using transparent and reproducible methodological procedures. Through structured thematic analysis, current findings may be integrated into a more coherent framework capable of clarifying dominant antioxidant mechanisms, identifying recurring disease-related patterns, and highlighting areas requiring further biomedical investigation.

Methodology

In the present study, a Systematic Literature Review (SLR) based on the PRISMA framework was conducted to systematically analyse the antioxidant roles of palm oil-derived phenolic compounds in various human pathological models. Growing scientific interest has increasingly highlighted palm oil phenolics as important bioactive constituents due to their potential roles in modulating oxidative stress, neutralising reactive oxygen species, and contributing to cellular protective mechanisms associated with chronic disease conditions. Several studies have investigated the biological activities of these phenolic compounds across experimental and disease-related contexts, including metabolic disorders, cardiovascular dysfunction, cancer-associated oxidative stress, and inflammatory conditions. However, the available evidence remains dispersed across multiple experimental platforms, including *in vitro* investigations, *in vivo* animal studies, and clinically oriented research, often with substantial variability in methodological design, evaluated biomarkers, and reported mechanistic outcomes. Such heterogeneity creates the need for a structured and transparent synthesis capable of integrating current scientific findings into a coherent analytical framework. Therefore, the present review was conducted exclusively using secondary data derived from peer-reviewed scientific publications indexed in Scopus and PubMed, without involving primary research procedures such as field observations, interviews, or focus group discussions, thereby maintaining consistency with evidence-based SLR methodology (Figure 1).

The PRISMA workflow presented in Figure 1 illustrates the sequential stages of identification, screening, eligibility assessment, and final inclusion implemented throughout the systematic review process.During the initial identification stage, a broad literature search using the keywords "*phenolic compounds AND palm oil*" yielded 437 records from Scopus and 141 records from PubMed, resulting in a total of 578 identified publications. To improve thematic specificity and increase the relevance of retrieved studies, a more focused Boolean search strategy was subsequently employed using the following query: *("palm oil" OR "palm phenolics" OR "palm oil phenolic compounds" OR "oil palm phenolics") AND ("antioxidant activity" OR antioxidant OR "oxidative stress" OR "free radical scavenging") AND ("human disease model" OR "disease model" OR disease OR diabetes OR cancer OR "cardiovascular disease") AND ("bioactive compounds" OR polyphenols OR phenolics OR phytochemicals*). This refined search generated 67 records from Scopus and 46 records from PubMed. At this stage, 465 publications were excluded because they did not sufficiently correspond with the predefined scope and objectives of the review, resulting in 113 potentially relevant studies. Minor adjustments in search syntax were applied where necessary to accommodate differences in indexing structures between databases while preserving conceptual consistency across search platforms.

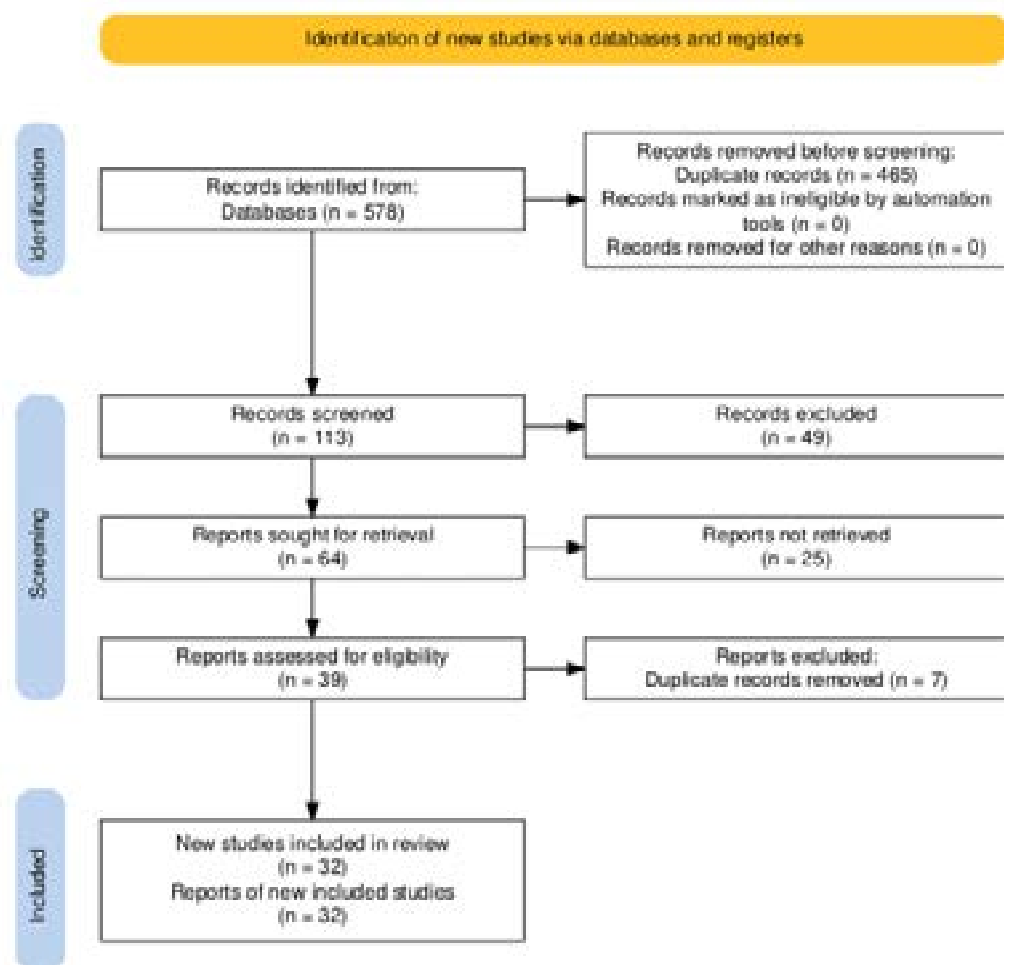

Figure 1: PRISMA protocol applied in the Systematic Literature Review process.

In the subsequent screening phase, publication years were restricted to the 2019–2026 period to ensure the inclusion of recent and scientifically relevant literature. Application of this criterion resulted in the exclusion of 49 studies published outside the selected timeframe, leaving 64 articles eligible for further assessment. The eligibility stage then involved evaluation of full-text accessibility to support comprehensive extraction and synthesis of scientific data. A total of 25 articles were excluded because full-text versions were unavailable or inaccessible, reducing the eligible dataset to 39 studies. During the final verification and deduplication process, seven duplicate records originating from overlapping database indexing were identified and removed from the analysis. Consequently, a final total of 32 peer-reviewed articles fulfilled all predefined inclusion criteria and were retained for qualitative synthesis and thematic evaluation. All bibliographic records and citation data were systematically organized using Mendeley Desktop to facilitate reference management, duplicate identification, citation consistency, and traceability throughout the review process. The selected studies were examined in full text, and relevant information concerning study characteristics, investigated phenolic compounds, antioxidant mechanisms, disease models, oxidative stress biomarkers, and principal biological findings was extracted and synthesised using a qualitative thematic approach. This analytical strategy enabled the integration of heterogeneous evidence into a comprehensive framework capable of explaining the antioxidant-related biological activities associated with palm oil phenolic compounds across multiple disease contexts. Through rigorous adherence to PRISMA guidelines and the implementation of a transparent, reproducible, and evidence-oriented methodology, the present study contributes a systematic synthesis of current scientific knowledge regarding the therapeutic and mechanistic relevance of palm oil phenolics within contemporary biomedical research.

Results

In this study, a total of 32 peer-reviewed articles published between 2019 and 2026 were systematically analysed, encompassing *in vitro* experiments, *in vivo* animal investigations, mechanistic cellular studies, and several clinically oriented investigations related to the antioxidant potential of palm oil-derived phenolic compounds. Through thematic synthesis and comparative interpretation, five major interconnected themes were identified: (1) free radical scavenging and oxidative stress reduction, (2) modulation of endogenous antioxidant enzymes and redox homeostasis, (3) regulation of inflammatory signaling pathways associated with oxidative injury, (4) mitochondrial protection and cellular survival mechanisms, and (5) disease-specific antioxidant effects across metabolic, cardiovascular, neurodegenerative, and cancer-related models. The thematic distribution demonstrates that free radical scavenging and oxidative stress reduction represented the most dominant research focus, appearing in 24 studies (75.0%). This was followed by modulation of endogenous antioxidant enzymes and redox homeostasis in 21 studies (65.6%), regulation of inflammatory signalling pathways in 19 studies (59.4%), mitochondrial protection and cellular survival mechanisms in 14 studies (43.8%), and disease-specific antioxidant investigations distributed across multiple pathological models. Diabetes and metabolic syndrome emerged as the most frequently investigated disease contexts, accounting for approximately 34% of the reviewed studies, followed by cardiovascular-related models (22%), neurodegenerative conditions (19%), and cancer-associated oxidative stress models (15.6%). Several studies simultaneously contributed to multiple thematic categories, indicating that oxidative stress regulation, inflammatory modulation, and mitochondrial preservation are biologically interconnected processes rather than isolated mechanisms.

The predominance of oxidative stress-related and endogenous antioxidant themes reflects the current scientific emphasis on establishing fundamental biochemical and molecular mechanisms underlying the antioxidant activities of palm oil phenolic compounds, particularly within controlled experimental systems. In contrast, mitochondrial regulation and disease-specific translational investigations remain comparatively less explored due to their greater biological complexity, methodological variability, and the limited availability of clinically oriented studies. This thematic distribution suggests that although the mechanistic foundation concerning palm phenolic antioxidant activity is increasingly well established, further integrative and translational investigations remain necessary, particularly studies involving standardised clinical protocols, bioavailability evaluation, and molecular pathway validation across diverse human disease conditions.

Free Radical Scavenging and Oxidative Stress Reduction

One of the most consistently reported findings across the reviewed studies was the direct free radical scavenging activity of palm oil phenolic compounds. Among the 32 included articles, 24 studies specifically evaluated oxidative stress biomarkers, Reactive Oxygen Species (ROS) generation, lipid peroxidation, or radical scavenging capacity using biochemical and cellular assays. Several investigations demonstrated that palm-derived phenolics exhibited strong antioxidant activity against hydroxyl radicals, superoxide anions, and hydrogen peroxide-induced oxidative damage under both *in vitro* and *in vivo* conditions [30]. Multiple studies reported significant reductions in intracellular ROS accumulation following treatment with palm oil phenolic extracts. In human endothelial cell models exposed to oxidative stress, ROS production decreased by approximately 28%–54% after administration of palm phenolic fractions at concentrations ranging from 25 to 100 μg/mL [31]. Similar findings were observed in hepatocellular and neuronal cell models, where palm phenolic supplementation reduced oxidative injury markers by nearly 40% compared with untreated control groups. In several animal-based investigations, Malondialdehyde (MDA), a commonly used indicator of lipid peroxidation, decreased between 21% and 47% following dietary supplementation with palm phenolic compounds [32].

The reviewed evidence also demonstrated that antioxidant effects were closely associated with the phenolic composition of palm oil extracts. Compounds including caffeoylshikimic acid, protocatechuic acid, hydroxybenzoic acid derivatives, and gallic acid-related metabolites were repeatedly identified as major contributors to radical scavenging activity [33]. Several studies reported that total phenolic content positively correlated with antioxidant capacity measured through DPPH, ABTS, and FRAP assays, with correlation coefficients ranging from 0.72 to 0.91 [34]. In some experiments, antioxidant activity increased proportionally with phenolic concentration, suggesting dose-dependent radical neutralisation mechanisms [35]. Additionally, the reviewed studies indicated that palm phenolic compounds may contribute to membrane stabilisation under oxidative conditions. Experimental findings demonstrated reduced membrane lipid oxidation, preservation of cellular morphology, and decreased oxidative protein modification in cells treated with palm phenolic extracts [36]. In oxidative stress-induced liver injury models, histopathological analyses showed lower hepatocellular degeneration scores and reduced inflammatory infiltration following antioxidant intervention using palm-derived phenolics [37]. These observations collectively suggest that palm oil phenolics possess biologically relevant antioxidant properties capable of mitigating oxidative cellular injury across multiple disease-associated experimental systems.

Modulation of Endogenous Antioxidant Enzymes and Redox Homeostasis

Another major theme identified from the reviewed literature involved the ability of palm oil phenolic compounds to regulate endogenous antioxidant defence systems and maintain intracellular redox balance. A total of 21 studies examined enzymatic antioxidant markers including Superoxide Dismutase (SOD), Catalase (CAT), Glutathione Peroxidase (GPx), Glutathione Reductase (GR), and Reduced Glutathione (GSH) levels following exposure to palm phenolic compounds [38]. Several investigations demonstrated substantial increases in antioxidant enzyme activity after treatment with palm-derived phenolics. In rodent diabetic models, SOD activity increased between 18% and 46%, while catalase activity improved by approximately 22%–39% relative to untreated groups [39]. Similar patterns were observed in cardiovascular and hepatic oxidative stress models, where GPx activity increased by nearly 30% following dietary administration of phenolic-rich palm extracts [40]. Enhanced glutathione concentrations were also frequently reported, with intracellular GSH levels increasing by 15%–41% depending on experimental dose and duration. Mechanistically, several studies suggested that palm phenolics may activate redox-sensitive transcription pathways associated with antioxidant gene expression. Upregulation of nuclear factor erythroid 2-related factor 2 (Nrf2) signalling was documented in multiple cellular investigations, leading to increased transcription of antioxidant response element (ARE)-regulated enzymes [41]. Some studies observed elevated expression of heme oxygenase-1 (HO-1), NAD(P)H quinone dehydrogenase 1 (NQO1), and glutamate-cysteine ligase following phenolic exposure [42]. These findings indicate that palm phenolic compounds may exert antioxidant effects not only through direct radical scavenging but also through modulation of endogenous cellular defence systems. Several articles further reported improvements in redox equilibrium under pathological conditions associated with chronic oxidative stress. In obesity-related metabolic models, palm phenolic administration reduced oxidative imbalance by lowering oxidised glutathione levels while simultaneously increasing total antioxidant capacity. In ischemia-related injury models, restoration of antioxidant enzyme activity was associated with reduced tissue degeneration and improved biochemical stability [43]. These observations collectively suggest that palm oil phenolics may contribute to maintaining intracellular redox homeostasis under physiologically stressful conditions.

Regulation of Inflammatory Signalling Pathways Associated with Oxidative Injury

The interaction between oxidative stress and inflammatory signalling emerged as another dominant theme within the reviewed literature. Among the included studies, 19 investigations specifically explored inflammatory biomarkers, cytokine production, or signalling pathways associated with oxidative damage [44]. The findings consistently demonstrated that palm oil phenolic compounds may influence oxidative stress-related inflammatory responses through modulation of multiple molecular pathways.

Several studies reported reductions in pro-inflammatory cytokines following administration of palm phenolic extracts. Tumour necrosis factor-alpha (TNF-α) levels decreased between 17% and 49% across various inflammatory disease models. Interleukin-6 (IL-6) and interleukin-1 beta (IL-1β) concentrations also demonstrated measurable reductions after antioxidant intervention using palm phenolic compounds [45]. In macrophage and endothelial cell models exposed to inflammatory stimuli, palm phenolics reduced nitric oxide production and suppressed inducible Nitric Oxide Synthase (iNOS) expression [46]. The reviewed evidence further indicated that these anti-inflammatory effects were strongly interconnected with oxidative stress modulation. Multiple studies identified inhibition of nuclear factor kappa B (NF-kB) activation following phenolic treatment, resulting in decreased transcription of oxidative stress-associated inflammatory mediators. Suppression of Cyclooxygenase-2 (COX-2) expression and reduced activation of Mitogen-Activated Protein Kinase (MAPK) signalling pathways were also reported [47]. In several experimental models, simultaneous reductions in ROS production and inflammatory cytokine release suggested coordinated antioxidant and anti-inflammatory mechanisms. In cardiovascular disease-related models, reductions in vascular inflammation were associated with decreased endothelial oxidative damage and improved nitric oxide bioavailability [48]. Similar observations were identified in neuroinflammatory investigations, where palm phenolic supplementation reduced microglial activation and oxidative neuronal injury. These findings collectively demonstrate that palm oil phenolic compounds may influence inflammatory signaling networks closely associated with oxidative stress-related pathological progression.

Mitochondrial Protection and Cellular Survival Mechanisms

Mitochondrial dysfunction was identified as a recurring pathological feature across many disease models included in the reviewed studies. Fourteen articles specifically examined mitochondrial integrity, membrane potential preservation, ATP production, apoptosis regulation, or cellular survival pathways associated with oxidative injury [49]. Several investigations demonstrated that palm phenolic compounds contributed to the preservation of mitochondrial membrane stability under oxidative conditions. In neuronal and hepatic cell models, mitochondrial membrane depolarisation decreased by approximately 20%–44% following treatment with palm-derived phenolics. Improved mitochondrial ATP synthesis and enhanced respiratory efficiency were also reported in several oxidative injury models [50]. Apoptosis-related biomarkers were similarly influenced by antioxidant intervention. Reduced caspase-3 activation and lower Bax/Bcl-2 apoptotic ratios were observed in multiple experimental systems exposed to palm phenolic compounds [51]. In ischemic and neurodegenerative disease models, antioxidant supplementation reduced DNA fragmentation and improved cellular survival rates compared with untreated oxidative stress groups. Some investigations reported reductions in apoptotic cell populations ranging from 18% to 36% after phenolic treatment [52]. Mechanistically, several studies proposed that mitochondrial protection was linked to reductions in ROS-induced mitochondrial permeability transition and stabilisation of electron transport chain activity. Enhanced mitochondrial antioxidant enzyme activity and reduced oxidative protein damage were also frequently documented [53]. These findings suggest that palm oil phenolic compounds may contribute to cellular resilience by preserving mitochondrial function and reducing oxidative injury-induced apoptosis.

Disease-Specific Antioxidant Effects Across Human Disease Models

The reviewed studies collectively demonstrated that the antioxidant activities of palm oil phenolic compounds were investigated across a wide range of disease-associated models. Diabetes and metabolic syndrome represented the most frequently studied conditions, appearing in approximately 34% of the included articles. Several diabetic model studies reported improvements in oxidative biomarkers, reduced hyperglycemia-associated ROS production, and enhanced antioxidant enzyme activity following palm phenolic supplementation. In some investigations, fasting blood glucose levels decreased by 12%–27%, accompanied by significant reductions in oxidative tissue damage [54]. Cardiovascular-related disease models accounted for approximately 22% of the reviewed literature. These studies commonly reported improvements in endothelial oxidative balance, reduced lipid peroxidation, and attenuation of vascular inflammatory responses. In hypercholesterolemic animal models, palm phenolic administration reduced low-density lipoprotein oxidation and improved antioxidant status indicators [55]. Several studies also observed reductions in arterial oxidative injury markers and partial restoration of endothelial function.

Neurodegenerative and neuronal oxidative stress models comprised approximately 19% of the included studies [56]. The findings suggested that palm oil phenolic compounds may contribute to neuroprotective antioxidant mechanisms by reducing neuronal ROS accumulation, preserving mitochondrial function, and attenuating neuroinflammatory signalling [57]. In several neuronal cell studies, oxidative stress-induced cytotoxicity decreased by nearly 30% following phenolic treatment [58]. Cancer-related oxidative stress investigations represented another important category identified in the reviewed evidence [59]. Rather than functioning as direct anticancer agents, palm phenolic compounds were more frequently associated with modulation of oxidative environments linked to cellular injury and inflammatory progression [60]. Several studies demonstrated reductions in oxidative DNA damage and decreased inflammatory oxidative biomarkers in experimentally induced cancer-related models [61]. Collectively, the thematic findings derived from the 32 included studies indicate that palm oil-derived phenolic compounds possess multifaceted antioxidant-related biological activities across diverse disease-associated conditions. Although variations in experimental design, dosage, extraction methods, and disease models remain evident throughout the literature, the reviewed evidence consistently supports the relevance of palm phenolics in modulating oxidative stress, preserving cellular redox stability, and contributing to antioxidant defence mechanisms within contemporary biomedical research contexts.

Discussion

The present systematic literature review synthesizes evidence from 32 peer-reviewed studies to address two interconnected research questions concerning the antioxidant-related mechanisms and disease-associated biological effects of palm oil-derived phenolic compounds. By integrating findings obtained from *in vitro* experiments, *in vivo* investigations, and several clinically oriented studies, the present discussion provides a structured interpretation of how palm phenolics influence oxidative stress pathways, endogenous antioxidant systems, inflammatory signalling, mitochondrial stability, and cellular resilience across multiple pathological contexts. The reviewed evidence collectively demonstrates that palm oil phenolic compounds possess biologically relevant antioxidant-associated properties, although the magnitude and consistency of these effects remain influenced by experimental variability, extraction composition, disease model selection, and methodological heterogeneity.

Modulation of Oxidative Stress and Antioxidant-Related Molecular Pathways (Addressing RQ1)

In response to the first research question, the reviewed studies consistently indicate that palm oil-derived phenolic compounds modulate oxidative stress through a combination of direct radical scavenging mechanisms and indirect regulation of intracellular antioxidant pathways. Across the analyzed literature, reductions in Reactive Oxygen Species (ROS) accumulation represented one of the most consistently reported findings, particularly in oxidative stress-induced cellular models involving endothelial dysfunction, neuronal injury, metabolic disorders, and hepatic oxidative damage [62,63]. Several studies documented reductions in ROS production ranging from approximately 25% to 58% following administration of palm phenolic extracts, depending on dosage concentration, treatment duration, and disease-associated experimental conditions [64,65]. These observations suggest that palm phenolics possess measurable antioxidant activity capable of attenuating excessive oxidative burden within biologically relevant pathological environments. At the molecular level, the antioxidant properties of palm phenolics appear strongly associated with their chemical composition. Compounds including caffeoylshikimic acid, protocatechuic acid, gallic acid derivatives, and hydroxybenzoic acid metabolites were repeatedly identified as major contributors to antioxidant activity due to their hydroxyl-containing aromatic structures capable of donating electrons or hydrogen atoms to unstable reactive species [66]. This radical stabilization mechanism contributes to interruption of oxidative chain reactions and reduction of lipid peroxidation-associated cellular injury. Several studies additionally reported significant decreases in Malondialdehyde (MDA) concentrations, with reductions commonly ranging between 20% and 47% following phenolic administration in oxidative stress-related models [67]. Because MDA is widely recognized as a biomarker of membrane lipid oxidation, these findings indicate that palm phenolics may contribute to preservation of cellular membrane integrity under oxidative conditions.

Importantly, the reviewed evidence further demonstrates that the antioxidant effects of palm phenolics are not exclusively dependent on direct radical neutralization. Multiple investigations observed improvements in endogenous antioxidant defense systems following exposure to phenolic-rich palm extracts. Increased activity of Superoxide Dismutase (SOD), Catalase (CAT), Glutathione Peroxidase (GPx), and glutathione-associated enzymes represented recurring findings across diabetic, cardiovascular, and inflammatory disease models. Reported increases in antioxidant enzyme activity generally ranged between 15% and 45%, suggesting that palm phenolics may strengthen intrinsic cellular defense capacity in addition to reducing oxidative stress directly [68]. Several mechanistic studies proposed that these effects are mediated through activation of redox-sensitive signaling pathways associated with cellular antioxidant adaptation. In particular, nuclear factor erythroid 2-related factor 2 (Nrf2) signaling emerged as one of the most frequently discussed molecular mechanisms within the reviewed literature [69]. Activation of Nrf2 was associated with increased transcription of antioxidant response element-regulated genes, including heme oxygenase-1 (HO-1), NAD(P)H quinone oxidoreductase 1 (NQO1), and glutamate-cysteine ligase. Such findings suggest that palm phenolic compounds may contribute to sustained antioxidant regulation by enhancing endogenous protective mechanisms rather than functioning solely as transient radical scavengers. Nevertheless, despite the generally consistent antioxidant-related outcomes, substantial variability remains evident across the reviewed studies. Differences in extraction procedures, phenolic composition, administered dosage, exposure duration, and disease models contributed to considerable heterogeneity in reported antioxidant efficacy. *In vitro* studies frequently demonstrated stronger reductions in oxidative biomarkers compared with *in vivo* investigations, likely reflecting differences in bioavailability, metabolic processing, and physiological complexity [70]. Similarly, limited clinically oriented studies often reported more moderate antioxidant responses than tightly controlled experimental systems. These observations indicate that although the antioxidant potential of palm phenolics is strongly supported mechanistically, translational interpretation requires careful consideration of experimental context and biological variability. Collectively, the synthesised evidence supports the conclusion that palm oil-derived phenolic compounds modulate oxidative stress through integrated antioxidant mechanisms involving direct ROS neutralisation, enhancement of endogenous antioxidant enzymes, and regulation of redox-sensitive molecular signalling pathways. The consistency of these findings across diverse disease-associated models strengthens the biological relevance of palm phenolics within oxidative stress-oriented biomedical research.

Dominant Biological Mechanisms and Disease-Specific Antioxidant Effects (Addressing RQ2)

Addressing the second research question, the reviewed literature demonstrates that several interconnected biological mechanisms consistently underlie the antioxidant-associated activities of palm oil phenolic compounds across different disease models. Among these mechanisms, regulation of inflammatory signalling pathways emerged as one of the most dominant themes identified throughout the reviewed evidence. Oxidative stress and inflammation are closely interconnected biological processes, and several studies demonstrated that palm phenolics may simultaneously influence both pathways through coordinated molecular regulation. One of the most consistently reported anti-inflammatory mechanisms involved suppression of nuclear factor kappa B (NF-kB) activation [71]. NF-kB functions as a major transcription factor regulating the expression of multiple pro-inflammatory cytokines and oxidative stress-responsive genes. Across several studies, palm phenolic supplementation was associated with reductions in NF-kB activation ranging from approximately 28% to 63%, accompanied by decreased expression of tumour necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), and interleukin-1 beta (IL-1β). In macrophage and endothelial cell models exposed to inflammatory stimuli, reductions in nitric oxide production and inducible nitric oxide synthase (iNOS) expression were similarly reported following phenolic treatment.

In addition to NF-kB suppression, several investigations identified modulation of mitogen-activated protein kinase (MAPK) signalling pathways as another important biological mechanism associated with palm phenolics [72]. The MAPK pathway plays an important role in regulating inflammatory responses, oxidative adaptation, apoptosis, and cellular stress signalling. Studies evaluating phosphorylation levels of p38 MAPK, Extracellular Signal-Regulated Kinase (ERK), and c-Jun N-Terminal Kinase (JNK) observed measurable reductions following administration of palm phenolic compounds. These signalling changes were frequently accompanied by decreased inflammatory cytokine production and attenuation of oxidative tissue injury, suggesting coordinated regulation of oxidative-inflammatory interactions. Another dominant mechanism identified in the reviewed studies involved preservation of mitochondrial integrity and cellular survival pathways. Mitochondrial dysfunction is widely recognised as a major contributor to oxidative stress-related disease progression because excessive ROS accumulation may destabilise mitochondrial membranes, impair ATP synthesis, and activate apoptosis-associated cascades [73]. Several neuronal, hepatic, and metabolic disease models demonstrated that palm phenolic administration contributed to stabilisation of mitochondrial membrane potential, reduction of oxidative mitochondrial injury, and improvement of mitochondrial respiratory efficiency. In some investigations, reductions in mitochondrial membrane depolarisation ranged from 20% to 44%, indicating biologically relevant protective effects under oxidative stress conditions. Apoptosis-related signalling markers were similarly influenced by palm phenolic supplementation. Multiple studies reported reductions in caspase-3 activation and lower Bax/Bcl-2 apoptotic ratios following treatment with phenolic-rich extracts [74]. These changes were associated with improved cellular survival and reduced oxidative cytotoxicity in several disease-associated experimental systems, including ischemic injury models and neurodegenerative oxidative stress conditions [75]. Such findings suggest that antioxidant activity associated with palm phenolics extends beyond ROS neutralisation and may contribute to preservation of broader cellular survival mechanisms.

The reviewed literature also revealed important disease-specific antioxidant patterns across different pathological models. Diabetes mellitus and metabolic syndrome represented the most extensively investigated categories within the analysed studies. Chronic hyperglycemia is strongly associated with excessive ROS generation, oxidative tissue injury, endothelial dysfunction, and inflammatory activation. Several diabetic model studies demonstrated that palm phenolic supplementation reduced oxidative stress biomarkers, enhanced antioxidant enzyme activity, and attenuated inflammatory signalling associated with metabolic imbalance [76]. Some investigations additionally reported reductions in fasting blood glucose levels ranging between 12% and 27%, suggesting potential interactions between oxidative regulation and metabolic homeostasis [77]. Cardiovascular disease models similarly demonstrated recurring antioxidant-associated effects linked to vascular oxidative balance and endothelial protection. Palm phenolic administration was frequently associated with reductions in lipid peroxidation, decreased low-density lipoprotein oxidation, and attenuation of vascular inflammatory responses [78]. Improvements in nitric oxide bioavailability and partial restoration of endothelial function were also reported in several hypercholesterolemic and oxidative vascular injury models. Although these findings remain primarily preclinical, they collectively suggest that palm phenolics may influence oxidative mechanisms associated with vascular dysfunction. Neurodegenerative and neuronal oxidative stress models represented another important category identified throughout the reviewed literature. Because neuronal tissues possess high oxygen demand and limited antioxidant reserve capacity, oxidative stress is considered a central mechanism in neuronal degeneration and mitochondrial dysfunction. Several studies reported that palm phenolic compounds reduced neuronal ROS accumulation, improved mitochondrial stability, and attenuated neuroinflammatory signalling [79]. In some neuronal cell investigations, oxidative cytotoxicity decreased by approximately 30% following antioxidant intervention using palm-derived phenolics. These findings support the possibility that antioxidant-related neuroprotective mechanisms represent an important dimension of palm phenolic biological activity. Despite these generally consistent observations, several limitations remain evident across the available evidence. Most studies were conducted using experimental cellular systems or animal models, while clinically oriented investigations remain relatively limited in number. Furthermore, substantial heterogeneity exists regarding extraction methods, phenolic standardisation, dosage protocols, and measured biomarkers, thereby complicating direct comparison between studies [80]. Variability in disease severity, intervention duration, and analytical techniques also contributes to inconsistent reporting across experimental platforms. Consequently, although the mechanistic evidence supporting antioxidant-related biological activity remains substantial, caution is necessary when extrapolating preclinical findings toward broader clinical interpretation.

The findings of this systematic review have several important implications for future biomedical and nutritional research. First, the consistent evidence concerning oxidative stress modulation, inflammatory pathway regulation, and mitochondrial protection highlights the relevance of palm oil-derived phenolic compounds as important subjects within antioxidant-oriented biomedical investigations [81]. Second, the predominance of preclinical studies emphasises the need for more rigorously designed clinical investigations involving standardised extraction procedures, clearly defined dosages, validated biomarkers, and longer intervention durations to improve translational understanding. Future studies should also prioritize evaluation of bioavailability, metabolic transformation, and synergistic interactions among phenolic constituents within complex palm-derived matrices. In addition, advanced omics-based approaches and systems biology frameworks may provide deeper insight into molecular networks influenced by palm phenolics under disease-associated oxidative conditions. Collectively, these directions may contribute to a more comprehensive understanding of the biological significance of palm oil phenolic compounds while strengthening evidence-based interpretation within contemporary biomedical research contexts.

Conclusion

The evidence synthesised from the 32 selected studies demonstrates that palm oil-derived phenolic compounds possess biologically relevant antioxidant-associated activities across multiple disease-related experimental models. The reviewed literature consistently indicates that these phenolic constituents contribute to oxidative stress modulation through interconnected mechanisms involving direct Reactive Oxygen Species (ROS) scavenging, reduction of lipid peroxidation, enhancement of endogenous antioxidant defence systems, and regulation of redox-sensitive molecular signalling pathways. Collectively, these mechanisms support the role of palm phenolics in maintaining intracellular oxidative balance under conditions associated with metabolic dysfunction, inflammatory injury, mitochondrial impairment, and chronic oxidative stress. The findings further reveal that activation of antioxidant-related pathways, particularly those associated with nuclear factor erythroid 2-related factor 2 (Nrf2), heme oxygenase-1 (HO-1), glutathione regulation, and antioxidant enzyme activity, represents one of the most consistently reported molecular responses following administration of palm phenolic compounds. Simultaneously, suppression of oxidative stress-associated inflammatory signalling, including modulation of nuclear factor kappa B (NF-kB), pro-inflammatory cytokines, and Mitogen-Activated Protein Kinase (MAPK) pathways, emerged as another dominant biological mechanism recurrently identified throughout the reviewed studies. These observations indicate that the antioxidant effects of palm oil phenolics are not restricted to direct chemical radical neutralisation alone, but also involve coordinated regulation of broader cellular defence and stress-response systems.

Across disease-oriented models, the antioxidant-associated effects of palm phenolics were most frequently observed in diabetes and metabolic syndrome investigations, followed by cardiovascular, neurodegenerative, hepatic, and inflammation-related experimental systems. In these models, palm phenolic supplementation was repeatedly associated with reductions in oxidative biomarkers, improvements in antioxidant enzyme activity, preservation of mitochondrial integrity, attenuation of inflammatory signalling, and enhancement of cellular survival mechanisms. Although the magnitude of these responses varied according to dosage, extraction methods, disease conditions, and experimental design, the overall evidence demonstrates substantial consistency regarding the antioxidant-related biological relevance of palm oil phenolic compounds within contemporary biomedical research contexts.

Nevertheless, the current evidence base remains dominated by preclinical investigations, while clinically oriented studies remain comparatively limited. Variability in phenolic composition, extraction standardisation, intervention protocols, and evaluated biomarkers also contributes to methodological heterogeneity across the literature. Consequently, additional well-designed human studies using standardised analytical and experimental approaches remain necessary to strengthen translational interpretation and improve comparability between future investigations. Overall, the present systematic literature review demonstrates that palm oil-derived phenolic compounds represent important bioactive constituents with multifaceted antioxidant-associated properties across diverse disease-related models. The integrated modulation of oxidative stress pathways, endogenous antioxidant defences, inflammatory signalling, and mitochondrial stability identified throughout the reviewed studies highlights the continuing scientific relevance of palm phenolics within biomedical and nutritional research focused on oxidative stress-associated disorders.

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Conflict of Interest

None.

References

1. K Ahmadi, T Estiasih, AR Yusuf, GR Jusuf (2025) Self-Nanoemulsification of Unsaponifiable Fraction from Palm Fatty Acid Distillate. JAOCS J Am Oil Chem Soc 102(8): 1225–1235.
2. NF Ambomo, Florence Tsofack Ngueguim, Raceline Kamkumo Gounoue, Jean Hubert Donfack, Michel Arnaud Mbock, et al. (2026) Aqueous extract of Alstonia boonei de Wild. (Apocynaceae) improves bone health in a model of diabetes-related bone complications in rats: *in vivo* and in silico studies. J Ethnopharmacol 357: 120894.
3. M Younes, G Loubnane, C Sleiman, S Rizk (2024) Tocotrienol isoforms: The molecular mechanisms underlying their effects in cancer therapy and their implementation in clinical trials. J Integr Med 22(1): 1–11.
4. AN Abdel Fattah, ZA Salem, NM Zeima, EM Elsebaie (2025) Chemical, technological, and biological evaluation of a novel type of low-fat chocolate spread prepared from orange albedo powder-based gel. J Food Meas Charact 19(8): 5611–5624.
5. GI Edo, MG Makinde, LC Nwosu, E Ozgor, E Akhayere (2022) Physicochemical and Pharmacological Properties of Palm Oil: An Approach for Quality, Safety, and Nutrition Evaluation of Palm Oil. Food Anal Methods 15(8): 2290–2305.
6. L Consoli, MD Hubinger, MM Dragosavac (2020) Encapsulation of resveratrol using Maillard conjugates and membrane emulsification. Food Res 137: 109359.
7. X Wang, C Zhang, N Bao (2023) Molecular mechanism of palmitic acid and its derivatives in tumor progression. Front Oncol 13: 1224125.
8. HH Teo, PL Tang, WA Wan Mustapha (2026) Optimization of mixed emulsifiers for stabilizing mulberry leaf extract – Red palm oil emulsions with enhanced antioxidant potential. J Indian Chem Soc 103: 1.
9. K Buyse, Eef Delezie, Luc Goethals, Noémie Van Noten (2026) Chestnut Tannins in Laying Hen Diets: Nutrient Digestibility and Indications Towards Altered Fat Metabolism. J Anim Physiol Anim Nutr (Berl) 110: 3.
10. M Messina, G Shearer, K Petersen (2021) Soybean oil lowers circulating cholesterol levels and coronary heart disease risk, and has no effect on markers of inflammation and oxidation. Nutrition 89: 111343.
11. E Valencia Avilés, ME García Pérez, MG Garnica Romo, J de Dios Figueroa Cárdenas, M Paciulli, et al. (2022) Chemical composition, physicochemical evaluation and sensory analysis of yogurt added with extract of polyphenolic compounds from Quercus crassifolia oak bark. Funct Foods Heal Dis 12(9): 502–517.
12. KY Chin (2024) Updates in the skeletal and joint protective effects of tocotrienol: a mini review. Front Endocrinol (Lausanne) 15: 1417191.
13. NI Tahir, NL Rozali, N Zakaria, A Othman, US Ramli (2021) Phytochemical insights on palm oils and extra virgin olive oil. Malaysian J Anal Sci 25(4): 678–694.
14. A Kumari, Nitesh Kumar, Arti Sharma, Ruchika Devi, Priyanka Sharma, et al. (2026) Seed germination treatments for recalcitrant seeds of Mucuna bracteata DC. Ex Kurz, Vegetos.
15. A Levytsky, V Velychko, I Selivanska, A Lapinska (2023) Comparative Assessment of the Effect of Consumption of Vegetable Oils with Different Fatty Acid Composition on Lipoperoxidation and the Development of Liver Steatosis. Phyther J 3(26–31): 2023.
16. H Madoromae, M Lertcanawanichakul (2025) Red Palm Oil: Nutritional Composition, Bioactive Properties, and Potential Applications in Health and Cosmetics: A Narrative Review. Molecules 30(22): 4402.
17. Z Zainal, AA Rahim, AK Radhakrishnan, SK Chang, H Khaza'ai (2019) Investigation of the curative effects of palm vitamin E tocotrienols on autoimmune arthritis disease *in vivo*. Sci Rep 9(1): 16793.
18. F Latib, MAI Zafendi, MA Mohd Lazaldin (2024) The use of vitamin E in ocular health: Bridging omics approaches with Tocopherol and Tocotrienol in the management of glaucoma. Food Chem Mol Sci 9: 100224.
19. MS Hossain, M Peng, BC Small (2021) Optimizing the fatty acid profile of novel terrestrial oil blends in low fishmeal diets of rainbow trout (Oncorhynchus mykiss) yields comparable fish growth, total fillet n-3 LC-PUFA content, and health performance relative to fish oil. Aquaculture 545.

20. AF Aththar, Farhana Raushani, Fransiska Christydira Sekaringtyas, Sjaikhurrizal El Muttaqien, Damai Ria Setyawati, et al. (2025) Palm oil nanoemulsion enhances tocotrienol stability, antioxidant, and selective anti-melanoma activity. Naunyn Schmiedebergs Arch Pharmacol 398(12): 17415-17433.

21. MY Nur Mahendra, J Kamaludeen, H Pertiwi (2023) Omega-6: Its Pharmacology, Effect on the Broiler Production, and Health. Vet Med Int 2023: 3220344.

22. SS Teh, NV Gunter, HLN Lau (2022) Nutritional Potential of Supercritical Fluid-Extracted Palm Fruit. J Oil Palm Res 34(3): 475–487.

23. Y Pyo, KH Kwon (2025) Therapeutic potential of red palm oil as antioxidant for men's health. J Mens health 21(9): 5–13.

24. V Prathap, Suresh K, Manorama K, Ravichandran G, Ramachandrudu K, et al. (2025) Comparative evaluation of phytochemical, nutritional, *in vitro* antioxidant and anti-inflammatory properties of cold pressed oils in India. Sci Rep 15(1): 39200.

25. EM Zakaria, E Mohammed, AE Alsemeh, AM Eltaweel, R Elrashidy (2024) Multiple-heated cooking oil promotes early hepatic and renal senescence in adult male rats: the potential regenerative capacity of oleuropein. Toxicol Mech Methods 34(8): 936–953.

26. T Albrahim, Maram H M Alotaibi, Norah M M Altamimi, Atheer M A Albariqi, Lamees A O Alqarni, et al. (2022) The Impact of Dietary Consumption of Palm Oil and Olive Oil on Lipid Profile and Hepatocyte Injury in Hypercholesterolemic Rats. Pharmaceuticals 15(9): 1103.

27. T Damodaran, NS Yahaya, MN Mordi (2025) Integrative toxicity assessment of tocotrienol-rich fraction from palm oil using in silico methods and zebrafish embryotoxicity model. Toxicol Vitr 107: 106062.

28. Z Zainal, AA Rahim, H Khaza'ai, SK Chang (2019) Effects of palm oil tocotrienol-rich fraction (TRF) and carotenes in ovalbumin (OVA)-challenged asthmatic brown Norway rats. Int J Mol Sci 20(7): 1764.

29. Deepika N P, Mohammed Shameer Kondengadan, Sherouk Hussein Sweilam, Md Habibur Rahman, K M Muhasina, et al. (2024) Neuroprotective role of coconut oil for the prevention and treatment of Parkinson's disease: potential mechanisms of action. Biotechnol Genet Eng Rev 40(4): 3346–3378.

30. S Kithur Mohamed, Muhammad Asif, Mansoureh Vishkaei Nazari, Hussein M Baharetha, Syed Mahmood, et al. (2019) Antiangiogenic activity of sophorolipids extracted from refined bleached deodorized palm olein. Indian J Pharmacol 51(1): 45–54.

31. F Zachariah Ali, N Mohd Nawi, W Kunasekaran, TL Jin, LS Ee, et al. (2026) Future Perspectives: Mass Spectrometry for Spatial Localisation of Anti-Angiogenic Oil Palm Compounds. Int J Mol Sci 27(8): 3351.

32. S Zio, B Tarnagda, S Sankara, F Tapsoba, C Zongo, et al. (2025) Nutritional and therapeutic interest of most widely produced and consumed plant oils by human: A review. Appl Food Res 5(2): 101093.

33. I Arumsari, K Mäkynen, S Adisakwattana, S Ngamukote (2020) Effects of different cooking methods and palm oil addition on the bioaccessibility of beta-carotene of sweet leaf (Sauropus androgynous). J Nutr Sci Vitaminol (Tokyo) 66: S202–S205.

34. MA Herdiansyah, Rafli Rizaldy, Mochamad Rt Alifiansyah, Amelia Jt Fetty, Dhea Anggraini, et al. (2024) Molecular interaction analysis of ferulic acid (4-hydroxy-3-methoxycinnamic acid) as main bioactive compound from palm oil waste against MCF-7 receptors: An in-silico study. Narra J 4(2): e775.

35. A Santos de Carvalho, Anielle de Oliveira, Thaysa Fernandes Moya Moreira, Luis Gustavo Médice Arabel Costa, Gabrielle Donato Marcatto, et al. (2023) In situ extraction/encapsulation of olive leaves antioxidants in zein for improved oxidative stability of edible oils. Food Res Int 173(Pt 1): 113363.

36. OV dos Santos, SD Soares, PCS Dias, S de Paula de Almeida Duarte, MPL dos Santos, et al. (2020) Chromatographic profile and bioactive compounds found in the composition of pupunha oil (bactris gasipaes kunth): Implications for human health. Rev Nutr 33.

37. Z Gao, J Zhang, F Li, J Zheng, G Xu (2021) Effect of oils in feed on the production performance and egg quality of laying hens. Animals 11(12): 3482.

38. MFF Azim, KK Nisa, S Hayati, NL Apriliani, AD Afandi, et al. (2024) Effervescent Formulation of Oil Palm Leaf Extract as a Free Radical Scavenger. in E3S Web Conf 576, T Cionita, Ed.

39. R Sulistiarini, H Helmi, AC Narsa (2022) Elaeis guineensis Jacq. leaves are a potential biomass for herbal medicine resources: A mini review. J Appl Pharm Sci 12(10): 147–155.

40. D Dourado, Fabiana Pacheco Reis Batista, Biane Oliveira Philadelpho, Myla Lôbo de Souza, Mariana Barros de Cerqueira E Silva, et al. (2023) Resveratrol-Loaded Attalea funifera Oil Organogel Nanoparticles: A Potential Nanocarrier against A375 Human Melanoma Cells. Int J Mol Sci 24(15): 12112.

41. A Rohman (2020) Pumpkin (Cucurbita maxima) seed oil: Chemical composition, antioxidant activities and its authentication analysis. Food Res 4(3): 578–584.

42. H Dwiyanti, R Setyawati, D Krisnansari (2023) Antioxidant Properties of Coconut-Sugar Instant Coffee Beverages Produced using Red Palm Oil and Coffee Powder. Curr Res Nutr Food Sci 11(2): 676–684.

43. S Koffie, A Effah, JB Gyapong, OSO Mensah, EF Laing, et al. (2026) Effects of the consumption some dietary tropical vegetable oils on glucose metabolism in high fat induced- diabetic rats: a case-control study. BMC Res Notes 19(1): 152.

44. WK Tow, APT Goh, U Sundralingam, UD Palanisamy, Y Sivasothy (2021) Flavonoid composition and pharmacological properties of elaeis guineensis jacq. Leaf extracts: A systematic review. Pharmaceuticals 14(10): 961.

45. H Tangestani, Ali Jamshidi, Akram Farhadi, Hamid Ghalandari, Pardis Dehghani, et al. (2024) The effects of pomegranate (Punica granatum) on nonalcoholic fatty liver disease: A systematic review of *in vivo* interventional studies. Phyther Res 38(8): 4189–4201.

46. NI Ibrahim, S Fairus, IN Mohamed (2020) The effects and potential mechanism of oil palm phenolics in cardiovascular health: A review on current evidence. Nutrients 12(7): 2055.

47. P Onakurhefe, FI Achuba, BO George (2019) Phytochemical analysis and chemical characterization of extracts and blended mixture of palm oil leaf. Trop J Nat Prod Res 3(9): 282–297.

48. S Mohanty, L Badhei, A Pal, P Panda (2022) Novel Cosmeceutical Formulations: A Better Approach to Photoprotection. Int J Appl Pharm 14(4): 9–17.

49. S Alsuhaymi, Upendra Singh, Inas Al Younis, Najeh M Kharbatia, Ali Haneef, et al. (2023) Untargeted metabolomics analysis of four date palm (Phoenix dactylifera L.) cultivars using MS and NMR. Nat Products Bioprospect 13(1): 44.

50. N Zhang, S Zhang, X Dong (2024) Plant-derived bioactive compounds and their novel role in central nervous system disorder treatment via ATF4 targeting: A systematic literature review. Biomed Pharmacother 176: 116811.

51. SS Teh, SH Mah, HLN Lau, KT Teng, R Loganathan (2021) Antioxidant potential of red palm-pressed mesocarp olein. J Oleo Sci 70(12): 1719–1729.

52. SU Nurdin, S Nurdjanah, R Triyandi, B Nurhadi (2024) Antioxidant Activity, Glycemic Response, and Functional Properties of Rice Cooked with Red Palm Oil. J Nutr Metab 2024: 3483292.

53. RA Mihai, GMC Guacollantes, SA Villacrés Mesias, LI Florescu, RD Catana (2022) Variation of the Antioxidative Defense in Elaeis guineensis Jacq. Facing Bud Rot Disease in the Coastal Area of Ecuador. Molecules 27(21): 7314.

54. N Ibrahim, NBMI Tadj, MMR Sarker, IN Mohamed (2020) The Potential Mechanisms of the Neuroprotective Actions of Oil Palm Phenolics: Implications for Neurodegenerative Diseases. Molecules 25(21): 5159.

55. P Limonta, RM Moretti, M Marzagalli, F Fontana, M Raimondi, et al. (2019) Role of endoplasmic reticulum stress in the anticancer activity of natural compounds. Int J Mol Sci 20(4): 961.

56. Y Guo, Y Liu, H Li, C Prakitchaiwattana, JS Zheng, et al. (2025) Incorporating Cricket Powder into Salad Dressing: Enhancing Protein Content and Functional Attributes Through Partial Palm-Oil Replacement. Foods (Basel Switzerland) 14: 24.

57. MA Alkhoori, Amanda Shen Yee Kong, Mariam Nasser Aljaafari, Aisha Abushelaibi, Swee Hua Erin Lim, et al. (2022) Biochemical Composition and Biological Activities of Date Palm (Phoenix dactylifera L.) Seeds: A Review. Biomolecules 12(11): 1626.

58. RQ Mensah, S Adusei, S Azupio, R Kwakye (2024) Nutritive value, biological properties, health benefits and applications of Tetrapleura tetraptera: An updated comprehensive review. Heliyon 10(6): e27834.

59. SB Syarifah Noratiqah, MS Zulfarina, SU Ahmad, S Fairus, I Naina Mohamed (2019) The pharmacological potential of oil palm phenolics (OPP) individual components. Int J Med Sci 16(5): 711–719.

60. KB Magalingam, P Ramdas, SD Somanath, KR Selvaduray, S Bhuvanendran, et al. (2022) Tocotrienol-Rich Fraction and Levodopa Regulate Proteins Involved in Parkinson's Disease-Associated Pathways in Differentiated Neuroblastoma Cells: Insights from Quantitative Proteomic Analysis. Nutrients 14(21): 4632.

61. H Ettakifi, Kaoutar Abbassi, Safae Maouni, El Hadi Erbiai, Abderrahmane Rahmouni, et al., (2023) Chemical Characterization and Antifungal Activity of Blue Tansy (Tanacetum annuum) Essential Oil and Crude Extracts against Fusarium oxysporum f. sp. albedinis, an Agent Causing Bayoud Disease of Date Palm. Antibiot (Basel Switzerland) 12(9): 1451.

62. NS Sulaiman, M D Sintang, S Mantihal, H M Zaini, E Munsu, et al. (2022) Balancing functional and health benefits of food products formulated with palm oil as oil sources. Heliyon 8(10): e11041.

63. RD Setiowati, FR Panjaitan, C Mardiana, MI Lubis (2024) Prospective oil palm (Elaeis sp) materials for high tocotrienol content in IOP Conference Series: Earth and Environmental Science 1308: 012050.

64. HS Izzah, M Karim, ASK Yong, JY Loh, Cyan, et al. (2026) Evaluating poultry fat and crude palm oil blends on growth performance, fatty acid profile, lipid metabolism and antioxidant capacity in juvenile Asian seabass (Lates calcarifer). Anim Feed Sci Technol 338.

65. X Li, Renlei Ji, Kun Cui, Qiuchi Chen, Qiang Chen, et al. (2019) High percentage of dietary palm oil suppressed growth and antioxidant capacity and induced the inflammation by activation of TLR-NF-κB signaling pathway in large yellow croaker (Larimichthys crocea). Fish Shellfish Immunol 87: 600–608.

66. Y Hao, Dezhou Sun, Xuejie Jiang, Anchi Zhang, Ruxin Ding, et al. (2026) Integrated proteomics and metabolomics profiling reveal mechanisms for the improvement of hoof health, liver function, and oxidative stress in lactating dairy cows fed rumen-protected biotin. J Dairy Sci 109(4): 4323–4340.

67. A Ruzicic, Tamara Dakic, Tijana Srdic, Iva Lakic, Sanja Stankovic, et al. (2025) Long-Term Intake of Oleic Acid-Rich Palm Oil Induces Obesity Without Impairing Hypothalamic Insulin Sensitivity and Redox Activity in Male Wistar Rats. BioFactors 51(4): e70036.

68. MA Absalome, Cisse Camara Massara, Ake Aké Alexandre, Koffi Gervais, Gauze Gnagne Agnero Chantal, et al. (2020) Biochemical properties, nutritional values, health benefits and sustainability of palm oil. Biochimie 178: 81–95.

69. NC Londoño, Nidia Casas Forero, Andres Felipe Garzón Méndez, Dalí Aleixandra Rojas Díaz, Mary Luz Olivares Tenorio, et al. (2026) Tocotrienols: A Review from Source to Therapeutic Applications. Food Front 7: 2.

70. MM Islam, R Rouf, JA Shilpi, BY Sheikh, MS Mubarak, et al. (2025) A comprehensive review on the neuropharmacological effects of Phoenix dactylifera and the potential role of its phenolic constituents. Food Biosci 66.

71. NN Uchegbu, K Oni, TM Olagunju (2022) Vernonia amygdalina processing as a functional ingredient: Oil-thermal influence on antioxidant, vitamin, mineral, and functional group retention. J Food Process Preserv 46: 10.

72. KT Teng, R Loganathan, BH Chew, TF Khang (2024) Diverse impacts of red palm olein, extra virgin coconut oil and extra virgin olive oil on cardiometabolic risk markers in individuals with central obesity: a randomised trial. Eur J Nutr 63(4): 1225–1239.

73. I Zulfahmi, Agung Setia Batubara, Adli Waliul Perdana, Alvi Rahmah, Badratun Nafis, et al. (2025) Chronic exposure to palm oil mill effluent induces oxidative stress and histopathological changes in zebrafish (Danio rerio). J Hazard Mater 490: 137844.

74. SNCM Zubaidi, SH Prof, ZM Kasini, NE Fazleen, V Thiruselvam, et al. (2021) Red Palm Oil Prevents Cognitive Impairment in a Rat Model of D-Galactose-Induced Aging. J Cell Mol Anesth 6(4): 294–305.

75. SA Shaikh, R Varatharajan, A Muthuraman (2022) Palm Oil Derived Tocotrienol-Rich Fraction Attenuates Vascular Dementia in Type 2 Diabetic Rats. Int J Mol Sci 23(21): 13531.

76. V Prathap, P Yadav, K Manorama, G Ravichandran, K Suresh, et al. (2025) Optimizing fatty acid composition and nutritional profile of palm oil-based blends for improved functional properties. J Food Meas Charact 19(4): 2861–2878.

77. N Hauzin, NM Hadzir, HAA Hamid, R Hasham, WNW Ibrahim (2024) Fabrication and Characterization of Water-In-Palm Oil Nanoemulsion as a Carrier for Catechin. Malaysian J Anal Sci 28 (2): 247–256.

78. A Habarakada, PABN Perumpuli, WTV Thathsaranee, IP Wanninaika (2021) Physical, chemical, and nutritional quality parameters of three different types of oil: Determination of their reusability in deep frying, Food Res 5(5): 226–235.

79. A García Pérez, JE Muñoz Hernández, C Guzmán Corona, A Cerón García, C Ozuna, et al. (2019) Performance of individual antioxidants and their blend during repeated frying of tortilla chips. J Food Process Preserv 43: 12.

80. MSC Zain, SY Lee, NM Nasir, S Fakurazi, K Shaari (2020) Metabolite characterization and correlations with antioxidant and wound healing properties of oil palm (Elaeis guineensis jacq.) leaflets via1 h-nmr-based metabolomics approach. Molecules 25(23): 5636.

81. X Xu, Pan Huang, Xuemei Cui, Xuefeng Li, Jiaying Sun, et al. (2022) Effects of Dietary Coated Lysozyme on the Growth Performance, Antioxidant Activity, Immunity and Gut Health of Weaned Piglets. Antibiotics 11(11): 1470.