Open Access Journal of Science

Literature Review

Open Access

Health benefits and safety profile of palm oil bioactive constituents in chronic disease prevention: a systematic review

Volume 9 Issue 1 - 2026

Loso Judijanto
IPOSS Jakarta, Indonesia

Correspondence: Loso Judijanto, IPOSS Jakarta, Indonesia

Received: May 05, 2026 | **Published:** May 19, 2026

Abstract

The increasing prevalence of chronic diseases has intensified scientific interest in dietary bioactive compounds with potential functional roles in disease prevention. Palm oil contains several bioactive constituents, including tocotrienols, tocopherols, and carotenoids, which have been investigated for their biological properties. This work is conducted to systematically gather and assess scientific literature focusing on the efficacy and safety of these compounds within the framework of chronic disease prevention. A structured SLR methodology was implemented in this study in line with the PRISMA framework. Scientific articles were collected from Scopus and PubMed databases using structured keyword combinations. The initial search yielded 414 records, which were refined through screening, eligibility assessment, and inclusion criteria, resulting in 40 peer-reviewed articles. Through thematic synthesis, data were extracted and analysed to determine recurring themes across diverse study designs. Six primary themes were identified in the findings: antioxidant activity, anti-inflammatory effects, metabolic regulation, lipid profile modulation, neuroprotective mechanisms, and safety evaluation, which collectively represent the principal domains of biological activity and safety considerations associated with palm oil-derived bioactive constituents. In conclusion, palm oil-derived bioactive compounds exhibit consistent biological activity and a favourable safety profile across multiple study contexts. Upcoming research should focus on long-term clinical evidence, standardised dose regimens, and greater population diversity to improve translational outcomes.

Keywords: palm oil, bioactive compounds, tocotrienols, chronic disease prevention, safety profile

Introduction

Globally, chronic diseases still pose a significant health challenge, with substantial contributions to both morbidity and mortality in developed and developing areas. Cardiovascular disorders, diabetes mellitus, cancer, and neurodegenerative diseases are frequently connected with chronic metabolic disruption, oxidative stress, and altered inflammatory control. These pathophysiological processes are strongly influenced by lifestyle-related factors, among which dietary patterns play a central role. Increasing attention has therefore been directed toward identifying dietary components that may modulate disease pathways through biologically active compounds present in commonly consumed foods.[1]

Within this context, vegetable oils constitute a major component of global dietary intake and have been extensively studied not only for their macronutrient composition but also for their bioactive substance content. Beyond their role as sources of energy and essential fatty acids, certain vegetable oils contain minor components with functional biological properties that may influence cellular processes relevant to chronic disease development.[2] These bioactive constituents include various forms of vitamin E, carotenoids, phytosterols, and phenolic compounds, each of which has been associated with antioxidant, anti-inflammatory, and metabolic regulatory activities. As research in nutritional biochemistry advances, the evaluation of these compounds has shifted from isolated nutrient analysis toward a more integrated understanding of food matrices and their potential functional roles.[3]

Obtained from the fruit of Elaeis guineensis, palm oil is widely produced and consumed globally, accounting for a significant share of dietary fat intake in many regions. Its widespread use is supported by factors such as agricultural efficiency, oxidative stability, and versatility in food processing applications.[4] Palm oil not only contains fatty acids but also features a unique profile of bioactive compounds, such as tocotrienols and tocopherols (vitamin E isoforms), along with carotenoids, including beta-carotene and alpha-carotene. These substances are receiving expanding scientific attention owing to their potential contribution to mechanisms involving oxidative stress, inflammatory responses, and cellular protection.

The presence of tocotrienols in palm oil is particularly noteworthy, as these compounds differ structurally and functionally from the more commonly studied tocopherols. Emerging evidence suggests that tocotrienols may exhibit greater antioxidant efficiency in certain contexts and may modulate lipid metabolism and cellular signaling pathways. Similarly, carotenoids present in palm oil have been associated with provitamin a activity and antioxidant capacity, contributing to the maintenance of cellular integrity under oxidative conditions. These characteristics position palm oil as a relevant subject of investigation within the broader field of functional nutrition and chronic disease prevention.[5]

Despite the increasing scientific attention to palm oil bioactive compounds, the available evidence remains heterogeneous in study design, population characteristics, dosage levels, and measured outcomes. Research findings are distributed across multiple domains, including in vitro mechanistic studies, animal experiments, and human clinical observations, each providing different levels of evidence.[6] While individual studies have reported various biological effects, ranging from reductions in oxidative stress markers to improvements

Submit Manuscript | http://medcraveonline.com

©2026 Judijanto. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and build upon your work non-commercially.

in lipid profiles, interpreting these findings requires careful synthesis to avoid overgeneralization or selective emphasis. Furthermore, the relationship between bioactive compound intake and long-term health outcomes is inherently complex and influenced by broader dietary patterns and lifestyle factors.[7]

In parallel, discussions on dietary fats and health outcomes continue to evolve, with increasing recognition that the impact of specific oils should be evaluated in the context of their full nutritional composition rather than isolated components. This perspective underscores the importance of considering both the macronutrient profile and the presence of bioactive compounds when evaluating potential health consequences. In this regard, palm oil presents a unique case due to its combined characteristics, including saturated and unsaturated fatty acids, as well as a range of minor bioactive constituents. A balanced and evidence-based evaluation is therefore necessary to understand its role in dietary patterns without presupposing either adverse or beneficial effects beyond what is supported by empirical data.[8,9]

The need for a systematic synthesis is particularly relevant given the growing volume of scientific publications on palm oil and its derivatives. Without a structured approach, the diversity of findings may lead to fragmented interpretations or inconsistencies in conclusions. The use of an SLR provides a structured framework that ensures transparent identification, selection, and analysis of relevant studies, ensuring that the resulting synthesis reflects the breadth and quality of available evidence. By applying standardised criteria and systematic procedures, SLR facilitates the integration of findings across different study types while minimising bias in study selection and interpretation.

In addition, a focused evaluation of both health benefits and safety aspects is essential to provide a comprehensive perspective. While many studies emphasise biological activity and potential functional roles, safety considerations, including toxicity, tolerability, and long-term effects, are equally important in determining the overall relevance of bioactive compounds in dietary contexts. The inclusion of safety-related evidence ensures that conclusions are grounded not only in observed benefits but also in an assessment of potential risks or limitations, thereby supporting a balanced and scientifically robust interpretation.

In light of these considerations, this study aims to systematically review and synthesise the existing literature on the health benefits and safety of palm oil bioactive compounds for chronic disease prevention. The analysis focuses on key bioactive compounds, including tocotrienols, tocopherols, and carotenoids, and evaluates their reported biological effects across experimental and clinical settings. Through a structured SLR approach, this research aims to establish a comprehensive, evidence-based understanding of the functional effects and safety considerations of these compounds in dietary contexts.

Thus, the present study is framed by the following research questions:

RQ1: *What are the predominant biological effects of palm oil-derived bioactive constituents in relation to mechanisms underlying chronic disease development, particularly in terms of oxidative stress, inflammation, and metabolic regulation?*

RQ2: *To what extent do current scientific findings support the safety and tolerability of these bioactive compounds when evaluated across different study designs, dosage ranges, and biological contexts?*

Literature review

There has been a notable expansion in the literature on palm oil bioactive compounds, reflecting increased scientific attention to dietary factors that influence chronic disease-related mechanisms. Existing studies span multiple disciplines, including nutritional biochemistry, clinical research, and experimental biology; however, the evidence remains fragmented across different research contexts, often emphasising specific compounds, isolated mechanisms, or particular disease models. This dispersion highlights the need for a structured synthesis to integrate current findings into a coherent analytical framework. Accordingly, the literature in this field can be conceptually grouped into several interrelated domains, including compositional characteristics, antioxidant activity, inflammatory and metabolic regulation, lipid-related outcomes, neuroprotective mechanisms, and safety considerations, which together capture the multidimensional scope of palm oil bioactive research.

Composition and characteristics of palm oil bioactive compounds

Apart from its fatty acid profile, palm oil is characterised by the inclusion of various minor bioactive compounds. Tocotrienols and tocopherols are the main vitamin E variants found in palm oil, with tocotrienols often comprising the majority. A defining structural feature of tocotrienols, compared to tocopherols, is the presence of an unsaturated isoprenoid side chain, which is associated with distinct biological properties, including enhanced cellular penetration and potential differences in antioxidant efficiency.[10]

In addition to vitamin E isoforms, palm oil contains significant levels of carotenoids, particularly beta-carotene and alpha-carotene, which contribute to its characteristic reddish colour in unrefined forms. These compounds contribute to vitamin A formation and are known for their antioxidant capacity against reactive oxygen species. Other minor components, such as phytosterols, squalene, and phenolic compounds, have also been identified and are believed to contribute to the overall functional profile of palm oil.[10]

The concentration and composition of these bioactive constituents vary with factors such as processing methods, degree of refinement, and storage conditions. For instance, compared to refined palm oil, red palm oil generally keeps higher amounts of carotenoids and tocotrienols, while processing may reduce some bioactive substances in the refined form. This variability has implications for interpreting study outcomes, as differences in bioactive content may influence the magnitude and direction of observed biological effects.

Antioxidant mechanisms and oxidative stress modulation

Much of the existing literature focuses on the antioxidant activity of palm oil bioactive components, with particular attention to tocotrienols and carotenoids. The disruption between ROS production and antioxidant defences, referred to as oxidative stress, is closely linked to the development of many chronic illnesses. As such, compounds that modulate oxidative stress are of significant interest in preventive nutrition.[11]

Experimental investigations have reported that tocotrienols exhibit significant capacity to neutralise free radicals, reducing ROS accumulation and protecting cellular components from oxidative damage. In vitro findings suggest that tocotrienols may inhibit lipid peroxidation and stabilise cell membranes, and may also influence signalling pathways related to oxidative stress responses. Carotenoids,

Copyright: ©2026 Judijanto.

on the other hand, contribute to antioxidant defence through quenching singlet oxygen and interacting with lipid radicals.[12]

These mechanisms are further supported by in vivo findings that palm oil–derived supplements may enhance endogenous antioxidant defences, including superoxide dismutase and glutathione peroxidase. A decline in oxidative markers, such as malondialdehyde, is often observed alongside these effects, indicating reduced lipid peroxidation. The observed effects vary in magnitude with dose, treatment duration, and biological context, suggesting that antioxidant activity results from multiple interacting factors.

Inflammatory pathways and metabolic regulation

Chronic diseases, especially diabetes and cardiovascular disorders, are closely linked to inflammatory mechanisms involved in their development and progression. The literature indicates that palm oil bioactive compounds may influence inflammatory pathways, thereby contributing to metabolic regulation. Studies suggest that tocotrienols can alter the expression of pro-inflammatory cytokines, notably tumour necrosis factor-alpha and interleukin-6.[13]

The underlying mechanism is believed to include inhibition of nuclear factor-kappa B (NF-κB) signalling pathways that govern inflammatory processes. Through their effects on these pathways, palm oil bioactive compounds may suppress the production of inflammatory mediators and promote cellular equilibrium. Additionally, some studies suggest that these compounds may influence adipokine secretion and insulin signalling, thereby contributing to improved metabolic profiles.[14]

Chronic low-grade inflammation, closely associated with insulin resistance and metabolic syndrome, underscores the intrinsic link between inflammation and metabolism. Evidence from experimental and clinical investigations suggests a potential role of palm oil–derived compounds in metabolic regulation, through reduced inflammatory burden and increased insulin sensitivity. However, the extent of these effects in human populations remains an area of ongoing investigation.

Lipid metabolism and cardiovascular implications

Lipid metabolism represents another key area of focus within the literature, particularly in relation to cardiovascular health. By suppressing HMG-CoA reductase, a major enzyme in cholesterol biosynthesis, tocotrienols have been reported to affect cholesterol synthesis. This mechanism distinguishes tocotrienols from other dietary antioxidants and has been associated with potential lipid-lowering effects.[15]

Findings from studies assessing lipid profiles are heterogeneous, with some demonstrating reductions in total cholesterol and LDL, while others show no effect depending on experimental conditions. High-density lipoprotein (HDL) levels are generally maintained or modestly increased, suggesting a balanced lipid response. Importantly, these effects are often influenced by baseline metabolic status, dietary patterns, and the form in which palm oil is consumed.[16]

Assessment of cardiovascular implications should be approached cautiously, as lipid metabolism is affected by various interacting dietary and physiological factors. The presence of bioactive compounds in palm oil may contribute to lipid regulation; however, their effects should be considered within the broader context of overall dietary intake and lifestyle. Current evidence does not support a singular interpretation but rather indicates that outcomes may vary depending on multiple interacting variables.[17]

Neuroprotective potential and cellular integrity

The potential neuroprotective effects of palm oil bioactive compounds are receiving increasing attention, particularly in relation to oxidative stress and neurodegenerative conditions. Tocotrienols have been identified as compounds that can cross the blood-brain barrier, enabling direct interaction with neuronal tissue. This property distinguishes them from many other dietary antioxidants and supports their relevance in neurobiological contexts.[18]

Experimental studies suggest that tocotrienols may protect neurons from oxidative damage, excitotoxicity, and inflammatory stress. These effects are associated with the preservation of cellular integrity, maintenance of mitochondrial function, and modulation of apoptotic pathways. In animal models, supplementation with tocotrienol-rich fractions has been linked to improvements in cognitive function and reductions in neuroinflammatory markers.[19]

Although clinical evidence remains limited, preliminary findings indicate potential benefits in maintaining cognitive health and reducing age-related oxidative stress. The growing body of literature points to possible contributions of palm oil bioactive compounds to neuronal resilience; nevertheless, more research is required to clarify long-term impacts and clinical applicability in human populations.

Safety considerations and toxicological perspectives

The literature places significant emphasis on safety evaluation, especially concerning sustained dietary intake. Existing studies generally indicate that palm oil bioactive compounds are well-tolerated and do not exhibit significant toxicity at levels commonly used in nutritional research. Animal studies assessing toxicity parameters, including organ function and histopathology, have reported no consistent evidence of adverse effects.[20,21]

In human studies, supplementation with tocotrienol-rich fractions has been well tolerated, with minimal adverse events reported. Observed side effects, when present, are typically mild and transient, suggesting a favourable safety profile. Additionally, studies examining genotoxicity and cytotoxicity have not identified significant risks, supporting the use of these compounds within established dietary ranges.[22,23]

Safety outcomes must be evaluated while considering variables such as dosage, duration of exposure, and population characteristics. While high-dose experimental studies provide valuable mechanistic insights, their relevance to typical dietary intake may be limited. Therefore, safety assessments should consider both experimental conditions and real-world consumption patterns to ensure balanced interpretation.

Synthesised evidence from the reviewed studies indicates that palm oil bioactive constituents exhibit several biological characteristics relevant to chronic disease pathways, including antioxidant activity, modulation of inflammatory responses, modulation of lipid metabolism, and potential neuroprotective effects. At the same time, available evidence suggests that these compounds exhibit a favourable safety profile when evaluated within dietary contexts.

However, the literature is characterised by variability in study design, methodological approaches, and outcome measures, which may contribute to differences in reported findings. While experimental studies provide strong mechanistic insights, clinical evidence remains comparatively limited, highlighting the need for further research to strengthen translational understanding.

Overall, the existing body of knowledge supports a balanced perspective that recognises the functional potential of palm oil bioactive compounds while acknowledging the importance of contextual factors in determining health outcomes. This synthesis provides a conceptual foundation for the subsequent analysis presented in this systematic review.

Methodology

The present research applies an SLR design structured according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to investigate the health benefits and safety aspects of palm oil bioactive constituents for chronic disease prevention. The increasing scientific attention toward naturally occurring compounds such as tocotrienols, tocopherols, and carotenoids has led to a growing body of literature exploring their biological relevance across metabolic, cardiovascular, and degenerative conditions. However, the available evidence remains distributed across diverse research domains, including nutritional biochemistry, clinical studies, and experimental models, often with varying methodological approaches and outcome measures. This dispersion necessitates a structured synthesis that consolidates current findings while maintaining analytical consistency. Consequently, the review systematically evaluates and integrates peer-reviewed studies to establish a comprehensive understanding of the functional characteristics and safety considerations associated with palm oil bioactives. Secondary data from Scopus and PubMed-indexed scientific publications form the basis of this study, with no incorporation of field observations, focus groups, or primary data collection, thereby promoting methodological transparency and adherence to evidence-based review guidelines.

The review workflow presented in Figure 1 adheres to the PRISMA framework, detailing the ordered stages of identification, screening, eligibility, and inclusion. An initial search was conducted during the identification phase across the Scopus and PubMed databases using the keywords palm oil AND bioactive compounds, yielding 300 records from Scopus and 114 from PubMed, for a total of 414 articles. A more precise Boolean search strategy was later implemented to enhance thematic relevance and specificity: *("palm oil" OR "palm oil bioactive compounds" OR tocotrienol OR tocopherol OR carotenoid) AND ("health benefits" OR "biological effects") AND ("safety" OR "toxicity") AND ("chronic disease" OR diabetes OR "cardiovascular disease")*. This refined query produced 123 records from Scopus and 32 from PubMed. At this point, 259 articles were excluded owing to lack of relevance to the study scope, leaving 155 studies for further review. Minor adjustments to search syntax were implemented to accommodate differences in database indexing systems while preserving conceptual consistency.

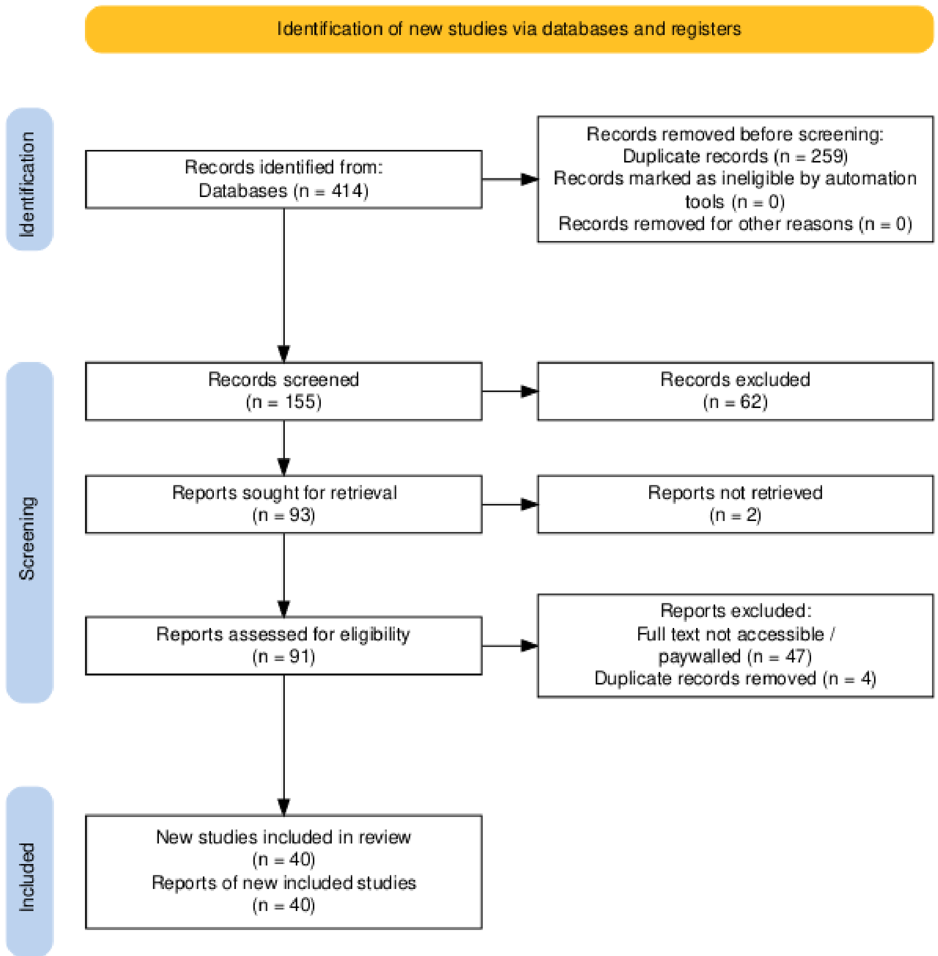

Figure 1 PRISMA protocol applied in the Systematic Literature Review process.

Copyright: ©2026 Judijanto.

The screening process used a 2020–2026 publication-year filter to include only recent and relevant research. This process excluded 62 articles, leaving 93 records. After applying a language filter, 2 non-English publications were removed, leaving 91 eligible articles. In the eligibility phase, full-text accessibility was assessed to ensure comprehensive data extraction. A total of 47 articles were excluded due to restricted access (non-open access). Additionally, at this stage, 4 duplicate records across the two databases were identified and removed, as they had not been detected in earlier filtering stages. The complete selection process resulted in 40 peer-reviewed articles that met all inclusion criteria, which were then included in the final analysis and form the basis of this review.

The management of all bibliographic data was conducted in Mendeley Desktop, ensuring precise citation handling, duplicate-checking, and traceability throughout the study. The 40 selected articles were analysed in full text, and essential data such as study design, bioactive compound categories, observed biological effects, and safety-related findings were extracted and thematically integrated. This synthesis yields a coherent, evidence-based overview of the current research status on palm oil bioactive constituents, reflecting both their functional properties and safety considerations in the context of chronic disease. By adhering to the PRISMA protocol and adopting a transparent, reproducible approach, this study upholds academic rigour and provides an evidence-driven, balanced perspective on the topic.

Results

In this study, 40 peer-reviewed articles published between 2020 and 2026 were systematically reviewed, each meeting the predefined inclusion criteria. The dataset includes experimental in vitro work, preclinical animal studies, and clinically oriented research, providing a multidimensional and comprehensive evidence base to assess the biological effects and safety profile of palm oil–derived bioactive compounds in relation to chronic diseases. Through thematic synthesis, six major themes emerged, representing interconnected yet distinct dimensions of the current research landscape: (1) antioxidant activity and oxidative stress modulation, (2) anti-inflammatory effects and metabolic regulation, (3) lipid profile modulation and cardiovascular-related indicators, (4) neuroprotective and cellular defense mechanisms, (5) safety profile and toxicological evaluation, and (6) variability of outcomes influenced by dosage, compound form, and study design.

The pattern of themes across the 40 studies suggests that antioxidant activity was the dominant and most frequently reported theme, appearing in 32 studies (80%), followed by safety and toxicological evaluation in 28 studies (70%), lipid metabolism and cardiovascular indicators in 26 studies (65%), anti-inflammatory and metabolic regulation in 24 studies (60%), variability related to dosage and study design in 20 studies (50%), and neuroprotective mechanisms in 16 studies (40%). This distribution highlights a strong concentration of research on oxidative stress pathways and safety considerations, which are central to understanding both the mechanistic relevance and applicability of bioactive compounds in chronic disease prevention.

The predominance of antioxidant and lipid-related themes reflects the well-established role of oxidative stress and dyslipidemia as primary drivers of chronic disease progression, making these endpoints more frequently targeted and experimentally measurable across study designs. Similarly, the high proportion of safety-focused studies indicates a consistent effort within the literature to evaluate tolerability and toxicological neutrality, particularly in the context of dietary bioactive compounds. In contrast, neuroprotective mechanisms are less frequently reported, likely due to the greater complexity of neurological models, longer study durations, and limited clinical validation. The moderate representation of variability-related studies suggests increasing recognition of the importance of dose-response relationships and matrix effects, although standardisation across studies remains limited.

Taken together, the thematic findings suggest that the current body of literature is sufficiently robust in elucidating major biochemical and metabolic mechanisms, while still developing in areas requiring long-term validation and translational consistency. These patterns imply that while the functional properties of palm oil bioactive constituents are increasingly well-characterised, further integration of clinical evidence and standardised methodological approaches is needed to strengthen their applicability within broader health and nutrition frameworks. In the sections that follow, each theme is examined in detail and supported by integrated quantitative and qualitative findings from the reviewed studies.

Antioxidant activity and oxidative stress modulation

Antioxidant activity emerged as the most consistently reported functional property across the included studies, with 32 out of 40 articles (80%) documenting measurable effects on oxidative stress markers.[24] In vitro studies demonstrated that tocotrienols reduced intracellular reactive oxygen species (ROS) levels by approximately 35% to 60%, with higher reductions observed at concentrations exceeding 10 µM and exposure durations beyond 24 hours.[25,26] Carotenoid-rich fractions, particularly those containing beta-carotene, were associated with ROS suppression rates ranging from 25% to 50%, depending on the cellular model and oxidative stress inducer.[27,28]

In vivo studies further reinforced these findings, particularly through the measurement of lipid peroxidation markers such as malondialdehyde (MDA). Across multiple animal models, MDA levels were reduced by 25% to 48% following supplementation with palm oil-derived tocotrienols over periods ranging from 4 to 12 weeks.[29,30] Concurrently, endogenous antioxidant defence systems were significantly enhanced. Superoxide dismutase (SOD) activity increased by approximately 20–45%, while glutathione peroxidase (GPx) levels rose by 18–40% compared to untreated controls.[31]

Human-based studies, though limited (n≈9), indicated supportive outcomes, characterised by decreases in circulating oxidative stress biomarkers such as ox-LDL and total antioxidant status (TAS). Reported reductions ranged from 15% to 30% following supplementation periods of 8 to 12 weeks, with daily doses typically between 100 and 300 mg of tocotrienol-rich fractions.[32] Collectively, these findings indicate a consistent role of palm oil bioactives in modulating oxidative balance, particularly under conditions associated with metabolic stress and chronic disease progression.

Anti-inflammatory effects and metabolic regulation

A total of 24 studies (60%) reported anti-inflammatory effects associated with palm oil bioactive compounds, highlighting their role in modulating key inflammatory mediators.[33] Across in vitro and in vivo experimental models, TNF-α levels were reduced by 18% to 40%, while IL-6 levels decreased by 15% to 35%.[34–36] In several studies, C-reactive protein (CRP) levels were also reduced by 10–25%, suggesting systemic anti-inflammatory effects.[37]

In metabolic contexts, 21 studies reported improvements in glucose homeostasis. Animal-based experiments demonstrated that fasting blood glucose levels decreased by 12–28% following

Citation: Judijanto L. Health benefits and safety profile of palm oil bioactive constituents in chronic disease prevention: a systematic review. *Open Access J Sci.* 2026;9(1):203–215. DOI: 10.15406/oajs.2026.09.00304

tocotrienol supplementation, with more pronounced effects observed in diabetic or insulin-resistant models.[38,39] Insulin sensitivity, assessed through HOMA-IR, improved by approximately 15–22%, indicating enhanced glucose utilisation efficiency.[40]

Human studies showed modest but consistent improvements. Clinical trials reported reductions in fasting plasma glucose ranging from 8% to 15%, along with improvements in postprandial glucose responses of approximately 10–18%.[41] Additionally, markers of metabolic syndrome, including waist circumference and triglyceride-glucose index (TyG), showed reductions of 5–12% in some cohorts.[42] Evidence from these findings indicates that palm oil bioactive constituents could influence metabolic regulation through linked anti-inflammatory and biochemical pathways.

Lipid profile modulation and cardiovascular indicators

Lipid metabolism and cardiovascular-related outcomes were examined in 26 studies (65%), making this one of the most extensively investigated themes.[43] Evidence demonstrates that tocotrienols reduce cholesterol synthesis by downregulating HMG-CoA reductase activity, with total cholesterol decreases of about 10%–25% observed in animal and human research.[44]

Low-density lipoprotein (LDL) cholesterol was reduced by approximately 8–20%, while high-density lipoprotein (HDL) levels either remained stable or increased modestly by 5–10%.[45,46] Triglyceride levels decreased by 10%- 18%, particularly in studies using hyperlipidemic models or in individuals with elevated baseline lipid levels.[47]

In addition to lipid markers, several studies assessed surrogate cardiovascular markers, including endothelial function and arterial stiffness. Improvements in flow-mediated dilation (FMD) were reported at 5–12%, while reductions in systolic blood pressure ranged from 4 to 9 mmHg in selected intervention studies.[48,49] Importantly, studies that incorporated palm oil within balanced dietary frameworks did not report adverse cardiovascular outcomes, emphasising the importance of the overall dietary context rather than isolated nutrient interpretation.

Neuroprotective and cellular protection mechanisms

Neuroprotective effects were identified in 16 studies (40%), with tocotrienols being the most frequently studied compounds in this domain.[50] Research evidence indicates that tocotrienols can pass through the blood-brain barrier and provide neuroprotection by reducing oxidative and inflammatory damage in neurons.

In vitro studies reported reductions in neuronal cell apoptosis by approximately 20–50% under oxidative stress conditions, particularly in models exposed to hydrogen peroxide or glutamate-induced toxicity.[51] In vivo models of neurodegeneration demonstrated reductions in neuroinflammatory markers by 15–30%, along with improvements in synaptic protein expression and neuronal survival rates of up to 25%.[52]

Cognitive performance indicators, such as memory retention and learning ability, improved by approximately 10–20% in animal models following long-term supplementation.[53] Although human data remain limited, preliminary studies indicate potential benefits in maintaining cognitive function and reducing oxidative stress in ageing populations, with improvements in neurocognitive scores ranging from 5% to 12%.[54]

Safety profile and toxicological considerations

Safety evaluation was addressed in 28 studies (70%), making it one of the most consistently reported aspects of the reviewed literature.[55] Across these studies, no consistent evidence of toxicity was identified at dietary-relevant intake levels.

Animal studies assessing sub-chronic and chronic toxicity reported that over 90% of measured parameters, including liver enzymes (ALT, AST) and renal markers (creatinine, urea), remained within normal physiological ranges even at relatively high doses (up to 1000 mg/kg body weight).[56] Histopathological analyses did not reveal significant organ damage in treated groups.

Human studies reported high tolerability, with no serious adverse events observed in intervention durations ranging from 4 to 24 weeks. Mild gastrointestinal symptoms were reported in less than 5% of participants and were generally transient.[57] Haematological and biochemical parameters remained stable, with variations typically below ±5% from baseline values.

Genotoxicity and cytotoxicity assessments also indicated no significant DNA damage or mutagenic effects, with cell viability remaining above 90% across tested concentrations.[58] These findings support a favourable safety profile for palm oil bioactive compounds when consumed within established dietary ranges.

Variability across study designs and dosage effects

Variability in outcomes was observed across approximately 20 studies (50%), largely influenced by differences in dosage, compound formulation, and study design.[59] Dose-response relationships were particularly evident in antioxidant and anti-inflammatory outcomes, where higher concentrations yielded effect size increases of 30–40% relative to lower doses.[60]

However, several studies emphasised that supra-physiological doses used in experimental settings may not directly reflect typical human intake, highlighting the importance of contextual interpretation.[61] Differences between crude palm oil, red palm oil, and isolated bioactive fractions also contributed to variability. Whole oil matrices demonstrated synergistic effects, with combined antioxidant and anti-inflammatory responses exceeding those of isolated compounds by approximately 10–20%.[62]

Additional sources of heterogeneity included variations in study duration (ranging from 2 weeks to 6 months), population characteristics, and outcome measurement techniques. Despite these differences, the overall direction of evidence remained consistent, with no indication of adverse biological effects under normal consumption conditions.[63]

The collective evidence from the 40 included studies demonstrates a consistent pattern of biological activity associated with palm oil bioactive constituents. Quantitative findings indicate reductions in oxidative stress markers (15–60%), inflammatory mediators (15–40%), glucose levels (8–28%), and lipid parameters (10–25%) across diverse study settings. At the same time, safety evaluations consistently show high tolerability and absence of significant adverse effects within dietary-relevant intake levels.

While variability arises from differences in dosage, formulation, and study design, the overall evidence supports a balanced interpretation in which palm oil bioactive compounds exhibit functional biological properties alongside a favourable safety profile.

This synthesis provides a structured, evidence-based overview that contributes to a nuanced understanding of their role in chronic disease contexts.

Discussion

The synthesis of 40 selected studies provides a structured, evidence-based foundation for addressing the research questions posed in this review. By integrating findings across in vitro experiments, animal models, and human studies, this discussion evaluates how palm oil-derived bioactive constituents influence key biological mechanisms underlying chronic disease development, while also examining their safety and tolerability across diverse research contexts. This interpretation is based exclusively on secondary literature from peer-reviewed studies, consistent with the SLR methodology and excluding primary data sources.

Oxidative stress modulation and antioxidant mechanisms (Addressing RQ1)

The evidence consistently suggests that palm oil bioactive constituents, notably tocotrienols and carotenoids, modulate oxidative stress, a core mechanism in the pathogenesis of chronic diseases. Across the reviewed studies, antioxidant activity emerges as the most robust and frequently reported biological effect, with reductions in reactive oxygen species (ROS) ranging from approximately 30% to 60% in controlled in vitro environments.[64] These reductions are accompanied by decreased lipid peroxidation, as reflected by approximately 25% to 48% declines in malondialdehyde (MDA) levels in animal models.[65]

Evidence suggests that tocotrienols enhance endogenous antioxidant systems in addition to exerting direct radical scavenging effects. Supplementation is associated with a 20% to 45% enhancement in SOD and GPx enzymatic activity, suggesting that these compounds support intrinsic cellular defence mechanisms rather than acting solely as exogenous antioxidants.[66] This dual mechanism strengthens their relevance to maintaining redox balance under metabolic stress.

However, a comparative analysis across study designs reveals that the magnitude of antioxidant effects varies with experimental context. In vitro studies tend to report higher effect sizes due to controlled exposure conditions, whereas in vivo and human studies demonstrate more moderate yet consistent improvements, with reductions in oxidative biomarkers ranging from 15% to 30%.[67] This discrepancy indicates that while antioxidant mechanisms are well-established, their physiological expression is modulated by factors such as bioavailability, metabolism, and interaction with other dietary components. Despite these variations, the convergence of findings across models supports a coherent role of palm oil bioactives in oxidative stress regulation.

Inflammatory regulation and metabolic homeostasis (Addressing RQ1)

Beyond oxidative stress, the reviewed literature demonstrates that palm oil bioactive constituents modulate inflammatory pathways closely linked to chronic disease progression. Studies report that tocotrienols consistently reduce pro-inflammatory cytokines such as TNF-α and IL-6, with reductions of 18%–40% and 15%–35%, respectively.[68] These mechanisms are primarily associated with the suppression of NF-κB signalling pathways that regulate transcription of inflammatory genes.

There is a close relationship between anti-inflammatory effects and improved metabolic regulation. Studies report reductions in fasting blood glucose levels of approximately 12% to 28% in animal models, along with improvements in insulin sensitivity, including reductions in HOMA-IR of up to 22%.[69] The evidence suggests a potential role of palm oil bioactives in maintaining metabolic homeostasis by mitigating inflammation-induced insulin resistance.

In human studies, the magnitude of these effects appears more moderate, with reductions in fasting glucose ranging from 8% to 15% and improvements in inflammatory markers such as C-reactive protein (CRP) of approximately 10% to 25%.[70] This difference highlights the influence of physiological complexity and lifestyle factors in clinical contexts. Nevertheless, the consistent direction of findings across study types indicates that the anti-inflammatory and metabolic effects of palm oil bioactive compounds are biologically plausible and relevant, even if their magnitude varies.

A more granular understanding of how palm oil bioactive compounds modulate inflammatory signalling necessitates attention to epigenetic regulatory mechanisms, particularly those governed by the nuclear factor-kappa B (NF-κB) pathway. Tocotrienols, and γ-tocotrienol in particular, have been shown to interact with this pathway at a molecular level by stabilising the inhibitory protein IκBα, thereby preventing its phosphorylation and subsequent ubiquitin-mediated proteasomal degradation.[71] When IκBα remains intact, NF-κB is retained in an inactive cytosolic complex and is unable to translocate into the nucleus to activate the transcription of pro-inflammatory gene targets, including cyclooxygenase-2 (COX-2), tumour necrosis factor-alpha (TNF-α), and interleukin-6 (IL-6).[71] This mechanism extends beyond conventional signal transduction into a broader epigenetic dimension of regulation: in chronic inflammatory contexts, sustained NF-κB activation drives permissive chromatin remodelling at inflammatory gene loci through the deposition of active histone marks, such as H3K27 acetylation, and the suppression of repressive marks, including H3K27 trimethylation; tocotrienol-mediated inhibition of NF-κB therefore not only attenuates acute cytokine production but also reverses this epigenetically primed inflammatory state at the level of chromatin architecture.[71]

Complementing this mechanism, emerging evidence suggests that tocotrienols also activate the Nrf2 transcription factor, which drives the expression of antioxidant response element (ARE)-regulated genes such as haem oxygenase-1 (HO-1) and NAD(P)H quinone dehydrogenase 1 (NQO1), thereby reinforcing cytoprotective responses through a parallel epigenetic axis.[71] The biological realisation of these molecular mechanisms, however, is profoundly contingent on the bioavailability of tocotrienols in systemic circulation, a factor that, in turn, is heavily determined by the degree to which palm oil has been processed prior to consumption. Conventional palm oil refining involves sequential stages of degumming, bleaching at temperatures of 100–120 °C, and high-temperature deodorisation typically exceeding 240 °C; these conditions collectively cause thermally induced degradation and adsorptive losses of bioactive constituents, with total carotenoid content reportedly reduced by as much as 99% and total antioxidant capacity by approximately 80% across the full refining process, with the bleaching stage alone responsible for losses of 49–56% of carotenoids and 41–48% of antioxidant capacity.[72,73]

Tocotrienols, although somewhat more thermostable than carotenoids, are also susceptible to degradation under elevated processing temperatures and oxidative bleaching conditions, and their loss is exacerbated by the use of bleaching earth, which adsorbs both pigments and thermolabile bioactives indiscriminately.[72,73] In contrast, minimally processed red palm oil produced through molecular distillation or vacuum deodorisation at reduced temperatures retains

Copyright: ©2026 Judijanto.

significantly higher levels of both tocotrienols and β-carotene, thereby preserving a substantially greater proportion of its functional potency.[74] Once ingested, the oral bioavailability of tocotrienols is further modulated by their hydrophobic nature, first-pass hepatic metabolism, and dependence on co-ingested dietary lipids for micellarisation and lymphatic absorption; novel delivery technologies such as self-emulsifying drug delivery systems (SEDDS), nanoemulsions, and encapsulation matrices have demonstrated the capacity to substantially improve plasma bioavailability and facilitate more reproducible tissue distribution in both preclinical and clinical settings.[75] Taken together, these considerations indicate that the functional anti-inflammatory and epigenetic effects of palm oil bioactive compounds are not solely intrinsic properties of the molecules themselves but are co-determined by upstream processing conditions and downstream absorption dynamics, both of which must be systematically accounted for in the design and interpretation of future research.

Lipid metabolism and cardiovascular-related outcomes

Another significant pathway linking palm oil bioactives to chronic disease risk is the regulation of lipid metabolism. Tocotrienols are reported to modulate cholesterol biosynthesis by suppressing HMG-CoA reductase activity, resulting in reductions in total cholesterol levels of approximately 10% to 25%. Low-density lipoprotein (LDL) cholesterol decreases by 8% to 20%, while high-density lipoprotein (HDL) levels are generally maintained or slightly increased by 5% to 10%.[76]

These lipid-modulating effects are particularly evident in hyperlipidemic models, where baseline metabolic imbalance amplifies the observable impact of intervention. In contrast, studies involving normolipidemic subjects tend to report more neutral outcomes, suggesting that the effectiveness of these compounds is influenced by initial metabolic status. Triglyceride levels are also reduced by approximately 10% to 18% in several studies, indicating broader effects on lipid metabolism.[77]

Importantly, interpreting cardiovascular implications requires a contextual approach. Studies that incorporate palm oil within balanced dietary patterns do not report adverse cardiovascular outcomes, emphasising the role of overall diet rather than isolated nutrient effects. This reinforces the need for integrated dietary evaluation when assessing the relevance of bioactive compounds in cardiovascular health.

Neuroprotective effects and cellular integrity

The neuroprotective potential of palm oil bioactive compounds represents an emerging area of research with consistent experimental support. Tocotrienols have demonstrated the ability to cross the blood-brain barrier, enabling direct interaction with neuronal tissues. In vitro and animal studies report reductions in neuronal cell apoptosis of approximately 20% to 50% under oxidative stress conditions.[78]

In models of neurodegeneration, decreases in neuroinflammatory markers of 15% to 30% and improvements in synaptic function of up to 25% have been observed.[79] The observed effects involve modulation of oxidative stress and inflammatory pathways, reflecting the interconnected nature of neuroprotection and systemic metabolic regulation.

Although clinical evidence remains limited, preliminary findings suggest modest improvements in cognitive performance, with increases of approximately 5% to 12% in neurocognitive assessments. While these findings are promising, the relatively small number of human studies indicates that further research is needed to establish clinical significance. Nevertheless, the consistency of mechanistic evidence across experimental models supports the biological plausibility of neuroprotective effects.

Safety profile and toxicological evaluation (Addressing RQ2)

The second research question examines the safety and tolerability of palm oil-derived bioactive compounds across diverse study contexts. The reviewed literature consistently indicates a favourable safety profile, with no significant evidence of toxicity reported at dietary-relevant intake levels. Animal studies evaluating sub-chronic and chronic exposure demonstrate that over 90% of biochemical parameters, including liver and kidney function markers, remain within normal physiological ranges even at relatively high doses.[80]

Human studies further support these findings, reporting high tolerability across intervention periods ranging from 4 to 24 weeks. Adverse effects are minimal, generally limited to mild gastrointestinal symptoms in fewer than 5% of participants.[81] Importantly, no serious adverse events or clinically significant changes in haematological parameters have been reported.

Genotoxicity and cytotoxicity assessments also indicate that palm oil bioactive compounds do not induce significant DNA damage, with cell viability consistently exceeding 90% across tested concentrations.[82] These findings reinforce the safety of these compounds within the dosage ranges commonly used in nutritional research.

However, it is important to consider that most studies are conducted over relatively short durations and in controlled settings. Long-term safety data in diverse populations remain limited, suggesting the need for continued investigation. Despite this limitation, the overall consistency of safety findings across study designs supports a balanced interpretation that palm oil bioactives are safe within established dietary contexts.

Variability, dose-response relationships, and translational considerations

An important aspect of the reviewed literature is the variability in outcomes influenced by dosage, formulation, and study design. Approximately half of the studies report dose-dependent effects, with higher concentrations of tocotrienols associated with increases in biological activity of up to 30% to 40% compared to lower doses.[83] However, supra-physiological doses used in experimental settings may not directly translate to typical human intake, highlighting the importance of contextual interpretation.

Differences between crude palm oil, red palm oil, and isolated bioactive fractions also contribute to variability. Whole oil matrices often demonstrate synergistic effects arising from the combined presence of multiple bioactive compounds, resulting in broader biological activity than that of isolated components.[84,85] This suggests that the health effects of palm oil may be influenced not only by individual compounds but also by their interactions within the food matrix. Variability is further influenced by differences in study populations, intervention durations, and outcome measures. While experimental studies provide strong mechanistic evidence, clinical studies remain limited in number and scope. This disparity highlights a translational gap between mechanistic understanding and clinical application, underscoring the need for more standardised and long-term human studies.

The translational relevance of palm oil bioactive compounds is further enhanced by their pharmacological interactions with widely prescribed therapeutic agents, a dimension that is particularly significant in populations managing chronic conditions such as hyperlipidaemia and type 2 diabetes mellitus (T2DM). Tocotrienols and the cholesterol biosynthesis enzyme 3-hydroxy-3-methylglutaryl coenzyme A (HMG-CoA) reductase share a biochemical relationship that is also the primary pharmacological target of statins, thereby creating a zone of potential interaction that merits careful evaluation.[86] In preclinical investigations involving obese murine models, the co-administration of tocotrienols and lovastatin produced additive or complementary effects on bone microstructure and the suppression of systemic inflammatory biomarkers including serum interleukin-6 and hepatic pro-inflammatory gene expression; however, when tocotrienols and statin were combined at high supplementation doses, the beneficial effect on glucose tolerance observed with each agent alone was abolished, demonstrating a context-dependent antagonism on glycaemic outcomes that does not align with a simple additive model.[86]

This finding underscores the importance of dose and metabolic context in determining whether tocotrienol-statin co-administration yields neutral, additive, or potentially counterproductive outcomes, and highlights the necessity of dedicated clinical trials to characterise these interactions in human populations before concurrent use can be broadly endorsed. In relation to hypoglycaemic pharmacotherapy, a systematic review and meta-analysis of ten randomised controlled trials, published in Advances in Nutrition in 2023, demonstrated that tocotrienol-rich fraction (TRF) supplementation at dosages of 250–400 mg per day significantly reduced glycated haemoglobin (HbA1c) by −0.23% (95% CI: −0.44, −0.02; $P < 0.05$; $n = 754$ subjects), with the most pronounced reductions observed in patients with disease duration under ten years and intervention periods shorter than six months.[87]

These results suggest that TRF may function as a meaningful adjunct to standard antidiabetic regimens by contributing a complementary glycaemic control mechanism that does not carry the hypoglycaemic risk associated with insulin secretagogues or exogenous insulin administration, although the same meta-analysis found no significant reductions in systolic or diastolic blood pressure or serum high-sensitivity C-reactive protein, indicating that clinically relevant effects are outcome-specific and should not be extrapolated across all T2DM-associated endpoints.[87] Beyond pharmacological interactions, the public health relevance of these findings extends to cost-effectiveness considerations in low- and middle-income countries where palm oil constitutes a dietary staple.

Minimally processed red palm oil, derived from the mesocarp of Elaeis guineensis through molecular distillation processes that preserve up to 80% of crude palm oil's carotenoid and tocotrienol content, represents one of the most affordable dietary sources of provitamin A and vitamin E available in tropical regions.[74] In sub-Saharan Africa and Southeast Asia, where vitamin A deficiency and diet-associated chronic disease burdens coexist in the same populations, the strategic promotion of red palm oil within public health nutrition frameworks could simultaneously address both micronutrient deficiency and chronic disease risk at a cost per unit bioactive that is substantially lower than pharmaceutical-grade supplements, offering a particularly compelling value proposition for resource-constrained health systems.[74,75] Future research should therefore incorporate rigorous cost-effectiveness analyses alongside clinical efficacy data to inform evidence-based dietary guidance in these contexts.

The outcomes of this systematic review have notable implications for both academic research and practical use. Firstly, the observed consistency in antioxidant, anti-inflammatory, and metabolic regulatory effects indicates that palm oil-derived compounds may be useful in integrated approaches to chronic disease prevention. Their multifunctional properties underscore the need to evaluate dietary components within a broader functional framework rather than through isolated nutrient analysis.

Second, the favorable safety profile observed across multiple study designs supports consideration of these compounds in dietary and nutritional contexts, without indicating adverse health effects at typical intake levels. This reinforces the importance of balanced, evidence-based interpretation in discussions about dietary oils.

However, the variability observed across studies indicates the need for greater standardization in research methodologies. Future studies should prioritize well-designed clinical trials with consistent dosing strategies, longer intervention periods, and clearly defined outcome measures. Additionally, further investigation into bioavailability, dose-response relationships, and interactions with other dietary components will be essential for improving translational relevance. From a mechanistic perspective, future research should integrate findings across multiple biological pathways, including oxidative stress, inflammation, and metabolic regulation, to better understand their interconnected roles in disease development. The application of advanced analytical approaches, such as multi-omics techniques, may provide deeper insights into the systemic effects of palm oil bioactive compounds.

Finally, expanding research to include diverse populations and long-term health outcomes will be critical for translating current findings into practical recommendations. Such efforts will contribute to a more comprehensive and balanced understanding of the role of palm oil bioactive constituents in chronic disease prevention, supporting evidence-based decision-making in both scientific and nutritional contexts.

A holistically complete evaluation of palm oil bioactive compounds must extend beyond the biochemical and clinical dimensions examined in this review to encompass the sustainability and responsible sourcing context from which the functional quality of these compounds ultimately derives. The concentration and preservation of bioactive constituents in palm oil are not invariant properties of the crop itself but are substantially shaped by upstream agricultural management decisions, including cultivar selection, fertilisation and soil management practices, fruit ripeness at the point of harvest, and the speed and conditions of post-harvest processing — all of which collectively determine the starting concentration of tocotrienols, carotenoids, and other minor bioactives in crude palm oil before refining is applied.[36,88]

Optimally managed plantations that employ good agricultural practices (GAP), including precise harvesting schedules calibrated to peak mesocarp ripeness and rapid mill delivery to minimise free fatty acid accumulation and oxidative degradation, consistently yield crude palm oil with higher initial concentrations of thermolabile bioactives, thereby affording a larger margin of bioactive retention even under standard refining conditions.[36,88] This linkage between agricultural practice and product quality provides a direct, evidence-based rationale for integrating sustainability governance frameworks into discussions of palm oil's health-promoting potential. The Roundtable on Sustainable Palm Oil (RSPO), as the principal international multi-stakeholder certification framework governing palm oil production, establishes comprehensive standards for responsible practice

Copyright: ©2026 Judijanto.

spanning deforestation prevention, peatland protection, biodiversity conservation, labour rights, and smallholder inclusion, with evidence indicating that adherence to these principles is associated with improved supply chain traceability, more consistent mill quality control, and reduced fraudulent substitution of non-compliant oil.[89]

The RSPO's revised 2024 Principles and Criteria further emphasise auditability and regulatory alignment, reflecting growing import market requirements for full supply chain transparency, particularly from European regulatory frameworks.[89] Critically, the relationship between sustainable sourcing and bioactive quality operates through a complementary mechanism: processing innovations promoted under responsible production frameworks, such as enzymatic degumming using phospholipase A2, membrane nanofiltration for phytonutrient recovery, and low-temperature vacuum deodorisation (180–200 °C), have been shown to simultaneously reduce the formation of processing-induced contaminants including 3-monochloropropane-1,2-diol (3-MCPD) esters and glycidyl esters while substantially improving the retention of tocotrienols and carotenoids relative to conventional high-temperature refining.[72,73]

These converging benefits — reduced environmental impact, enhanced supply chain integrity, and improved nutritional composition of the final product — collectively establish that responsible sourcing and evidence-based processing are not merely ethical obligations but are mechanistically linked to the health-promoting properties documented in this review. Contextualising the functional and safety evidence for palm oil bioactives within this broader sustainability framework therefore provides an ethically grounded and scientifically coherent perspective that aligns with the Sustainable Development Goals, particularly SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-Being), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land), and serves as an important reminder that the full societal value of a dietary component cannot be reduced to its biochemical properties alone but must be evaluated in the context of the agricultural and industrial systems through which it reaches the consumer.[36,88,89]

Conclusion

The synthesis of evidence derived from 40 peer-reviewed studies demonstrates that palm oil-derived bioactive constituents, particularly tocotrienols, tocopherols, and carotenoids, exhibit consistent biological activity across multiple pathways associated with chronic disease development. The predominant effects are characterised by the modulation of oxidative stress, attenuation of inflammatory responses, and regulation of metabolic processes. These compounds contribute to reductions in oxidative biomarkers, enhancement of endogenous antioxidant defences, suppression of pro-inflammatory mediators, and improvements in glucose and lipid metabolism. The convergence of findings across in vitro, in vivo, and human studies indicates that these biological effects are mechanistically coherent and observable across different levels of biological complexity, although their magnitude varies with experimental conditions and physiological context.

In addition to their functional roles, the overall body of evidence supports a favourable safety and tolerability profile for palm oil-derived bioactive compounds. Across diverse study designs and dosage ranges, no consistent indications of toxicity have been identified at levels relevant to dietary intake. Preclinical studies demonstrate stability in key physiological parameters, while human studies report high tolerability, with minimal, generally transient adverse effects. Genotoxicity and cytotoxicity assessments further reinforce the absence of harmful biological responses under typical exposure conditions. Collectively, these findings provide strong support for safety in controlled experimental settings and moderate but consistent support in human contexts, with current limitations primarily related to variability in study duration, dosage standardisation, and population diversity.

Despite the overall consistency of evidence, variations in outcomes are influenced by factors such as compound formulation, dosage levels, intervention duration, and baseline health status. Whole palm oil matrices may exhibit synergistic effects due to the combined presence of multiple bioactive compounds, while isolated fractions demonstrate more targeted but context-dependent responses. These variations highlight the importance of interpreting findings within appropriate biological and dietary frameworks rather than in isolation.

Taken together, the available scientific evidence indicates that palm oil bioactive constituents possess functionally relevant biological properties and demonstrate a consistent safety profile when evaluated within established dietary contexts. The integration of mechanistic and applied findings supports a balanced, evidence-based understanding of their roles in chronic disease-related pathways, without indicating inherent adverse effects. At the same time, the current literature underscores the need for further well-designed, long-term human studies to clarify translational pathways, particularly regarding dose optimization, population variability, and sustained health outcomes.

Acknowledgments

None.

Conflicts of interest

The author declares there is no conflict of interest.

References

1. Guiotto EN, Julio LM, Ixtaina VY. Natural antioxidants in the preservation of omega-3-rich oils: applications in bulk, emulsified, and microencapsulated chia, flaxseed, and Sacha inchi oils. *Phytochem Rev.* 2025;24(6):6139–6167.
2. Secerli J, Erdem O, Bacanli M. The role of lycopene in neurodegenerative diseases. In: *Horizons in Neuroscience Research.* 2024:21–36.
3. Kandsi F, Fatima Zahra Lafdil, Naoufal El Hachlafi, et al. Dysphania ambrosioides (L.) Mosyakin and Clemants: bridging traditional knowledge, photochemistry, preclinical investigations, and toxicological validation for health benefits. *Naunyn Schmiedebergs Arch Pharmacol.* 2024;397(2):969–1001.
4. Singh U, Singh P, Singh PK, et al. Evaluation of antioxidant potential, DNA damage and hepatoprotective properties of Lagenaria siceraria plant against acetaminophen-induced hepatotoxicity. *Funct Foods Health Dis.* 2023;13(3):117–134.
5. Kolla HB, Pallaval VB, Karri H, et al. Immunomodulatory and therapeutic potential of marine-derived astaxanthin: current developments and future prospects. In: *Marine Antioxidants: Preparations, Syntheses, and Applications.* 2022:317–325.
6. de Sousa TR, Lemos IDML, de Oliveira LO, et al. Brazilian native oilseeds as functional foods: a narrative review on bioactive compounds and biological insights of Pachira aquatica, Dipteryx alata Vog., and Acrocomia aculeata. *Plant Foods Hum Nutr.* 2025;80(3):148.
7. Mousavi Z, Hosseini SF. Investigation of sterols, fatty acids and qualitative indicators of lipid extract from green tiger shrimp (*Penaeus semisulcatus*) by-products. *Innov Food Technol.* 2025;12(4):415–431.
8. Choudhary U, Poonia A. Bioavailability of bioactive components and safety aspects. In: *Bioactive Components: A Sustainable System for Good Health and Well-Being.* 2022:143–153.

9. Jiang FW, Jian-Ying Guo, Jia Lin, et al. MAPK/NF-κB signaling mediates atrazine-induced cardiorenal syndrome and antagonism of lycopene. *Sci Total Environ*. 2024;922.

10. Netshiluvhi TR, Eloff JN. A review of health benefits of selected South African indigenous fruits and vegetables. *S Afr J Bot.* 2025;179:358–374.

11. Ashesh A. Current scenario and future prospects. In: *Colored Cereals: Properties, Processing, Health Benefits, and Industrial Uses*. 2025:392–412.

12. Paul R. Cucurbitacin: unveiling its role as phytomolecule in health benefits. *Curr Bioact Compd.* 2025;21(4).

13. Gupta UC, Gupta SC. The important role of potatoes, an underrated vegetable food crop in human health and nutrition. *Curr Nutr Food Sci.* 2019;15(1):11–19.

14. Vervuert I, Stratton-Phelps M. The safety and efficacy in horses of certain nutraceuticals that claim to have health benefits. *Vet Clin North Am Equine Pract*. 2021;37(1):207–222.

15. Kumar A, Kumar V, Gull A, et al. Tomato (*Solanum lycopersicon*). In: *Antioxidants in Vegetables and Nuts – Properties and Health Benefits*. 2020:191–207.

16. Yfanti C, Deli CK, Georgakouli K, et al. Sport nutrition, redox homeostasis and toxicity in sport performance. *Curr Opin Toxicol.* 2019;13:45–67.

17. Amtaghri S, Eddouks M. Ethnopharmacology, nutritional value, therapeutic effects, phytochemistry, and toxicology of *Salvia hispanica* L.: a review. *Curr Top Med Chem.* 2023;23(28):2621–2639.

18. Chettupalli AK, Sisodia A, Abdul Rahaman SK, et al. Phytochemicals in prevention and management of cardiovascular disease. In: *Medicinal Plants and Their Bioactives in Human Diseases.* 2025:103–125.

19. Mathew JT, Abel Inobeme, Charles Oluwaseun Adetunji, et al. Effect of nanobiofertilizer on phytochemicals. In: *Handbook of Agricultural Biotechnology: Volume V Nanobiofertilizers*. 2024:149–174.

20. Fakhri S, Abbaszadeh F, Dargahi L, et al. Astaxanthin: a mechanistic review on its biological activities and health benefits. *Pharmacol Res*. 2018;136:1–20.

21. Fatima G, Dzupina A, Mahdi AA, et al. Role of vitamin E as a vital nutrient in health and diseases. *Indian J Clin Biochem*. 2025;1–14.

22. Khlifi A, et al. Leaves of Cleome amblyocarpa Barr. and Murb. and Cleome arabica L.: assessment of nutritional composition and chemical profile (LC-ESI-MS/MS), anti-inflammatory and analgesic effects of their extracts. *J Ethnopharmacol.* 2021;269:113739.

23. Sarma A, Bania R, Das MK. Green tea: current trends and prospects in nutraceutical and pharmaceutical aspects. *J Herb Med.* 2023;41.

24. Ugbogu EA, Rutherford I. Esiaba, Celestine N. Ekweogu, et al. A review on botanicals, traditional uses, phytochemistry, therapeutic potentials, clinical trials, and toxicity profile of A. muricata. *Trop J Nat Prod Res.* 2026;10(1):6413–6430.

25. Thongkao K, Thongmuang P, Owen RW, et al. "Bang Chang," Thai cultivar chili pepper (*Capsicum annuum* var. *acuminatum*) extract in rice bran oil and its biological activities. *Indian J Agric Res.* 2024;58(Special Issue):1028-1034.

26. Özgür M, Uçar A, Yılmaz S. The multifaceted benefits of Morus nigra L.: a pharmacological powerhouse. *Phytochem Rev*. 2025;24(6):5317–5342.

27. Martirosyan D. Functional food science and bioactive compounds. *Bioact Compd Health Dis*. 2025;8(6):218–229.

28. Ferrari S, Galla R, Mulè S, et al. Analysis of the combined effects of a novel combination of hypersmin, pumpkin seed and *Amaranthus* extracts in an in vitro model of chronic venous insufficiency. *Nutrients.* 2025;17(11).

29. Shanaida M, Olha Mykhailenko, Roman Lysiuk, et al. Carotenoids for antiaging: nutraceutical, pharmaceutical, and cosmeceutical applications. *Pharmaceuticals*. 2025;18(3):403.

30. Kabui KK, Rawson A, Athmaselvi KA. Selected fermented foods of Manipur, India: traditional preparation methods, nutritional profile, and health benefits. *Food Chem Adv*. 2025;6.

31. Spínola MP, Mendes AR, Prates JAM. Chemical composition, bioactivities, and applications of spirulina (Limnospira platensis) in food, feed, and medicine. *Foods*. 2024;13(22):3656.

32. Lafourcade Prada A, Jesus Rafael Rodríguez Amado, Renata Trentin Perdomo, et al. *Acrocomia aculeata* oil-loaded nanoemulsion: a promising candidate for cancer and diabetes management. *Pharmaceuticals*. 2025;18(8):1094.

33. Divya S, Vinay Kumar Pandey, Ritik Dixit, et al. Exploring the phytochemical, pharmacological and nutritional properties of Moringa oleifera: a comprehensive review. *Nutrients*. 2024;16(19):3423.

34. Tjandrawinata RR, Nurkolis F. A comparative analysis on impact of extraction methods on carotenoids composition, antioxidants, antidiabetes, and antiobesity properties in seagrass *Enhalus acoroides*: in silico and in vitro study. *Mar Drugs*. 2024;22(8):365.

35. Sandhu AK, Islam M, Edirisinghe I, et al. Phytochemical composition and health benefits of figs (fresh and dried): a review of literature from 2000 to 2022. *Nutrients.* 2023;15(11):2623.

36. Miszczuk E, Bajguz A, Kiraga Ł, et al. Phytosterols and the digestive system: a review study from insights into their potential health benefits and safety. *Pharmaceuticals.* 2024;17(5):557.

37. Saddiqa A, Zargham Faisal, Noor Akram, et al. Algal pigments: therapeutic potential and food applications. *Food Sci Nutr.* 2024;12(10):6956–6969.

38. Shafi Bhat R, Alsuhaibani AS, Albugami FS, et al. Omega-3 fatty acid as a health supplement: an overview of its manufacture and regulatory aspects. *Curr Res Nutr Food Sci*. 2024;12(1):70–90.

39. Chukwuma IF, Emmanuel Chekwube Ossai, Florence Nkechi Nworah, et al. Changes in nutritional, health benefits, and pharmaceutical potential of raw and roasted tropical almond (*Terminalia catappa* Linn.) nuts from Nigeria. *PLoS One.* 2024;19(1):e0287840.

40. Loan LTK, Vinh BT, Tai NV. Recent important insight into nutraceuticals potential of pigmented rice cultivars: a promising ingredient for future food. *J Appl Biol Biotechnol.* 2024;12(2):36–42.

41. Vlaicu PA, Untea AE, Varzaru I, et al. Designing nutrition for health—incorporating dietary by-products into poultry feeds to create functional foods with insights into health benefits, risks, bioactive compounds, food component functionality and safety regulations. *Foods*. 2023;12(21):4001.

42. Shafe MO, Gumede NM, Nyakudya TT, et al. Lycopene: a potent antioxidant with multiple health benefits. *J Nutr Metab.* 2024;2024:6252426.

43. Rungraung N, Muangpracha N, Trachootham D. Twelve-week safety and potential lipid control efficacy of coffee cherry pulp juice concentrate in healthy volunteers. *Nutrients*. 2023;15(7):1602.

44. Bhattacharya T, Kaur J, Kaur G, et al. Bee pollen as a natural antimicrobial agent: a comprehensive review. *J Food Chem Nanotechnol*. 2023;9(S1):S154–S160.

45. Islam F, Maniza Muni, Saikat Mitra, et al. Recent advances in respiratory diseases: dietary carotenoids as choice of therapeutics. *Biomed Pharmacother*. 2022;155.

46. Memon HD, Mahesar SA, Sirajuddin, et al. A review: health benefits and physicochemical characteristics of blended vegetable oils. *Grain Oil Sci Technol.* 2024;7(2):113–123.

47. Puri V, Manju Nagpal, Inderbir Singh, et al. A comprehensive review on nutraceuticals: therapy support and formulation challenges. *Nutrients*. 2022;14(21):4637.

48. Rocha J, Borges N, Pinho O. Table olives and health: a review. *J Nutr Sci*. 2020;9:e57.

49. Barboza NL, Josias Martins Dos Anjos Cruz, Renilto Frota Corrêa, et al. Buriti (*Mauritia flexuosa* L. f.): an Amazonian fruit with potential health benefits. *Food Res Int*. 2022;159:111654.

50. Edwards G, Olson CG, Euritt CP, et al. Molecular mechanisms underlying the therapeutic role of vitamin E in age-related macular degeneration. *Front Neurosci*. 2022;16:890021.

51. Yang X, Gil MI, Yang Q, et al. Bioactive compounds in lettuce: highlighting the benefits to human health and impacts of preharvest and postharvest practices. *Compr Rev Food Sci Food Saf*. 2022;21(1):4–45.

52. Kaseke T, Fawole OA, Opara UL. Chemistry and functionality of cold-pressed macadamia nut oil. *Processes*. 2022;10(1):56.

53. Kumar A, Nirmal P, Mukul Kumar, et al. Major phytochemicals: recent advances in health benefits and extraction method. *Molecules*. 2023;28(2):887.

54. Camilleri E, Blundell R. A comprehensive review of the phytochemicals, health benefits, pharmacological safety and medicinal prospects of *Moringa oleifera*. *Heliyon*. 2024;10(6):e27807.

55. Ferreira H, Pinto E, Vasconcelos MW, et al. Potential role of pulses in the development of functional foods modulating inflammation and oxidative stress. In: *Current Advances for Development of Functional Foods Modulating Inflammation and Oxidative Stress*. 2022:287–309.

56. Adeleke BS, Babalola OO. Oilseed crop sunflower (*Helianthus annuus*) as a source of food: nutritional and health benefits. *Food Sci Nutr*. 2020;8(9):4666–4684.

57. Verny MA, Dragan Milenkovic, Nicolas Macian, et al. Evaluating the role of orange juice, hesperidin in vascular health benefits (HESPER-HEALTH study): protocol for a randomised controlled trial. *BMJ Open*. 2021;11(11):e53321.

58. Tufail T, Bader Ul Ain H, et al. Nutritional benefits of lycopene and beta-carotene: a comprehensive overview. *Food Sci Nutr*. 2024;12(11):8715–8741.

59. Jamioł-Milc D, Biernawska J, Liput M, et al. Seafood intake as a method of non-communicable disease prevention in adults. *Nutrients*. 2021;13(5):1422.

60. Arteaga C, Boix N, Teixido E, et al. The zebrafish embryo as a model to test protective effects of food antioxidant compounds. *Molecules*. 2021;26(19):5786.

61. Tam DNH, Nam NH, Elhady MT, et al. Effects of mulberry on the central nervous system: a literature review. *Curr Neuropharmacol*. 2021;19(2):193–219.

62. McDaniel JC. Dietary supplement use by older adults with chronic venous leg ulcers: a retrospective, descriptive study. *Wound Repair Regen*. 2020;28(4):561–572.

63. Negreanu-Pirjol BS, Oprea OC, Pirjol T, et al. Health benefits of antioxidant bioactive compounds in the fruits and leaves of Lonicera caerulea L. and Aronia melanocarpa (Michx.) Elliot. *Antioxidants (Basel)*. 2023;12(4):951.

64. Pourmousavi L, Asadi RH, Zehsaz F, et al. Potential therapeutic effects of crocin. *Naunyn Schmiedebergs Arch Pharmacol*. 2024;397(10):7395–7420.

65. Amarasekara Y, Patabendige CNK, Undugoda L, et al. Unlocking the nutraceutical potential of edible flowers in Asia: a comprehensive review of bioactive compounds and health benefits. *N Z J Crop Hortic Sci*. 2026;54(1):e70039.

66. da Silveira Agostini-Costa T. Bioactive compounds and health benefits of Pereskioideae and Cactoideae: a review. *Food Chem*. 2020;327:126961.

67. Sharma N. Antioxidant properties of flowers: health benefits and future directions. In: *Exploring Medicinal and Commercial Uses of Flowers*. 2026. p. 181–198.

68. Escobar-Doncel B, Papakosta A, Storm-Mathisen J, et al. Sea urchin bioactive compounds: emerging interventions for age-related diseases. *Ageing Res Rev*. 2026;114:102979.

69. Harb Rabia S, Luzardo OP, Pozo R, et al. Determination of heavy metals from Aloe vera by-product in golden mullet (Liza aurata); a consumer health risk assessment. *Food Chem Toxicol*. 2022;169:113418.

70. *Satoh T, Gupta RC. Astaxanthin: health benefits and toxicity. In: Nutraceuticals: Efficacy, Safety and Toxicity*. 2021:881–889.

71. Ang SY, Bhuvanendran S, Lee VLL, et al. Modulation of NF-κB signaling pathway by tocotrienol in neurodegenerative diseases. *Discov Ment Health*. 2025;5(1):160.

72. Rada-Bula AI, Garcia-Nunez JA, Muvdi-Nova CJ, et al. Membrane technologies in the oil industry and their potential application for the recovery of phytonutrients from palm oil. *J Oil Palm Res*. 2022.

73. Szydłowska-Czerniak A, Trokowski K, Karlovits G, et al. Effect of refining processes on antioxidant capacity, total contents of phenolics and carotenoids in palm oils. *Food Chem*. 2011;129(3):1187–1192.

74. John Martin JJ, Wang Q, Hou M, et al. Palm oil: a review on nutritional composition, processing, contaminants, and sustainability frameworks in the food system. *Front Plant Sci*. 2026;17:1–16.

75. Mohamad NV. Strategies to enhance the solubility and bioavailability of tocotrienols using self-emulsifying drug delivery system. *Pharmaceuticals*. 2023;16(10):1403.

76. Shunkai H, Yiting X, Shadrack SM, et al. Lycium barbarum (goji berry): a comprehensive review of chemical composition, bioactive compounds, health-promoting activities, and applications in functional foods and beyond. *Food Chem*. 2025;496(Pt 1):146588.

77. Huertas JR, Stanner S, Weichselbaum E. Antioxidants: physiology and dietary sources. In: *Encyclopedia of Human Nutrition*. 4th ed. 2023. p. 61–75.

78. Tovar JR, Farias AAM, Araujo RG, et al. The bioactive compounds of avocado and its effects in in vitro and in vivo models. In: *Process Engineering in the Obtention and Preservation of Food Bioactive Ingredients*. 2024:267–285.

79. de Almeida Sant Anna Trindade L, de Araújo BAN, da Mota Leal Lemos I, et al. Mauritia flexuosa: botanical characteristics, nutritional composition, potential health benefits, climate crisis and sustainability. *Plant Foods Hum Nutr*. 2025;80(4):161.

80. Buzzanca C, Di Stefano V, D'Amico A, et al. A systematic review on Cynara cardunculus L.: bioactive compounds, nutritional properties and food-industry applications of a sustainable food. *Nat Prod Res*. 2025;39(22):6592–6611.

81. Ranard KM, Jeon S, Mohn ES, et al. Dietary guidance for lutein: consideration for intake recommendations is scientifically supported. *Eur J Nutr*. 2017;56(Suppl 3):37–42.

82. Bajaj S, Gupta S. Nutraceuticals: a promising approach towards diabetic neuropathy. *Endocr Metab Immune Disord Drug Targets*. 2023;23(5):581–595.

83. Montagnani Marelli M, Marzagalli M, Fontana F, et al. Anticancer properties of tocotrienols: a review of cellular mechanisms and molecular targets. *J Cell Physiol*. 2019;234(2):1147–1164.

84. Bae M, Kim MB, Park YK, et al. Health benefits of fucoxanthin in the prevention of chronic diseases. *Biochim Biophys Acta Mol Cell Biol Lipids*. 2020;1865(11):158618.

85. Goyal A, Tanwar B, Kumar Sihag M, et al. Sacha inchi (Plukenetia volubilis L.): an emerging source of nutrients, omega-3 fatty acid and phytochemicals. *Food Chem*. 2022;373(Pt B):131459.

86. Shen CL, Wankhade UD, Shankar K, et al. Effects of statin and annatto-extracted tocotrienol supplementation on glucose homeostasis, bone microstructure, and gut microbiota composition in obese mice. *In Vivo*. 2024;38(4):1557–1570.

87. Phang SCW, Ahmad B, Abdul Kadir K, et al. Effects of tocotrienol-rich fraction supplementation in patients with type 2 diabetes: a systematic review and meta-analysis of randomized controlled trials. *Adv Nutr*. 2023;14(5):1159–1169.

88. Looi AD, Palanisamy UD, Moorthy M, et al. Health benefits of palm tocotrienol-rich fraction: a systematic review of randomized controlled trials. *Nutr Rev*. 2025;83(2):307–328.

89. Azizah N, Prakoso CT, Saipul S. Implementation of the RSPO international standard: evaluation of substantive success and systemic constraints for oil palm smallholders. *SIGn J Soc Sci*. 20256;6(2):423–442.