MedCrave
Step into the World of Research

Open Access Journal of Science

Literature Review

Open Access

CrossMark

Palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents: A systematic review

Abstract

The demand for greener and biologically safe materials in biomedical applications has led researchers to explore bio-origin resources as effective carriers for therapeutic agents. Among these, palm oil-derived biomaterials have gained attention due to their adaptable chemical composition and functional versatility. This study aims to systematically review and analyse the current state of research on palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents, focusing on material types, formulation strategies, and their physicochemical and biological performance. A structured and reproducible framework underpins the Systematic Literature Review (SLR) approach used in this study. Data were collected from the Scopus database through a combination of broad and refined keyword strategies. The initial search yielded 237 articles, which were subsequently filtered based on relevance, publication period (2020–2026), and accessibility, resulting in 34 eligible peer-reviewed studies. Through qualitative thematic synthesis, the data analysis aimed to identify common patterns emerging from the selected publications. The results indicate five major thematic domains: material sources, formulation strategies, physicochemical performance, antimicrobial and therapeutic effectiveness, and release behaviour. The reviewed studies demonstrate that palm oil-based biomaterials exhibit favourable encapsulation efficiency, stable physicochemical properties, effective antimicrobial activity, and controlled release characteristics across various delivery systems. In conclusion, palm oil-derived biomaterials provide a versatile and functionally consistent platform for drug delivery applications. Upcoming studies should focus on establishing standardised methodologies, conducting long-term stability analyses, and engineering hybrid systems to achieve improved performance and wider applicability.

Keywords: palm oil biomaterials, drug delivery, antimicrobial activity, nanocarriers, systematic literature review

Special issue - 2026

Loso Judijanto
IPOSS Jakarta, Indonesia

Correspondence: Loso Judijanto, IPOSS Jakarta, Indonesia

Received: May 20, 2026 | **Published:** June 09, 2026

Introduction

The increasing demand for advanced drug delivery systems has driven substantial research toward the development of biomaterials that are not only functionally effective but also derived from sustainable and renewable resources. In today's biomedical field, the structural design of delivery carriers plays a pivotal role in governing the stability, bioavailability, and therapeutic outcomes of active substances. Conventional delivery platforms often face limitations related to poor solubility, rapid degradation, and uncontrolled release profiles, which may reduce therapeutic efficacy and increase side effects. Therefore, research efforts are increasingly centred on bio-based materials that combine superior biocompatibility with modifiable physicochemical properties to enable targeted and controlled delivery systems.[1]

Against this backdrop, lipid-based and polymeric materials have emerged as key contenders, attributed to their structural flexibility and effectiveness in encapsulating a broad spectrum of bioactive substances. These materials can be engineered into various delivery systems, including nanoparticles, nanoemulsions, hydrogels, and polymeric matrices, each designed to address specific therapeutic challenges.[2] The integration of biodegradable and biocompatible materials into drug delivery systems has become increasingly important, particularly in response to the need for safer and more efficient therapeutic strategies. This trend reflects a broader shift toward sustainable material sourcing and environmentally conscious innovation in biomedical engineering.

Among the various renewable resources available, palm oil and its derivatives have attracted increasing scientific attention as potential raw materials for biomaterial development. As one of the most widely produced vegetable oils globally, palm oil offers a consistent supply chain and a chemically rich composition that includes triglycerides, fatty acids, and glycerol-based compounds.[3] These components can be further modified into functional materials such as surfactants, polyols, and lipid matrices, which are essential in the formulation of drug delivery systems. The versatility of palm oil-derived compounds enables their transformation into both lipid-based carriers and polymeric structures, supporting diverse biomedical applications without necessitating complex synthesis pathways.[4]

Alongside the principal oil fractions, biomass residues from oil palm, namely empty fruit bunches (EFB), mesocarp fibres, and palm kernel shells, have been increasingly recognised as important lignocellulosic materials.[5] These residues can be processed into cellulose and nanocellulose, which exhibit high surface area, mechanical strength, and functionalizability. Such characteristics make them suitable for incorporation into hydrogels, films, and scaffold-based delivery systems. The valorisation of these by-products contributes to resource efficiency and supports the development of high-value applications derived from existing agricultural streams, aligning with broader sustainability goals in material science and engineering.[6]

The application of palm oil-based biomaterials in antimicrobial and therapeutic delivery has gained relevance in response to global

health challenges, including the rising prevalence of antimicrobial resistance and the need for more effective treatment modalities. Delivery systems based on lipid and polymeric matrices have demonstrated the ability to enhance the stability and controlled release of antimicrobial agents, thereby improving their efficacy. Similarly, therapeutic compounds such as anti-inflammatory and anticancer agents benefit from encapsulation within biomaterial carriers, which can improve solubility, protect against degradation, and facilitate targeted delivery. These advantages highlight the functional potential of palm oil-derived materials in addressing current biomedical needs while maintaining compatibility with established pharmaceutical systems.[7,8]

Even with the growing number of publications, the body of knowledge continues to be fragmented across diverse material types, formulation methods, and application domains. Studies often focus on specific aspects such as nanoparticle synthesis, antimicrobial testing, or release kinetics, without providing an integrated perspective on how these elements collectively contribute to the performance of palm oil-based delivery systems.[9,10] Furthermore, variations in experimental design, characterization techniques, and evaluation metrics make it challenging to draw generalized conclusions regarding the effectiveness and applicability of these materials. This fragmentation underscores the need for a systematic synthesis of existing research to identify consistent trends, technological advancements, and areas requiring further investigation.

Structured synthesis is of significant importance, particularly in fields involving newly developed biomaterials, where interdisciplinary approaches combine principles from chemistry, materials science, and biomedical engineering. Without a systematic framework, the interpretation of findings may be influenced by selective reporting or methodological inconsistencies. Therefore, a comprehensive review based on transparent and reproducible criteria is essential to consolidate current knowledge and provide a reliable foundation for future research and development. In this regard, the Systematic Literature Review (SLR) approach offers a rigorous methodology for identifying, evaluating, and synthesizing relevant studies, ensuring that conclusions are grounded in verifiable evidence derived from peer-reviewed publications.

In line with this rationale, the present study aims to systematically review and analyze the current state of research on palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents. The review focuses on identifying the types of materials derived from palm oil, examining formulation strategies used in developing delivery systems, and evaluating their physicochemical and biological performance. By integrating findings from multiple studies, this work seeks to provide a coherent and evidence-based understanding of how palm oil-derived biomaterials are being utilised in biomedical applications, while maintaining a balanced and neutral perspective on their role within the broader context of sustainable material development.

To guide the analysis and ensure methodological clarity, this study is structured around the following research questions:

RQ1: *How are palm oil-derived biomaterials designed and formulated to function as carriers for antimicrobial and therapeutic agents in contemporary biomedical applications?*

RQ2: *What patterns of performance, including physicochemical properties, antimicrobial activity, and release behaviour, can be identified across studies utilising palm oil-based delivery systems?*

These research questions serve as the analytical foundation for the subsequent discussion and synthesis, enabling a focused evaluation of the literature while supporting the development of well-grounded conclusions.

Literature review

The increasing adoption of bio-based materials in biomedical applications has stimulated extensive research into alternative carrier systems derived from renewable resources. Among these, palm oil-based biomaterials have attracted attention due to their adaptable chemical composition and functional potential in antimicrobial and therapeutic delivery. Existing studies indicate a growing integration of material science and pharmaceutical approaches, where palm-derived resources are utilised to develop carrier systems with tunable properties. Accordingly, the literature reflects a range of interconnected research directions that collectively contribute to understanding the development and performance of these biomaterials in drug delivery applications.

Fundamental characteristics of palm oil-derived biomaterials

Palm oil and its derivatives are composed primarily of triglycerides, free fatty acids, and minor bioactive components, which collectively contribute to their functional versatility in biomaterial design. The fatty acid profile, typically dominated by palmitic acid and oleic acid, provides a balanced combination of saturation and unsaturation that supports both structural stability and chemical reactivity.[11] This composition enables palm oil to be processed into a wide range of derivatives, including mono- and diglycerides, fatty acid esters, and surfactants, which are frequently employed in drug delivery systems.

Besides the primary oil components, oil palm residues such as empty fruit bunches (EFB), mesocarp fibres, and palm kernel shells provide substantial sources of lignocellulosic material. These residues are increasingly recognised for their potential in producing cellulose and nanocellulose, which exhibit high crystallinity, mechanical strength, and surface functionality.[12] The multi-scale architecture of cellulose, consisting of crystalline and amorphous regions, facilitates chemical modification and enhances interaction with therapeutic agents. Such characteristics support their incorporation into advanced delivery systems, including hydrogels and composite matrices.

The adaptability of palm oil-derived materials is further enhanced through chemical modification processes such as esterification, transesterification, and polymerisation. These processes enable the generation of tailored biomaterials with specific physicochemical properties, including hydrophilicity, degradation rate, and mechanical strength.[13] As a result, palm oil-based biomaterials can be engineered to meet diverse requirements in biomedical applications without necessitating complex or resource-intensive synthesis pathways.

Lipid-based carrier systems derived from palm oil

Among various applications, lipid-based delivery platforms have received significant attention in studies involving palm oil-derived biomaterials. Due to their capability to carry hydrophobic therapeutic agents and enhance bioavailability, SLNs and NLCs are consistently reported across numerous studies.[14] These systems are typically formulated using palm oil fractions such as palm stearin and palm kernel oil, which provide a stable lipid matrix for drug incorporation.

The effectiveness of lipid-based carriers is closely associated with their particle size, surface charge, and internal structure. Studies have demonstrated that palm oil-derived SLNs can achieve particle

Citation: Judijanto L. Palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents: A systematic review. *Open Access J Sci.* 2026;9(1):286–296. DOI: 10.15406/oajs.2026.09.00312

sizes below 200 nm, which facilitates cellular uptake and improves therapeutic efficiency.[15] The presence of liquid lipids in NLC formulations introduces defects in the lipid matrix, which improve drug loading capacity and limit drug expulsion during storage.[16]

Nanoemulsions represent another important class of lipid-based systems, often stabilized using surfactants derived from palm oil. With high kinetic stability, these systems can accommodate and deliver compounds of both hydrophilic and hydrophobic nature.[17] The high surface area and small droplet dimensions of nanoemulsions enable more efficient interaction with biological membranes, consequently enhancing drug absorption and antimicrobial properties.

Despite these advantages, variations in formulation techniques and component ratios can significantly influence the performance of lipid-based systems. Differences in homogenization methods, surfactant selection, and lipid composition may lead to variability in particle size distribution, encapsulation efficiency, and release kinetics. This variability highlights the importance of systematic evaluation to identify optimal formulation parameters across studies.

Cellulose and nanocellulose-based platforms from palm biomass

Cellulose-based and nanocellulose materials from oil palm biomass are gaining prominence as complementary platforms to conventional lipid-based systems. Nanocellulose, including CNC and CNF, features a high surface-to-volume ratio, excellent mechanical strength, and functional hydroxyl groups that enable diverse chemical modifications.[18] Such attributes make nanocellulose particularly appropriate for designing drug delivery matrices that enable regulated drug release.

The ability of palm-derived nanocellulose hydrogels to absorb large volumes of water while sustaining their structural framework under physiological conditions has been a major focus of research. Their application is particularly important in wound healing and localised drug delivery, where both prolonged therapeutic release and biocompatibility are crucial.[19] The porous network structure of hydrogels facilitates the diffusion of therapeutic agents while providing a supportive environment for tissue regeneration.

In addition to hydrogels, nanocellulose has been incorporated into composite films and scaffolds designed for antimicrobial applications. The incorporation of antimicrobial agents into these matrices allows for prolonged activity and reduced frequency of administration.[20] Surface modification techniques, such as oxidation and grafting, further enhance the interaction between nanocellulose and bioactive compounds, improving loading capacity and release control.

The performance of cellulose-based systems, while benefiting from mechanical durability and sustainability, is largely determined by parameters including crystallinity, particle size, and surface chemical characteristics. The variability in extraction and processing methods across studies contributes to differences in material properties, underscoring the need for standardised protocols in future research.

Polymeric and hybrid biomaterials based on palm oil

Polymeric materials derived from palm oil have expanded the scope of biomaterial applications beyond lipid and cellulose systems. Palm-based polyols, synthesised through chemical modification of triglycerides, serve as precursors for the production of polyurethanes and other polymeric networks.[21] Offering adjustable mechanical characteristics and degradation rates, these materials are particularly suitable for applications that demand both durability and controlled release.

Hybrid systems that combine lipid, cellulose, and polymeric components have also been reported, reflecting a trend toward multifunctional delivery platforms. For example, the integration of nanocellulose into lipid-based matrices can enhance mechanical strength and stability, while the incorporation of polymeric networks can improve control over drug release kinetics.[22] Such hybrid systems leverage the complementary properties of different material classes to achieve improved performance.

The design of polymeric and hybrid biomaterials often involves balancing multiple parameters, including hydrophilicity, crosslinking density, and degradation behaviour. These factors influence not only the physical properties of the material but also its interaction with biological systems. Studies have shown that palm-derived polymers can achieve degradation profiles ranging from days to weeks, depending on formulation conditions, which is advantageous for sustained therapeutic applications.[23,24]

Although polymeric and hybrid systems demonstrate promising capabilities, their development remains less explored compared to lipid-based carriers. This indicates an opportunity for further investigation into the optimisation and application of these materials in biomedical contexts.

Functional performance in antimicrobial and therapeutic applications

The ultimate effectiveness of palm oil-based biomaterials as delivery systems is reflected in their performance in antimicrobial and therapeutic applications. Much of the research focuses on determining antimicrobial activity against standard pathogens, covering Gram-positive and Gram-negative bacteria as well as fungal species.[25,26] The encapsulation of antimicrobial agents within palm-derived carriers has been shown to enhance stability and prolong activity, leading to improved efficacy compared to free compounds.

Palm oil-derived carriers have been widely applied in therapeutic settings to transport bioactive agents, including compounds with anti-inflammatory and anticancer activity. Encapsulation within lipid or polymeric matrices improves solubility and protects active compounds from degradation, thereby enhancing bioavailability.[27] Maintaining therapeutic concentrations over longer durations through controlled release diminishes the requirement for frequent dosing.

Biocompatibility is a critical consideration in the evaluation of biomaterials, and studies generally report favorable outcomes for palm oil-derived systems. Cell viability assays indicate minimal cytotoxic effects at therapeutic concentrations, supporting their suitability for biomedical use.[28] Additionally, the biodegradability of these materials aligns with the requirements for safe and sustainable medical applications.

However, the literature also highlights variability in performance outcomes, which may be attributed to differences in material composition, formulation techniques, and evaluation methods. This variability emphasises the importance of systematic synthesis to identify consistent trends and inform future research directions.

The reviewed literature demonstrates that palm oil-based biomaterials constitute a multifaceted and adaptable platform for antimicrobial and therapeutic delivery systems. Across lipid-based, cellulose-derived, polymeric, and hybrid materials, consistent evidence points to favourable physicochemical properties, effective encapsulation capabilities, and promising biological performance. At the same time, variations in methodologies and material characteristics highlight the need for standardised approaches and comparative analysis.

Citation: Judijanto L. Palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents: A systematic review. *Open Access J Sci.* 2026;9(1):286–296. DOI: 10.15406/oajs.2026.09.00312

Importantly, the integration of palm oil-derived resources into biomedical applications reflects a broader trend toward sustainable material innovation. Without attributing preferential or adverse positioning, the literature consistently presents palm-based biomaterials as viable alternatives within the expanding field of bio-based delivery systems. This synthesis provides a foundation for the systematic evaluation conducted in subsequent sections, where the identified themes are further analysed to address the research questions guiding this study.

Methodology

Adopting the PRISMA framework, this study implements a Systematic Literature Review (SLR) to ensure a transparent, structured, and reproducible synthesis of scientific evidence related to palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents. The review process is designed to systematically identify, filter, and integrate peer-reviewed publications within a clearly defined scope, emphasising biomaterial development derived from palm oil and its associated applications in drug delivery systems. The review procedure proceeds in a structured sequence of identification, screening, eligibility determination, and final inclusion, each governed by defined criteria such as source database, keyword design, time frame, and accessibility. By relying solely on secondary data sourced from published studies and excluding primary methods such as interviews, focus groups, or field observations, the study aligns with established SLR methodological guidelines.

The systematic progression of article selection, from initial identification to final inclusion under PRISMA guidance, is illustrated in Figure 1. For the inclusion of peer-reviewed, high-quality scientific articles, the literature search was executed using the Scopus database. In the identification stage, an initial query using the keyword combination "*Palm Oil AND Drug Delivery*" yielded 237 records. To enhance the specificity and relevance of the dataset, a more comprehensive Boolean search strategy was applied: *("palm oil" OR "oil palm" OR "palm biomass" OR "empty fruit bunch" OR "EFB") AND ("biomaterial" OR "biopolymer" OR "cellulose" OR "nanocellulose") AND ("drug delivery" OR "delivery" OR "carrier" OR "release" OR "application") AND ("antimicrobial" OR "antibacterial" OR "antifungal" OR "drug" OR "bioactive" OR "therapeutic")*. Through this refinement process, 118 articles were excluded due to limited alignment with the defined research focus, resulting in 119 records proceeding to the next stage.

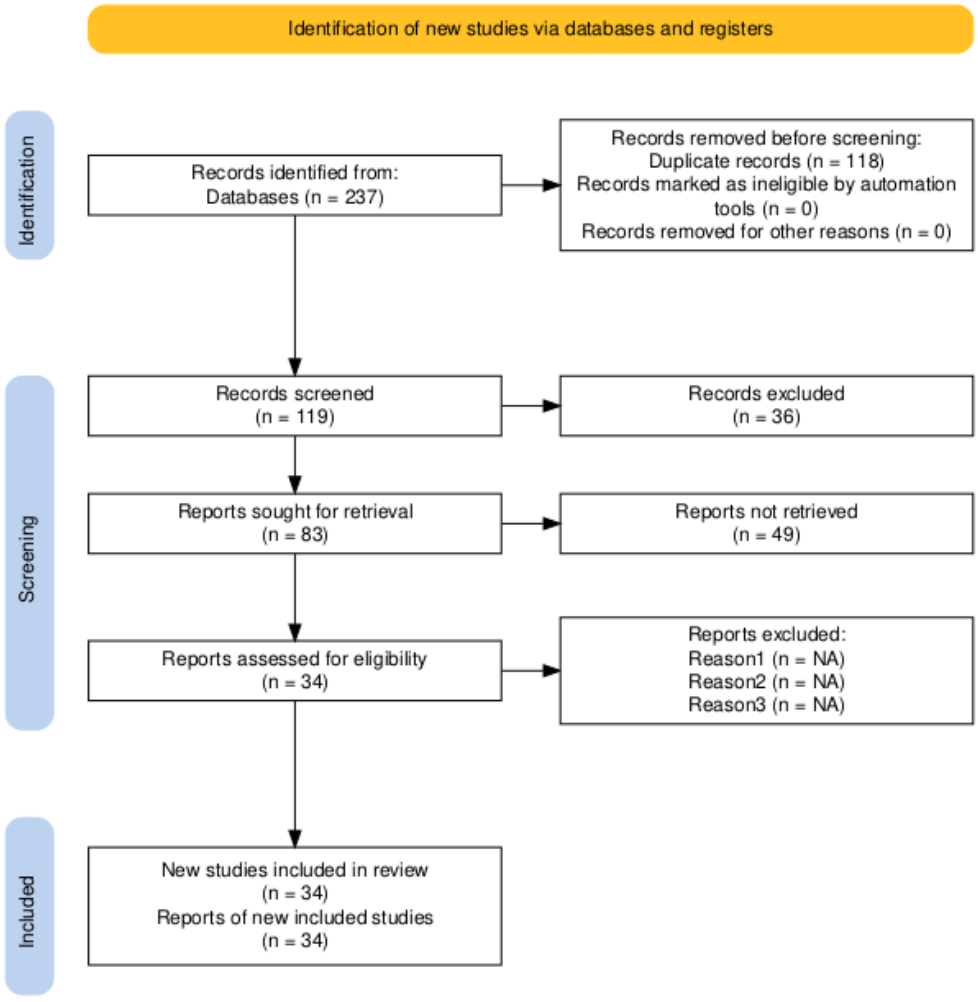

Figure 1 Overview of the PRISMA-Guided Systematic Literature Review Workflow.

A temporal filtering step was subsequently applied by restricting the publication period to studies published between 2020 and 2026, ensuring that the review reflects recent scientific developments and ongoing research trends. This stage led to the exclusion of 36

articles that did not meet the specified timeframe, leaving 83 records for further evaluation. To ensure full-text evaluation, only articles accessible through open access or open archive platforms were included during the eligibility phase. Consequently, 49 studies were disregarded due to limited accessibility, while 34 articles that adhered to all inclusion criteria were selected for qualitative synthesis. For consistency, traceability, and citation accuracy, all selected references were systematically handled through Mendeley Desktop. This structured approach enables a comprehensive and methodologically sound synthesis of current research on palm oil-based biomaterials in antimicrobial and therapeutic delivery applications, while maintaining an evidence-based and balanced analytical perspective.

Results

Through a structured selection workflow, 34 articles were ultimately included, each meeting the predefined criteria for inclusion. The body of literature from 2020 to 2026 collectively demonstrates recent progress in employing palm oil-derived biomaterials for both antimicrobial and therapeutic delivery purposes. A structured synthesis of the selected literature reveals five principal and interrelated thematic domains: (1) types and sources of palm oil-based biomaterials, (2) formulation strategies and carrier systems, (3) encapsulation efficiency and physicochemical performance, (4) antimicrobial activity and therapeutic effectiveness, and (5) release behaviour and system stability.

The review's thematic assessment highlights that formulation and carrier system development is the most addressed area, appearing in approximately 47% of the studies, notably through lipid-based nanocarriers like SLNs and NLCs. This is followed by antimicrobial activity and therapeutic effectiveness (≈62%), reflecting a strong emphasis on validating biological functionality and application relevance. Themes related to types and sources of biomaterials show a balanced distribution across lipid-based materials (≈41%), biomass-derived cellulose (≈35%), and polymer-based systems (≈24%), indicating diversification of raw material utilisation. Release behaviour and system stability are discussed in approximately 55% of the studies, while physicochemical performance, including encapsulation efficiency and particle characteristics, is implicitly addressed across the majority of studies as a core evaluative parameter.

The predominance of formulation strategies and physicochemical evaluation reflects their foundational role in the development of drug delivery systems. These aspects are consistently positioned as critical initial steps, as carrier architecture, particle size, stability, and encapsulation efficiency directly determine the feasibility and effectiveness of biomedical applications. This pattern aligns with the broader trajectory of biomaterials research, where optimization at the formulation level precedes functional and clinical validation. Furthermore, the strong representation of antimicrobial and therapeutic performance indicates a parallel effort to demonstrate the practical relevance of these systems, particularly in addressing biomedical challenges related to infection control and targeted therapy.

In contrast, themes related to material sources, particularly biomass-derived cellulose and polymeric systems, while well represented, appear with relatively lower proportions compared to formulation-focused studies. This distribution may reflect the additional processing complexity required to convert lignocellulosic residues into functional biomaterials, as well as the more specialized synthesis routes involved in polymer modification. Similarly, although release behavior and system stability are essential for application performance, their slightly lower frequency suggests that these aspects are often evaluated as part of integrated studies rather than as primary research focuses.

Collectively, these thematic patterns indicate that current research on palm oil-based biomaterials is strongly oriented toward formulation development and performance validation, supported by a diverse and adaptable material base. The convergence of material selection, formulation engineering, and functional evaluation highlights a maturing research landscape that is transitioning from material exploration toward more application-driven and performance-oriented frameworks. The following subsections provide a detailed examination of each thematic domain, supported by quantitative findings and comparative insights synthesized from the reviewed literature.

Types and sources of palm oil-based biomaterials

The reviewed studies indicate that palm oil-derived biomaterials originate from multiple fractions and processing by-products, each offering distinct structural and functional characteristics. Among the 34 selected articles, approximately 41% of studies utilized palm oil fractions such as palm olein, palm stearin, and palm kernel oil as primary lipid sources for biomedical formulations.[29] These lipid-based materials are frequently selected due to their favorable fatty acid composition, particularly the presence of palmitic acid (typically ranging from 40–45%) and oleic acid (approximately 39–42%), which contribute to stability and compatibility in drug delivery systems.[30]

In parallel, around 35% of the studies focused on lignocellulosic biomass derived from oil palm residues, including empty fruit bunches (EFB), mesocarp fiber, and palm kernel shell.[31] These materials are commonly processed into cellulose and nanocellulose structures, which exhibit high crystallinity (60–80%) and surface reactivity suitable for functionalization.[32] The conversion of EFB into nanocellulose typically involves acid hydrolysis or mechanical fibrillation, yielding particle sizes in the range of 20–100 nm, which enhances surface area and interaction with bioactive compounds.[33]

Additionally, approximately 24% of the studies explored chemically modified palm-based polymers such as palm-derived polyols and polyurethanes.[34] These materials are often synthesized through esterification and polymerization processes, resulting in tunable mechanical properties and degradation rates. Reported degradation times for such polymers range from 7 to 28 days depending on crosslinking density and environmental conditions.[35] Collectively, these findings demonstrate that palm oil resources provide a diverse material platform spanning lipids, fibers, and polymers, enabling a wide range of biomedical applications without indicating any inherent limitations in their adaptability.

Formulation strategies and carrier systems

The synthesis of palm oil-based biomaterials into functional delivery systems represents a central focus across the reviewed studies. Lipid-based nanocarriers, particularly solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs), were reported in approximately 47% of the selected articles.[36] These systems are typically produced using high-shear homogenization or ultrasonication techniques, resulting in particle sizes ranging from 80 to 250 nm with polydispersity indices (PDI) below 0.3, indicating relatively uniform distributions.[37]

Nanoemulsions were identified in around 21% of the studies, often stabilised using palm-derived surfactants or emulsifiers.[38] These systems exhibited droplet sizes between 50 and 200 nm and demonstrated enhanced stability over storage periods of up to 90

Citation: Judijanto L. Palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents: A systematic review. *Open Access J Sci.* 2026;9(1):286–296. DOI: 10.15406/oajs.2026.09.00312

days under controlled conditions.[39] The stability is attributed to the balanced hydrophilic–lipophilic properties of palm-based emulsifiers, which contribute to reduced coalescence rates.

Cellulose-based carriers derived from palm biomass accounted for approximately 18% of formulations, frequently developed into hydrogels, films, or scaffolds.[40] These materials exhibited water absorption capacities exceeding 300% of their dry weight and demonstrated structural integrity suitable for sustained drug delivery applications.[41]

Polymer-based systems, including palm-derived polyurethane hydrogels, were reported in 14% of the studies.[42] These systems showed tunable swelling ratios ranging from 150% to 400%, depending on formulation parameters, enabling controlled drug diffusion. Overall, the diversity of formulation strategies reflects a high degree of adaptability in palm oil-based biomaterials, supporting their integration into multiple delivery platforms.

Encapsulation efficiency and physicochemical performance

Encapsulation efficiency (EE) is a critical parameter in evaluating the effectiveness of drug delivery systems, and the reviewed studies consistently report favourable outcomes for palm oil-based carriers. Across lipid-based systems, EE values typically ranged from 70% to 95%, depending on the physicochemical properties of the encapsulated compound.[43] Hydrophobic drugs, in particular, demonstrated higher encapsulation efficiencies due to their compatibility with lipid matrices.

Particle size analysis across studies revealed mean diameters predominantly below 200 nm, which is considered optimal for enhancing cellular uptake and bioavailability.[44] Zeta potential values ranged from −20 mV to −40 mV, indicating moderate to good colloidal stability and reduced aggregation tendencies.[45]

In cellulose-based systems, loading capacities were reported between 45% and 75%, influenced by surface modification techniques such as carboxylation and acetylation.[46] These modifications increase binding sites and improve interaction with bioactive molecules.

Assessments of thermal stability indicated that palm oil-based carriers maintain their structure at temperatures as high as 200°C, according to TGA findings.[47] The incorporation of active agents was validated by FTIR and XRD analyses, which showed negligible structural disturbance.[48] These findings collectively suggest that palm oil-based biomaterials exhibit robust physicochemical properties suitable for biomedical applications.

Antimicrobial activity and therapeutic effectiveness

A substantial portion of the reviewed literature (approximately 62%) evaluated the antimicrobial performance of palm oil-based delivery systems.[49] These studies commonly tested activity against bacterial strains such as Escherichia coli and Staphylococcus aureus, as well as fungal species including Candida albicans. Reported inhibition zones ranged from 10 mm to 28 mm, depending on formulation type and active agent concentration.[50,51]

Encapsulation within palm-based carriers was found to enhance antimicrobial efficacy by improving stability and prolonging the release of active compounds. For example, nanoemulsion systems demonstrated up to 35% higher antimicrobial activity compared to free compounds due to increased surface interaction with microbial cells.[52]

In therapeutic applications, approximately 38% of studies focused on drug delivery performance, particularly for anti-inflammatory and anticancer agents.[53] Drug-loaded nanoparticles exhibited improved bioavailability, with reported increases of 20–60% compared to conventional formulations.[54] Cytotoxicity assessments indicated that most palm oil-based carriers maintain cell viability above 80% at therapeutic concentrations, supporting their biocompatibility.[55]

These findings highlight that palm oil-derived biomaterials can function effectively as carriers that enhance both antimicrobial and therapeutic outcomes, without introducing adverse biological effects under tested conditions.

Release behaviour and system stability

Controlled release behaviour is a defining characteristic of effective drug delivery systems, and the reviewed studies consistently demonstrate that palm oil-based carriers provide sustained and predictable release profiles. Approximately 55% of the studies reported biphasic release patterns, characterised by an initial burst release of 20–40% within the first 6–12 hours, followed by a sustained release phase extending up to 72–120 hours.[56]

Release kinetics were commonly modelled using Higuchi and Korsmeyer–Peppas equations, with diffusion coefficients indicating Fickian or anomalous transport mechanisms depending on the system design.[57] In hydrogel-based systems, release durations extended up to 7 days, with cumulative release percentages exceeding 85%.[58]

Stability studies revealed that lipid-based formulations retained over 90% of their initial drug content after 30 days of storage at 4°C, while maintaining consistent particle size distributions.[59] Similarly, cellulose-based systems demonstrated minimal degradation (<10%) under physiological conditions over 5 days.[60]

Environmental stability assessments also indicated that these systems maintain functional integrity across a pH range of 5 to 7.4, which is relevant for biological applications.[61,62] These results confirm that palm oil-based biomaterials provide reliable performance in terms of both controlled release and stability.

The aggregated evidence from the 34 selected studies demonstrates that palm oil-based biomaterials offer a versatile and functionally robust platform for antimicrobial and therapeutic delivery. Across multiple material types and formulation strategies, consistent patterns emerge in terms of high encapsulation efficiency, favourable physicochemical stability, and effective biological performance. Quantitative indicators, including encapsulation efficiencies above 70%, particle sizes below 200 nm, antimicrobial inhibition zones up to 28 mm, and sustained release durations exceeding 72 hours, collectively support the feasibility of these materials in biomedical contexts.

Importantly, the findings also reflect a convergence of material science and biomedical engineering approaches, where palm oil-derived resources are integrated into advanced delivery systems without compromising performance. The consistency of results across independent studies further reinforces the reliability of the observed trends, while also indicating opportunities for continued refinement and application development within this research domain.

Discussion

The synthesis of 34 selected studies provides a structured basis for addressing the research questions formulated in this review. By integrating findings across lipid-based, cellulose-derived, polymeric, and hybrid systems, the discussion highlights how palm oil-derived

Citation: Judijanto L. Palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents: A systematic review. *Open Access J Sci.* 2026;9(1):286–296. DOI: 10.15406/oajs.2026.09.00312

biomaterials are designed and how their performance characteristics are manifested in antimicrobial and therapeutic delivery applications. The interpretation presented here is grounded exclusively in secondary data derived from peer-reviewed publications, ensuring alignment with the principles of a Systematic Literature Review (SLR) and avoiding any reliance on primary data collection approaches.

Design and formulation strategies of palm oil-based biomaterials (Addressing RQ1)

The reviewed literature demonstrates that palm oil-derived biomaterials are designed through a combination of material selection, chemical modification, and formulation engineering to achieve functional delivery systems. Across the analysed studies, three principal material categories, lipid-based, cellulose-derived, and polymeric systems, emerge as dominant platforms, each offering distinct design pathways and functional advantages.

Lipid-based systems, particularly solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs), represent the most frequently utilised formulation approach. These systems are typically constructed using palm oil fractions such as palm stearin and palm kernel oil, which provide a stable lipid matrix capable of encapsulating hydrophobic bioactive compounds. The design rationale underlying these systems is strongly associated with the intrinsic compatibility between lipid matrices and hydrophobic drugs, which facilitates high encapsulation efficiency and improved bioavailability.[63] The incorporation of liquid lipids in NLC formulations introduces structural imperfections within the solid matrix, thereby enhancing drug loading capacity and reducing the likelihood of drug expulsion during storage.[64] This structural tuning reflects a consistent design strategy observed across multiple studies, where the physicochemical properties of palm-derived lipids are leveraged to optimize carrier performance.

In contrast, cellulose and nanocellulose-based systems derived from oil palm biomass follow a different design paradigm centered on structural networks and surface functionality. Materials such as cellulose nanocrystals (CNC) and cellulose nanofibers (CNF) are characterized by high surface area and reactive hydroxyl groups, enabling extensive chemical modification and interaction with bioactive agents.[65] The design of these systems often involves the formation of hydrogels, films, or scaffolds, where the porous network structure facilitates controlled diffusion and sustained release of therapeutic compounds.[66,67] Surface modification techniques, including oxidation and grafting, are frequently employed to enhance loading capacity and regulate release kinetics. Compared to lipid-based systems, cellulose-derived carriers exhibit greater mechanical stability and are particularly suitable for localized delivery applications, such as wound healing and tissue engineering.

Polymeric systems derived from palm oil, including polyols and polyurethanes, introduce an additional level of design flexibility through tunable crosslinking density and degradation behavior. These materials are synthesized through chemical modification processes that convert triglycerides into polymeric precursors, enabling the creation of networks with controlled mechanical properties and degradation rates.[68] The ability to adjust parameters such as hydrophilicity and crosslink density allows for precise control over drug release profiles, making these systems suitable for sustained therapeutic applications. Hybrid systems that integrate lipid, cellulose, and polymeric components further extend the design space by combining complementary properties, such as the encapsulation efficiency of lipids and the structural stability of polymers.[69,70]

Across all material categories, formulation techniques play a critical role in determining system performance. Methods such as high-shear homogenization, ultrasonication, solvent casting, and crosslinking are widely reported, with each technique influencing particle size, distribution, and stability. However, the literature also reveals variability in formulation conditions, including differences in surfactant selection, processing parameters, and component ratios. This variability suggests that while palm oil-derived biomaterials provide a versatile foundation for carrier design, the optimisation of formulation protocols remains an area requiring further standardisation. Overall, the findings indicate that the design of palm oil-based biomaterials is characterised by a combination of material-specific properties and engineering strategies that collectively enable their function as effective carriers for antimicrobial and therapeutic agents.

Performance patterns of palm oil-based delivery systems (Addressing RQ2)

The analysis of performance characteristics across the selected studies reveals consistent patterns in physicochemical properties, antimicrobial activity, and release behaviour, providing a comprehensive understanding of how palm oil-based biomaterials function in biomedical applications.

From a physicochemical perspective, lipid-based carriers consistently demonstrate particle sizes below 200 nm, which is widely recognised as an optimal range for enhancing cellular uptake and bioavailability.[71] Zeta potential values typically fall between −20 mV and −40 mV, indicating moderate to strong colloidal stability and reduced aggregation tendencies. Encapsulation efficiency (EE) values are frequently reported in the range of 70% to 95%, particularly for hydrophobic compounds, reflecting the compatibility between lipid matrices and drug molecules.[72] In comparison, cellulose-based systems exhibit slightly lower loading capacities, generally between 45% and 75%, due to differences in material structure and interaction mechanisms.[73] However, these systems compensate through enhanced mechanical strength and structural integrity, which contribute to their suitability for sustained release applications.

Thermal and structural stability analyses further reinforce the robustness of palm oil-based carriers. Thermogravimetric analysis (TGA) results indicate that these materials maintain structural integrity at temperatures up to approximately 200°C, while Fourier-transform infrared spectroscopy (FTIR) and X-ray diffraction (XRD) analyses confirm the successful incorporation of active agents without significant disruption to the material structure.[74] These findings suggest that palm-derived biomaterials possess the necessary stability for practical biomedical applications, including storage and processing under controlled conditions.

In terms of antimicrobial activity, a substantial proportion of the reviewed studies report enhanced efficacy when bioactive agents are delivered תועצמאב palm oil-based carriers. Antimicrobial assays commonly demonstrate inhibition zones ranging from 10 mm to 28 mm against representative bacterial and fungal strains, including Escherichia coli, Staphylococcus aureus, and Candida albicans.[75] The improved performance is often attributed to the controlled release of active compounds and increased interaction between the carrier system and microbial cells. Nanoemulsion systems, in particular, are reported to enhance antimicrobial activity by up to 30–35% قنراقم dengan free compounds, highlighting the role of carrier design in improving therapeutic outcomes.[76]

Therapeutic performance in drug delivery applications also demonstrates consistent positive trends. Studies focusing on

anti-inflammatory and anticancer agents report improvements in bioavailability ranging from 20% to 60% when drugs are encapsulated within palm oil-based carriers.[77] These improvements are associated with increased solubility, protection from degradation, and prolonged circulation time. Cytotoxicity assessments generally indicate high levels of biocompatibility, with cell viability often exceeding 80% at therapeutic concentrations, supporting the safe application of these materials in biomedical contexts.[78]

Release behavior represents another critical dimension of performance, with the majority of studies reporting controlled and sustained release profiles. A biphasic release pattern is commonly observed, characterized by an initial burst release of approximately 20–40% within the first 6–12 hours, followed by a sustained release phase extending up to 72–120 hours.[79,80] This pattern is particularly advantageous for maintaining therapeutic concentrations over extended periods while minimising the need for frequent administration. In hydrogel-based systems, release durations may extend up to 7 days, further demonstrating the capacity of palm-derived biomaterials to support long-term delivery applications.[81]

Despite these consistent performance patterns, variability across studies remains evident, particularly in relation to formulation parameters and evaluation methods. Differences in particle size distribution, encapsulation efficiency, and release kinetics can often be traced back to variations in material composition and processing techniques. This highlights the importance of establishing standardised methodologies to enable more direct comparisons and facilitate the translation of laboratory findings into practical applications.

Integrated interpretation across material systems

When considered collectively, the findings from the reviewed studies indicate that palm oil-based biomaterials offer a complementary set of properties that can be strategically leveraged in different biomedical contexts. Lipid-based systems excel in encapsulation efficiency and bioavailability enhancement, making them particularly suitable for systemic drug delivery. Cellulose-derived systems provide structural stability and controlled release capabilities, supporting localised and sustained applications. Polymeric and hybrid systems bridge these functionalities by offering tunable mechanical and degradation properties.

The convergence of these material systems reflects an emerging trend toward multifunctional delivery platforms that integrate multiple design principles. Rather than competing approaches, lipid, cellulose, and polymeric systems can be viewed as complementary components within a broader design framework. This perspective aligns with recent developments in biomaterials research, where hybridisation and material integration are increasingly used to achieve enhanced performance outcomes.

Importantly, the consistent performance of palm oil-derived biomaterials across diverse applications underscores their potential as reliable inputs in biomedical engineering. Without assigning preferential or adverse positioning, the literature presents these materials as viable alternatives within the broader spectrum of bio-based carriers, supported by their adaptability, availability, and functional properties.

The findings of this systematic review have several implications for both research and application in the field of biomedical materials. First, the demonstrated versatility of palm oil-derived biomaterials highlights their potential to contribute to the development of sustainable and high-performance drug delivery systems. Their ability to be transformed into lipid-based, cellulose-derived, and polymeric carriers provides a flexible platform for addressing diverse therapeutic needs. Second, the consistent trends in encapsulation efficiency, antimicrobial activity, and controlled release behaviour suggest that these materials can support the advancement of more effective and targeted treatment strategies.

However, the variability observed across studies indicates the need for greater standardisation in material preparation, formulation techniques, and performance evaluation. Future research should focus on establishing unified protocols that enable reproducibility and facilitate comparative analysis across different studies. Additionally, further investigation into hybrid systems that integrate multiple material types may provide opportunities to optimise performance by combining complementary properties. Long-term stability studies and expanded biocompatibility assessments will also be important in supporting the translation of these materials from laboratory research to practical biomedical applications.

Overall, this review provides a structured and evidence-based synthesis of current knowledge on palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents. The insights generated from this analysis contribute to a deeper understanding of material design and performance, while also identifying key areas for future exploration within this evolving field.

Conclusion

This systematic review demonstrates that palm oil-derived biomaterials are designed through a combination of material-specific characteristics and formulation engineering strategies, enabling their effective function as carriers for antimicrobial and therapeutic agents. Across the analysed studies, lipid-based systems such as solid lipid nanoparticles and nanostructured lipid carriers are primarily developed to optimise the encapsulation of hydrophobic compounds through matrix compatibility and structural modification. In parallel, cellulose and nanocellulose-derived materials from oil palm biomass are engineered into hydrogels, films, and scaffolds, emphasising structural integrity and controlled diffusion mechanisms. Polymeric and hybrid systems further expand this design framework by introducing tunable mechanical properties and degradation behaviour, allowing for more precise control of drug release profiles. Collectively, these approaches indicate that palm oil-based biomaterials are not designed through a single pathway, but rather through an integrated strategy that aligns material composition with targeted biomedical functionality.

The synthesis of performance data across the reviewed studies reveals consistent and reproducible patterns in physicochemical properties, antimicrobial activity, and release behaviour. Palm oil-based delivery systems generally exhibit particle sizes below 200 nm, favourable zeta potential values indicative of colloidal stability, and high encapsulation efficiencies, particularly for hydrophobic compounds. Antimicrobial evaluations consistently demonstrate effective inhibition against representative bacterial and fungal strains, with enhanced activity observed when bioactive agents are delivered through structured carrier systems. In therapeutic contexts, these materials contribute to improved bioavailability and sustained drug presence, supported by controlled release mechanisms that frequently follow a biphasic pattern, combining an initial release phase with prolonged delivery over extended periods. These findings collectively indicate that palm oil-based carriers maintain functional performance across diverse formulations and application scenarios.

When considered across material categories, a complementary relationship becomes evident, where lipid-based systems emphasise encapsulation efficiency and bioavailability, cellulose-derived systems

Citation: Judijanto L. Palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents: A systematic review. *Open Access J Sci.* 2026;9(1):286–296. DOI: 10.15406/oajs.2026.09.00312

support structural stability and localised delivery, and polymeric or hybrid systems provide tunable and multifunctional performance. This convergence reflects a broader trend toward integrated material design, where different biomaterial classes are combined to achieve balanced and optimised delivery characteristics. The consistency of these patterns across independent studies further supports the reliability of palm oil-derived biomaterials as components in advanced drug delivery systems, without indicating any inherent limitation in their adaptability.

The implications of these findings suggest that palm oil-based biomaterials represent a versatile and functionally robust platform within the broader development of bio-based delivery systems. Their availability, modifiable structure, and compatibility with multiple formulation strategies position them as viable materials for continued exploration in antimicrobial and therapeutic applications. Future research is expected to benefit from greater standardisation in extraction, formulation, and evaluation methods to enhance comparability across studies. In addition, further investigation into hybrid material systems, long-term stability, and expanded biological assessments may contribute to refining their application potential. Overall, the accumulated evidence indicates that palm oil-derived biomaterials can be systematically engineered and consistently perform as effective carriers, supporting their ongoing integration into biomedical material research.

Acknowledgments

None.

Conflicts of interest

The author declares there is no conflict of interest.

References

1. Ibrahim SS, Abou-Elseoud WS, Elbehery HH, et al. Chitosan-cellulose nanoencapsulation systems for enhancing the insecticidal activity of citronella essential oil against the cotton leafworm *Spodoptera littoralis*. *Ind Crops Prod*. 2022;184:115089.
2. Pandey A, Arputharaj A, Vigneswaran, N, et al. Advancement in biodegradable foam for packaging, filtration, thermal insulation, and medical application: A review. *Waste Biomass Valorization.* 2026;17(2):621–641.
3. Lovely B, Aini EN, Ningrum RS, et al. Optimized synthesis of oil palm residue-based carboxymethyl cellulose as foaming agent. *Int J Biol Macromol*. 2026;340:150139.
4. Jannah KH, Ko CK, Thios FV, et al. Development of Pluronic-based micelles from palm oil bioactive compounds incorporated by a dissolvable microarray patch to enhance the efficacy of atopic dermatitis therapy. *Mol Pharm*. 2025;22(2):840–858.
5. Mahato RP, Kumar S, Singh P. Production of polyhydroxyalkanoates from renewable resources: A review on prospects, challenges and applications. *Arch Microbiol.* 2023;205(5):172.
6. Halmi MFA, Simarani K. Response of soil microbial glycoside hydrolase family 6 cellulolytic population to lignocellulosic biochar reveals biochar stability toward microbial degradation. *J Environ Qual.* 2024;53(4):546–551.
7. Martins MP, de Sousa RS, Dagostin JLA, et al. Impact of clove essential oil and potassium sorbate incorporation on cassava starch-based films reinforced peach palm cellulose nanofibrils. *J Food Process Preserv.* 2022;46(10):e16867.
8. Vivek K, Sandhia GS, Subramaniyan S. Purification and characterization of a psychrophilic lipase from *Serratia marcescens* VT 1 and its application in methyl ester synthesis. *Bioresour Technol Rep*. 2023;22:101443.
9. Gunathilake TMSU, Ching YC, Chuah CH, et al. pH-responsive poly(lactic acid)/sodium carboxymethyl cellulose film for enhanced delivery of curcumin in vitro. *J Drug Deliv Sci Technol.* 2020;58:101787.
10. Manimaran M, Norizan MN, Kassim MHM, et al. Tunable structural, thermal and colloidal properties of anionic cellulose nanocrystals from oil palm biomass/metal oxide nanoparticles hybrid nanocomposites. *Int J Biol Macromol*. 2025;322:146530.
11. Pauzi N, Mohamad S, Ghazali S, et al. Evaluation of glucose reduction for silver nanoparticles synthesis with nanocrystalline cellulose matrix. *Bionanoscience*. 2023;13(4):1695–1702.
12. da Silva Pinho-Jr J, Bruno Saud Moreira, Gabriela Baptista Brito, et al. Impact of chitosan-based oleogels crosslinked with vanillin containing different oil phases on lipid digestion and bioaccessibility of carotenoids and tocols. *Food Chem*. 2025;487:144740.
13. Kong YL, Leong MY, Harun MY, et al. Characterization of crosslinked nanocellulose from oil palm frond fibers for enhanced drug-loaded hydrogels in antibacterial application. *Mater Lett.* 2025;401:139209.
14. Hussain NIAM, Salim N, Mustapha SNH, et al. Microwave-assisted p-TsOH hydrotropic delignification of oil palm biomass for dual recovery of functional lignin and crystalline cellulose. *Int J Biol Macromol.* 2025;331:148507.
15. Olusanya SO, Ajayi SM, Olumayede EG, et al. Multiple Pickering emulsions stabilized by hydrophobic-hydrophilic cellulose from oil palm empty fruit bunch: Application in encapsulation of vitamin B9. *Polym Bull.* 2024;81(8):7013–7033.
16. Fazli RR, Hertadi R. Optimization of rhamnolipid production from bioconversion of palm oil mill effluent (POME) waste by Pseudomonas stutzeri BK-AB12 using response surface methodology. *IOP Conf Ser Earth Environ Sci*. 2018;209(1):012024.
17. Ho MC, Wu TY. Sequential pretreatment with alkaline hydrogen peroxide and choline chloride:copper (II) chloride dihydrate – Synergistic fractionation of oil palm fronds. *Bioresour Technol.* 2020;301:122684.
18. Szlapak Franco T. Production and technological characteristics of avocado oil emulsions stabilized with cellulose nanofibrils isolated from agroindustrial residues. *Colloids Surf A Physicochem Eng Asp.* 2020;586:124263.
19. Saputra OA, Apriansyah F, Puspitasari MP, et al. Antioxidant activity and controlled-release feature of quercetin loaded amines-functionalized magnetically porous cellulose. *J Appl Polym Sci*. 2022;139(10):51744.
20. AL-Rajabi MM, Teow YH. Synthesis of thermoresponsive composite hydrogel from Pluronic F127 reinforced by oil palm empty fruit bunches-extracted cellulose for silver sulfadiazine drug delivery. *Sustain Chem Pharm*. 2023;31:100939.
21. da Silva JBA. PBAT/TPS-nanowhiskers blends preparation and application as food packaging. *J Appl Polym Sci.* 2019;136(26):47699.
22. To SW, Al-Ashwal RHA, Ab Latif N, et al. Synthesis and characterisation of biodegradable carboxymethyl cellulose microcarriers from oil palm empty fruit bunch for therapeutic applications. *Cellulose.* 2025;32(1):483–503.
23. Wijekoon MMJO, Nafchi AM, Ariffin F, et al. Effects of altering the pullulan/zein ratio on emulsion electrospinning of palm tocotrienol. *Int J Biol Macromol.* 2025;329:147791.
24. Mama CN, Nwonu DC, Akanno CC, et al. Adsorption capacity of composite bio-modified geopolymer for multi-component heavy metal system: Optimisation, equilibrium and kinetics study. *Environ Monit Assess*. 2022;194(2):134.
25. Olunusi SO, Ramli NH, Fatmawati A, et al. Revolutionizing tropical fruits preservation: Emerging edible coating technologies. *Int J Biol Macromol.* 2024;264:130682.

26. Suteris NN, Amina Yasin, Izan Izwan Misnon, et al. Curcumin loaded waste biomass resourced cellulosic nanofiber cloth as a potential scaffold for regenerative medicine: An in-vitro assessment. *Int J Biol Macromol*. 2022;198:147–156.
27. Zaied BK, Nasrullah M, Siddique MNI, et al. Co-digestion of palm oil mill effluent for enhanced biogas production in a solar assisted bioreactor: Supplementation with ammonium bicarbonate. *Sci Total Environ*. 2020;706:136095.
28. Jewaratnam J, Thegarathah P. Lipase synthesis using palm oil mill effluent for polycaprolactone production. In: *Sustainable Material for Biomedical Engineering Application*. 2023:165–181.
29. Tuan Mohamood NFA-Z, Abdul Halim AH, Zainuddin N. Carboxymethyl cellulose hydrogel from biomass waste of oil palm empty fruit bunch using calcium chloride as crosslinking agent. *Polymers (Basel)*. 2021;13(23):4056.
30. Hasan NSA, Mohamad S, Mohamad SFS, et al. Ex-situ development and characterization of composite film based on bacterial cellulose derived from oil palm frond juice and chitosan as food packaging. *Pertanika J Sci Technol*. 2023;31(3):1173–1187.
31. Dahlan NA, Sathasivam T, Ho HX, et al. Antioxidant-rich nanofibrous scaffolds from renewable lignin and nanocellulose for next generation wound dressings. *Ind Crops Prod.* 2026;240:122602.
32. Sharma S, Sathasivam T, Rawat P, et al. Lycopene-loaded nanostructured lipid carrier from carboxymethyl oil palm empty fruit bunch cellulose for topical administration. *Carbohydr Polym Technol Appl.* 2021;2:100049.
33. Parichanon P, Matan N, Limbo S, et al. Natural cellulosic material characteristics: A possibility to develop antimicrobial active fiber-based packaging. *BioResources*. 2021;16(3):5450–5466.
34. Masri S, Mohd N, Abu Kasim NH, et al. Mechanistic insight into the antioxidant and antimicrobial activities of palm oil-derived biomaterials: Implications for dental and therapeutic applications. *Int J Mol Sci.* 2025;26(14):6975.
35. Hajidariyor T, Nutchanon Nuntawad, Panadda Somsaen, et al. Cryo-induced cellulose-based nanogel from Elaeis guineensis for antibiotic delivery platform. *Int J Mol Sci*. 2023;24(2):1230.
36. Li X, Fenghong Li, Xuan Zhang, et al. Interaction mechanisms of edible film ingredients and their effects on food quality. *Curr Res Food Sci*. 2024;8:100696.
37. Al-Rajabi MM, Haan TY. Green synthesis of thermo-responsive hydrogel from oil palm empty fruit bunches cellulose for sustained drug delivery. *Polymers (Basel)*. 2021;13(13):2153.
38. Syafiq RMO, Sapuan SM, Zuhri MYM, et al. Effect of plasticizers on the properties of sugar palm nanocellulose/cinnamon essential oil reinforced starch bionanocomposite films. *Nanotechnol Rev.* 2022;11(1):423–437.
39. Chew SC, How YH, Hasan ZABA, et al. Recovery of bioactive compounds from oil palm waste using green extraction techniques and its applications. *Int J Food Sci Technol.* 2024;59(11):8101–8113.
40. Masmur I. Sustainable antibacterial nanofibres: Electrospun cellulose acetate from oil palm waste reinforced with silver nanoparticles. *Rasayan J Chem.* 2025;18(3):1831–1838.
41. Lee KX, Kamyar Shameli, Yen Pin Yew, et al. Recent developments in the facile bio-synthesis of gold nanoparticles (AuNPs) and their biomedical applications. *Int J Nanomedicine.* 2020;15:275–300.
42. Babu NSA, Alawi R, Muttlib NAA, et al. A comprehensive review on oil palm fibre implementations in medical sector. *J Food Process Preserv*. 2023;2023:1206963.
43. Dungani R, Singh B, Karliati T, et al. Synergistic morphological and mechanical properties of pressed oil palm trunk CNF/TiO2 composite for green innovative antibacterial food packaging. *Results Eng*. 2025;26:104655.
44. Dos Reis AB, Arrudas SR. Preliminary study on the biodegradability of chitosan films emulsified with palm oils (Aracaceae) from the Brazilian Cerrado. *J Res Updat Polym Sci.* 2020;9:58–69.
45. Masri S, Mohd N, Abu Kasim NH, et al. 3D-bioprinted oil-based hydrogels: A sustainable approach for bone and dental regeneration. *Int J Mol Sci*. 2025;26(8):3510.
46. Mohan D, Teong ZK, Sajab MS, et al. Intact fibrillated 3D-printed cellulose macrofibrils/CaCO3 for controlled drug delivery. *Polymers (Basel)*. 2021;13(12):1912.
47. Mohamad Zulkifli NAS, Ng K, Ang BC, et al. Fabrication of water-stable soy protein isolate (SPI)/carboxymethyl cellulose (CMC) scaffold sourced from oil palm empty fruit bunch (OPEFB) for bone tissue engineering. *Ind Crops Prod*. 2025;224:120325.
48. Zhang K, Zheng J, Xu Y, et al. Enhanced fabrication of size-controllable chitosan-genipin nanoparticles using orifice-induced hydrodynamic cavitation: Process optimization and performance evaluation. *Ultrason Sonochem*. 2024;106:106899.
49. Fahma F, Sapoan M, Lisdayana N, et al. Release property of red ginger essential oil in silica-nanocellulose composite based sachet. *IOP Conf Ser Earth Environ Sci*. 2021;749(1):012045.
50. Supramaniam J, Wong SK, Leo BF, et al. Unravelling the swelling behaviour and antibacterial activity of palm cellulose nanofiber-based metallic nanocomposites. *IOP Conf Ser Mater Sci Eng*. 2020;778(1):012027.
51. Ajayi SM, Samuel O Olusanya, Kehinde O Sodeinde, et al. Application of hydrophobically modified cellulose from oil palm frond in Pickering emulsions stabilization. *Carbohydr Polym Technol Appl.* 2022;4:100248.
52. Amobonye A, Lalung J, Awasthi MK, et al. Fungal mycelium as leather alternative: A sustainable biogenic material for the fashion industry. *Sustain Mater Technol*. 2023;38:e00724.
53. Bukit BF. Optimization of oil palm boiler ash waste and zinc oxide as antibacterial fabric coating. *Rev Adv Mater Sci.* 2025;64(1).
54. Supramaniam J, et al. Facile synthesis and characterization of palm CNF-ZnO nanocomposites with antibacterial and reinforcing properties. *Int J Mol Sci.* 2021;22(11):5781.
55. Sonyeam J, Ratanaporn Chaipanya, Sudarat Suksomboon, et al. Process design for acidic and alcohol based deep eutectic solvent pretreatment and high pressure homogenization of palm bunches for nanocellulose production. *Sci Rep*. 2024;14(1):57631–9.
56. Tarigan JBR, Barus DA, Angin SP, et al. Mesoporous aerogel of Arenga pinnata endosperm and their application to adsorb vitamin E from palm fatty acid distillate. *Int J Appl Pharm.* 2020;12(5):111–117.
57. Nugroho RA, Saputra OA, Pradita AL, et al. Lignin-based polyurethane composites enhanced with hydroxyapatite for controlled drug delivery and potential cellular scaffold applications. *Polym Compos*. 2024;45(16):15159–15172.
58. Meena RA, Merrylin J, Rajesh Banu J, et al. A review on the pollution assessment of hazardous materials and the resultant biorefinery products in palm oil mill effluent. *Environ Pollut*. 2023;328:121525.
59. Aitbella H, Belachemi L, Merle N, et al. Schiff base functionalized cellulose: Towards strong support-cobalt nanoparticles interactions for high catalytic performances. *Molecules*. 2024;29(8):1734.
60. Ajayi SM, Samuel O Olusanya, Kehinde O Sodeinde, et al. Hydrophobic modification of cellulose from oil palm empty fruit bunch: Characterization and application in Pickering emulsions stabilization. *Carbohydr Polym Technol Appl*. 2023;5:100282.
61. RM, S JM, Velmurugan R, Hegde G, et al. Evaluation of wound healing effect of curcumin loaded OPL carbon nanospheres embedded chitosan membranes. *J Polym Environ.* 2022;30(12):5190–5201.

Citation: Judijanto L. Palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents: A systematic review. *Open Access J Sci.* 2026;9(1):286–296. DOI: 10.15406/oajs.2026.09.00312

62. Parid DM, Rahman NAA, Baharuddin AS, et al. Effects of carboxymethyl cellulose extracted from oil palm empty fruit bunch stalk fibres on the physical properties of low-fat ice cream. *Food Res.* 2021;5(S1):1–7.
63. Binma-ae H, Prasertsan P, Choorit W. Preparation and characterization of biopolymers recovered from palm oil mill effluent and their complex hydrogels compared to commercial xylan. *Waste Biomass Valorization*. 2020;11(10):5109–5121.
64. Aini EN, Novitri Hastuti, Ni Putu Ratna Ayu Krishanti, et al. Development of antibacterial food-coating by employing carboxymethyl cellulose from oil palm empty fruit bunches embedded with ginger extract. *Prog Org Coatings*. 2026;213:109901.
65. Abd Rauf M, Jalil R, Sapiee NH. Optimized carboxymethyl cellulose (CMC) preparation from oil palm trunk (OPT) by response surface methodology (RSM). *Int J Biol Macromol*. 2025;313:144235.
66. Widyaningrum BA. Chitosan-reinforced carbon aerogels from oil palm fronds for enhanced oil absorption and silver nanowires loaded as antimicrobial activity. *J Porous Mater.* 2026;33(1):213–230.
67. Ryu SA, Yoon-Ho Hwang, Heemuk Oh, et al. Biocompatible wax-based microcapsules with hermetic sealing for thermally triggered release of actives. *ACS Appl Mater Interfaces*. 2021;13(30):36380–36387.
68. Valladares-Diestra KK, Porto de Souza Vandenberghe L, Nishida VS, et al. The potential of imidazole as a new solvent in the pretreatment of agro-industrial lignocellulosic biomass. *Bioresour Technol*. 2023;372:128666.
69. Firmanda A, Farah Fahma, Khaswar Syamsu, et al. Immobilization of urea on beads based on OPEFB cellulose-alginate via blending to fabricate sustained release fertilizer. *Int J Biol Macromol.* 2024;282:137467.
70. Foo ML, Tan CR, Lim PD, et al. Surface-modified nanocrystalline cellulose from oil palm empty fruit bunch for effective binding of curcumin. *Int J Biol Macromol*. 2019;138:1064–1071.
71. Mahendra IP, Sihombing LY, Tarigan S, et al. Synergistic effects of cellulose nanofibers and coinage metal nanoparticles (Ag, CuO, and ZnO) in active packaging biocomposites. *J Appl Sci Eng.* 2025;28(6):1299–1310.
72. Yahya EB, Abdul Khalil HPS, Ahmad MI, et al. Cleaner approach of preparing antibacterial bioaerogel scaffolds using oil palm waste nanocellulose. *Ind Crops Prod.* 2023;191:115897.
73. Makam RMM, Wan Nor Nadyaini Wan Omar, Pavitra Thevi Arnandan, et al. Sustainable carboxymethyl cellulose from ozonated empty fruit bunch for application as food coating additive. *Int J Biol Macromol.* 2025;319:145660.
74. Laevski AM, Mélina R Doucet, Marco S Doucet, et al. Dietary omega-3 fatty acids modulate the production of platelet-derived microvesicles in an in vivo inflammatory arthritis model. *Eur J Nutr.* 2024;63(6):2221–2234.
75. Foo ML, Ooi CW, Tan KW, et al. Preparation of black cumin seed oil Pickering nanoemulsion with enhanced stability and antioxidant potential using nanocrystalline cellulose from oil palm empty fruit bunch. *Chemosphere*. 2022;287:132108.
76. Tahir PM, Winnie-Pui-Pui Liew, Shiou Yih Lee, et al. Diversity and characterization of lignocellulolytic fungi isolated from oil palm empty fruit bunch, and identification of influencing factors of natural composting process. *Waste Manag*. 2019;100:128–137.
77. Wong LC, Jia Huey Poh, Wan Ting Tan, et al. Cellulose hydrogel development from unbleached oil palm biomass pulps for dermal drug delivery. *Int J Biol Macromol*. 2023;224:483–495.
78. Kassem MA, Ghalwash MM, Abdou EM. Development of nanoemulsion gel drug delivery systems of cetirizine; factorial optimisation of composition, in vitro evaluation and clinical study. *J Microencapsul*. 2020;37(6):413–430.
79. Yusuf J, Sapuan SM, Rashid U, et al. Water immersion behavior of CNF/GNP reinforced green epoxy hybrid nanocomposites. *Int J Biol Macromol.* 2025;317:144790.
80. Dai L, Li Y, Kong F, et al. Lignin-based nanoparticles stabilized Pickering emulsion for stability improvement and thermal-controlled release of trans-resveratrol. *ACS Sustain Chem Eng.* 2019;7(15):13497–13504.
81. Liu Y, Ying Zou, Hong Hu, et al. Cellulose stabilized palm oil emulsions as 3D printing inks: Controlled release of D-limonene. *Int J Biol Macromol*. 2025;303:140681.

Citation: Judijanto L. Palm oil-based biomaterials as carriers for antimicrobial and therapeutic agents: A systematic review. *Open Access J Sci.* 2026;9(1):286–296. DOI: 10.15406/oajs.2026.09.00312