Jurnal Kesehatan, Sains, dan Teknologi (JAKASAKTI)
Vol. 5, No. 1 April 2026
Available online at https://jurnal.undhirabali.ac.id/index.php/jakasakti/index

Research Article e-ISSN: 2963-0940

TiO_2/Chitosan-Moringa oleifera Nanocomposites for Wound Dressings: A Systematic Review

Nanokomposit TiO_2/Kitosan-*Moringa oleifera* untuk Penyembuh Luka: Tinjauan Sistematis

Misriyani[1*], Nita Damayanti[2], Wijoyo Halim[3]

[1]Department of Biochemistry, Faculty of Medicine, University of Alkhairaat, Jl. Diponegoro Palu 94221, Central Sulawesi, Indonesia
[2]Department of Public Health, Faculty of Medicine, University of Alkhairaat, Jl. Diponegoro Palu 94221, Central Sulawesi, Indonesia
[3]Department of Neurology, Faculty of Medicine, University of Alkhairaat, Jl. Diponegoro Palu 94221, Central Sulawesi, Indonesia

[*]Corresponding authors: e-mail: misriyani85@gmail.com

Article info

Keywords:
Chitosan; Moringa oleifera; nanocomposite; titanium dioxide; wound dressing

Abstract

Chronic wounds present a major clinical challenge due to persistent infection, oxidative stress, and inflammation that delay healing. TiO_2/chitosan nanocomposites enriched with Moringa oleifera extract have shown potential to enhance wound healing through antibacterial, antioxidant, and anti-inflammatory activities. This systematic review aimed to synthesize current evidence on the development, properties, and biological mechanisms of these composites. A literature search was conducted in PubMed, Embase, and Web of Science up to September 2025 following PRISMA 2020 guidelines. Eligible studies included experimental, preclinical, and clinical research. Data extraction and quality assessment were performed independently. Thirteen studies met the inclusion criteria. The findings indicate that TiO_2 nanoparticles improve mechanical strength and antibacterial activity, while chitosan contributes biocompatibility and intrinsic antimicrobial effects. Moringa oleifera extract provides bioactive compounds that enhance antioxidant activity and modulate inflammation. These composites promote wound closure and tissue regeneration. However, most studies remain preclinical with methodological heterogeneity. Further standardized in vivo studies and clinical trials are required to confirm their long-term safety and therapeutic effectiveness.

Kata kunci:
Kitosan, *Moringa oleifera*, nanokomposit, pembalut luka, titanium dioksida

Abstrak

Luka kronis merupakan tantangan klinis akibat infeksi persisten, stres oksidatif, dan peradangan yang menghambat penyembuhan. Nanokomposit TiO_2/kitosan yang diperkaya ekstrak *Moringa oleifera* berpotensi meningkatkan penyembuhan luka melalui aktivitas antibakteri, antioksidan, dan anti-inflamasi. Tinjauan sistematis ini bertujuan mensintesis bukti terkait pengembangan, sifat, dan mekanisme biologis komposit tersebut. Pencarian literatur dilakukan pada PubMed, Embase, dan Web of Science hingga September 2025 sesuai pedoman PRISMA 2020. Studi yang memenuhi kriteria meliputi penelitian eksperimental, praklinis, dan klinis. Ekstraksi data dan penilaian kualitas dilakukan secara independen. Sebanyak 13 studi memenuhi kriteria inklusi. Hasil menunjukkan bahwa nanopartikel TiO_2 meningkatkan kekuatan mekanik dan aktivitas antibakteri, sementara kitosan memberikan biokompatibilitas dan efek antimikroba. Ekstrak *Moringa oleifera* berkontribusi melalui senyawa bioaktif yang meningkatkan aktivitas antioksidan dan modulasi inflamasi. Komposit ini terbukti mempercepat penutupan luka dan regenerasi jaringan. Namun, sebagian besar studi masih bersifat praklinis dengan metodologi yang beragam. Diperlukan penelitian *in vivo* terstandar dan uji klinis untuk memastikan efektivitas dan keamanan jangka panjang.

INTRODUCTION

Wound healing is a complex and dynamic process involving hemostasis, inflammation, proliferation, and remodeling (Fernández-Guarino et al., 2023). Disruption of this sequence, often caused by microbial infection, oxidative stress, or persistent inflammation, can delay recovery and lead to chronic wounds such as diabetic ulcers, burns, and pressure sores (Dasari et al., 2021). These conditions impose significant health burdens, not only causing pain and functional impairment but also increasing the risk of systemic infection and long-term disability (Briggs et al., 2023; Nguyen et al., 2024). As the prevalence of chronic wounds rises globally, there is a pressing need for advanced therapeutic strategies that actively support tissue regeneration while also addressing infection and inflammation, limitations often observed with conventional wound dressings (Alberts et al., 2025; Deng et al., 2022).

Chitosan, a naturally derived polysaccharide from chitin, has emerged as one of the most promising biomaterials for wound management due to its biocompatibility, biodegradability, and ease of modification (Rajkumar et al., 2024). Beyond serving as a structural scaffold, chitosan exhibits hemostatic, antimicrobial, and tissue-regenerative properties, making it suitable for accelerating wound closure and re-epithelialization (Zhang et al., 2025). Its versatility allows formulation into films, hydrogels, sponges, and nanocomposites, enabling integration with other bioactive agents (Thang et al., 2023). Titanium dioxide (TiO_2) nanoparticles, for instance, possess strong antibacterial activity and have been shown to promote collagen deposition and angiogenesis, further enhancing healing (Sutanti et al., 2022). When combined, chitosan provides a stable and biocompatible matrix, while TiO_2 contributes antimicrobial and regenerative functions, creating a synergistic platform for advanced wound dressings (Ul-Islam et al., 2024).

In addition to synthetic and biopolymer-based components, natural plant-derived extracts such as *Moringa oleifera* have attracted increasing interest in regenerative medicine (Mamgain et al., 2024). Rich in flavonoids, phenolics, and alkaloids, *Moringa* extracts display antimicrobial, antioxidant, and anti-inflammatory properties, all of which are crucial for preventing wound chronicity and promoting tissue repair (Villegas-Vazquez et al., 2025). Experimental evidence suggests that *Moringa* formulations accelerate wound closure, enhance collagen maturation, and strengthen regenerated tissue (Mohammad Shafie et al., 2022). Incorporating *Moringa* into chitosan/TiO_2-based nanocomposites offers an innovative strategy to amplify their bioactivity, combining structural support with phytochemical-mediated modulation of the wound microenvironment (Ganesh et al., 2025).

Despite a growing body of literature, available studies remain heterogeneous, often limited to *in vitro* or small-scale *in vivo* models with variable formulations and outcome measures. This fragmentation makes it difficult to establish standardized protocols or fully understand the synergistic effects of chitosan, TiO_2, and *Moringa*-based systems in wound healing. Therefore, this systematic review aims to consolidate current evidence on these multifunctional wound dressings, focusing on their antibacterial, antioxidant, and anti-inflammatory activities, as well as their capacity to enhance wound repair.

MATERIALS AND METHODS

Study design

This systematic review was conducted according to the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Pagano et al., 2020). The protocol was designed to ensure transparency, reproducibility, and methodological rigor in synthesizing evidence on multifunctional wound dressings based on TiO_2/chitosan nanocomposites incorporating *Moringa oleifera* extract.

Literature search strategy

A comprehensive search was performed in PubMed, Embase, and Web of Science from database inception to September 2025. Both controlled vocabulary (MeSH and Emtree) and free-text terms were used, focusing on *Moringa oleifera*, chitosan, titanium dioxide (TiO_2), and wound dressing or wound healing applications. Boolean operators (AND, OR) and truncation were applied where appropriate, and the complete search strategies for each database are presented in Table 1. No restrictions were applied to publication year or language, and reference lists of included articles and relevant reviews were manually screened to identify additional records.

Table 1. Search strategies used for online databases

Database	Search Strategies	Records
PubMed	(*Moringa oleifera* OR moringa OR kelor) AND (chitosan OR kitosan OR chitin derivative* OR titanium dioxide OR TiO_2 OR titania) AND (wound healing OR wound dressing* OR wound heal* OR biomedical application*)	62
Web of Science	(*Moringa oleifera* OR moringa OR kelor) AND (chitosan OR kitosan OR chitin derivative* OR titanium dioxide OR TiO_2 OR titania) AND (wound dressing* OR wound heal* OR biomedical application*)	36
Medline & EMBASE	(*Moringa oleifera* OR moringa OR kelor) AND (chitosan OR kitosan OR chitin derivative* OR titanium dioxide OR TiO_2 OR titania) AND (wound healing OR wound dressing* OR wound heal* OR biomedical application*)	72

Eligibility criteria

Studies were eligible if they reported the preparation, characterization, or evaluation of TiO_2/chitosan nanocomposites combined with *Moringa oleifera* extract in the context of wound dressings or wound healing. Eligible study types included *in vitro*, *in vivo* (animal), and clinical research. Exclusion criteria were studies unrelated to wound healing, those not involving *Moringa oleifera*, chitosan, or titanium dioxide, narrative reviews, conference abstracts without full text, editorials, and opinion pieces.

Study selection and data extraction

All retrieved records were imported into a reference management tool, and duplicates were removed. Two reviewers independently screened titles and abstracts,

Jurnal Kesehatan, Sains, dan Teknologi (JAKASAKTI)
Vol. 5, No. 1 April 2026
Available online at https://jurnal.undhirabali.ac.id/index.php/jakasakti/index
Research Article e-ISSN: 2963-0940

followed by full-text assessment according to eligibility criteria, with disagreements resolved by consensus or a third reviewer. Data were extracted into a standardized form capturing study characteristics, material composition, synthesis methods, physicochemical and biological outcomes (wound healing, cytotoxicity, and biocompatibility), as well as additional findings such as antibacterial, antioxidant, or anti-inflammatory activity when available. The methodological quality of the included studies was assessed using the Joanna Briggs Institute (JBI) critical appraisal checklists appropriate to each study type, with results summarized in Table 2.

Table 2. Quality assessment and risk of bias of included studies for meta-analysis

ID	Study (Publication year)	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?	Total
1	Ahmed et al (2016)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
2	Al-Fathonah et al (2025)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
3	Alsulimani et al (2025)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
4	Bessalah et al (2024)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
5	Dai et al (2011)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
6	Gupta et al (2019)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
7	Harti et al (2024)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
8	Hassan et al (2021)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
9	Inayatullah et al (2022)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
10	Pagano et al (2020)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
11	Sivaranjani et al (2024)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
12	Soylu et al (2025)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
13	Yaqoob et al (2024)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7

Data synthesis

Given the heterogeneity in study designs, experimental models, material formulations, and reported outcomes, quantitative meta-analysis was not feasible. Instead, a qualitative synthesis was performed, highlighting the consistency and strength of evidence regarding the potential of TiO_2/chitosan/Moringa oleifera nanocomposites as multifunctional wound dressings and the biological mechanisms underpinning their activity.

Jurnal Kesehatan, Sains, dan Teknologi (JAKASAKTI)
Vol. 5, No. 1 April 2026
Available online at https://jurnal.undhirabali.ac.id/index.php/jakasakti/index
Research Article e-ISSN: 2963-0940

RESULT AND DISCUSSION
RESULT
Study selection

The database search identified 170 records (PubMed, n = 62; Embase, n = 72; Web of Science, n = 36). After removing 17 duplicates, 153 articles remained for title and abstract screening. Of these, 127 were excluded as irrelevant, leaving 26 articles for full-text review. Thirteen reports were excluded for reasons such as exposure or intervention not reported (n = 6), outcomes not reported (n = 5), conference abstract or review (n = 1), and non-English publication (n = 1). Ultimately, 13 studies published between 2011 and 2025 were included in this review (Figure 1).

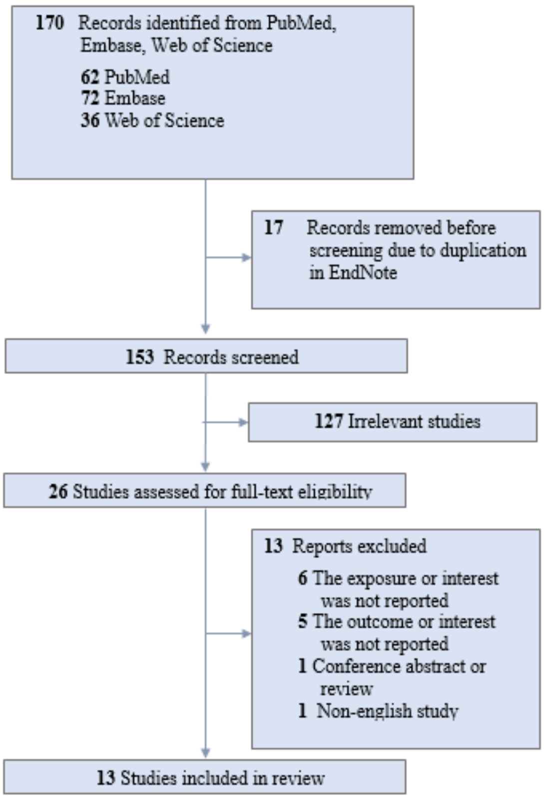

Figure 1. PRISMA 2020 flow diagram illustrating the study selection process, including identification, screening, eligibility, and inclusion stages.

DISCUSSION
Study characteristics

The included studies originated from Asia, Africa, Europe, and the Middle East, reflecting the global interest in biopolymer-based wound dressings. Most studies were experimental, including *in vitro* evaluations, *in vivo* animal models, or physicochemical characterization of nanocomposites, with only one clinical study involving human participants (Gupta et al., 2019). Chitosan was the most common base material (Ahmed & Ikram, 2016; Gupta et al., 2019; Hassan et al., 2021), often combined with gelatin, polyvinyl alcohol (PVA), or other polysaccharides to enhance structural stability and biofunctionality (Bessalah et al., 2024; Inayatullah et al., 2022; Yaqoob et al., 2024). *Moringa oleifera* extracts, derived from leaves, flowers, or seeds, were incorporated for their phytochemical constituents such as flavonoids, tannins, alkaloids, and polyphenols, while TiO_2 nanoparticles were employed to contribute additional antibacterial and regenerative effects (Soylu et al., 2025).

Antibacterial activity

Antibacterial effects were the most consistently observed outcomes across the included studies. Chitosan-based membranes demonstrated notable inhibition of *Staphylococcus aureus* and Escherichia *coli*, particularly when blended with polyvinyl alcohol and subjected to crosslinking processes, which enhanced their antimicrobial activity compared with native polymers (Hassan et al., 2021). The incorporation of Moringa extracts into composite membranes or microparticles also provided antibacterial benefits, particularly against Gram-positive bacteria such as S. aureus, with additional effects on bacterial motility and biofilm formation (Bessalah et al., 2024; Inayatullah et al., 2022).

Similarly, green-synthesized nanoparticles, including TiO_2 and SnO_2 prepared using Moringa extracts, demonstrated dose-dependent bactericidal effects that in some cases were comparable to standard antibiotics (Alsulimani et al., 2025). Formulations such as Moringa seed oil-based oleogels with chitosan further extended antibacterial activity, especially against Gram-negative species such as E. coli (Yaqoob et al., 2024). Together, these findings confirm the strong antimicrobial potential of TiO_2/chitosan/Moringa-based composites through a combination of cell membrane disruption, reactive oxygen species generation, and phytochemical-mediated bacterial inhibition.

Antioxidant activity

Antioxidant mechanisms were also prominent in several studies, supporting the role of these composites in reducing oxidative stress at wound sites. Gelatin-chitosan-Moringa biopolymers effectively prevented oxidative DNA damage, highlighting their ability to act as radical scavengers (Bessalah et al., 2024). Microparticles loaded with *Moringa oleifera* extract released quercetin derivatives with both antioxidant and cell-proliferative effects, promoting keratinocyte growth and thereby contributing to wound closure (Pagano et al., 2020). Similarly, Moringa-based oleogels formulated with chitosan exhibited strong antioxidant activity, with measurable free radical scavenging capacity that protected tissues from oxidative injury (Yaqoob et al., 2024). In addition, TiO_2 nanoparticles synthesized with Moringa leaf extract were shown to mitigate oxidative burden during wound healing, indirectly contributing to antioxidant defense (Santhosh et al., 2025). These findings suggest that antioxidant activity is a critical complementary mechanism in wound healing, preventing secondary tissue damage and supporting the regenerative process.

Anti-inflammatory activity

Anti-inflammatory effects were reported in multiple formulations, reflecting both the intrinsic properties of chitosan and the bioactive compounds of Moringa. Chitosan scaffolds were described as modulators of inflammatory responses, with the ability to reduce pro-inflammatory signaling while promoting tissue repair (Ahmed & Ikram, 2016; Dai et al., 2011). Extracts of Moringa leaves and flowers also provided notable anti-inflammatory activity, although results varied; for instance, Al-Fathonah (2025) found no significant differences in collagen formation *in vivo*, suggesting model-specific or dose-dependent limitations. By contrast, Bessalah et al., (2024) demonstrated that a gelatin–chitosan–Moringa composite strongly suppressed inflammatory markers while maintaining biocompatibility.

Additional support comes from experimental formulations such as galenic anti-inflammatory creams based on chitosan and natural extracts, which effectively reduced inflammation across various wound models including burns and diabetic ulcers (Harti et al., 2024). Reviews of multifunctional polymeric wound dressings further emphasized the integration of anti-inflammatory properties as a crucial step toward optimizing wound healing outcomes (Soylu et al., 2025).

DISCUSSION

This systematic review synthesized evidence from thirteen studies published between 2011 and 2025, examining the potential of TiO_2/chitosan/*Moringa oleifera*-based composites as multifunctional wound dressings. The included studies comprised *in vitro* experiments, *in vivo* animal models, material characterization studies, and one clinical trial, highlighting the growing global interest in biopolymer–nanoparticle–plant extract hybrids for regenerative medicine. Across all studies, these nanocomposites demonstrated promising antibacterial, antioxidant, and anti-inflammatory properties, underscoring their potential to accelerate wound healing through multimodal mechanisms.

The findings confirm that chitosan remains a critical base material due to its biocompatibility, biodegradability, and inherent antimicrobial activity, which can be further enhanced through chemical modifications or blending with other polymers (Ahmed & Ikram, 2016; Dai et al., 2011). Incorporation of TiO_2 nanoparticles provided additional antimicrobial and regenerative, tanninsbenefits, largely through the generation of reactive oxygen species that disrupt bacterial membranes and stimulate tissue remodeling (Soylu et al., 2025). *Moringa oleifera* extracts, rich in flavonoids, and phenolic compounds, contributed to both antibacterial and antioxidant effects, and in some formulations demonstrated anti-inflammatory activity by modulating cytokine expression and collagen deposition (Bessalah et al., 2024; Inayatullah et al., 2022; Pagano et al., 2020). The synergy between these components arises from complementary mechanisms, where TiO_2 generates reactive oxygen species for antibacterial action, chitosan provides membrane disruption and biocompatible scaffolding, and Moringa oleifera extracts contribute antioxidant and anti-inflammatory effects, collectively enhancing wound healing outcomes beyond single-component systems.

Antibacterial activity was consistently reported, with multiple studies showing inhibition of *Staphylococcus aureus and Escherichia coli* through membrane disruption, biofilm inhibition, and oxidative stress pathways (Bessalah et al., 2024; Hassan et al., 2021). These results align with previous literature on chitosan-based biomaterials, where cationic interactions with bacterial cell walls were identified as a key mechanism (Petroni et al., 2023). The addition of Moringa extracts appears to broaden the antibacterial spectrum, while TiO_2 nanoparticles contribute durable, photocatalytic antibacterial effects (Pranoto et al., 2025). Taken together, these findings suggest that multifunctional composites can provide sustained protection against infection, a crucial factor in wound management.

The antioxidant properties observed in several studies further support their role in protecting tissues from secondary damage caused by free radicals during the wound healing process (Pagano et al., 2020; Yaqoob et al., 2024). Oxidative stress is a well-documented barrier to tissue regeneration, particularly in chronic wounds, and the presence of Moringa-derived phytochemicals may represent a natural solution to this challenge (Divya et al., 2024). Similarly, anti-inflammatory outcomes highlight the therapeutic value of these composites (Olson et al., 2024). By suppressing pro-inflammatory responses and promoting granulation tissue formation, chitosan/Moringa-based dressings appear capable of modulating the wound microenvironment to favor tissue repair (Ahmed & Ikram, 2016; Harti et al., 2024). However, results were not entirely consistent, as one study (Dewi, 2024)did not observe significant improvements in collagen formation, suggesting that dose, formulation, or experimental model may influence efficacy.

Despite these promising findings, several limitations must be acknowledged. First, some of the included studies were preclinical, with only one small-scale clinical investigation, limiting the generalizability of results to human populations. Second, there was heterogeneity in study design, including differences in extraction methods, nanoparticle synthesis, polymer modifications, and wound models, which restricts direct comparison and precludes meta-analysis. Third, outcome measures were highly variable, with some studies focusing on antibacterial activity alone, while others evaluated broader endpoints such as collagen deposition, oxidative stress markers, or functional wound closure. Fourth, the absence of standardized long-term follow-up data means that the durability, safety, and potential cytotoxicity of these nanocomposites remain incompletely understood. Finally, the possibility of publication bias cannot be excluded, as positive findings are more likely to be reported than neutral or negative results

CONCLUSION

This systematic review suggests that TiO_2/chitosan/*Moringa oleifera*-based composites represent a promising class of multifunctional wound dressings with demonstrated antibacterial, antioxidant, and anti-inflammatory properties. By combining the biocompatibility and antimicrobial activity of chitosan, the photocatalytic and regenerative effects of TiO_2 nanoparticles, and the bioactive phytochemicals of *Moringa oleifera*, these hybrid materials address several key barriers in wound healing, including infection, oxidative stress, and chronic inflammation. However, current evidence is largely derived from preclinical studies with heterogeneous methodologies, limited clinical validation, and short-term outcomes. Future research should focus on standardized protocols, *in vivo* translational models, and well-designed clinical trials to confirm safety, efficacy, and long-term performance.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Faculty of Medicine, Alkhairaat University for the support, facilities, and academic environment provided during the preparation of this manuscript.

REFERENCES

Ahmed, S., & Ikram, S. (2016). Chitosan based scaffolds and their applications in wound healing. *Achievements in the Life Sciences*, *10*(1), 27–37.

Alberts, A., Moldoveanu, E.-T., Niculescu, A.-G., & Grumezescu, A. M. (2025). Hydrogels for wound dressings: applications in burn treatment and chronic wound care. *Journal of Composites Science*, *9*(3), 133.

Alsulimani, A., Abdullah, S. M., Jerah, A. A., Hendi, A. M., & Farasani, A. (2025). Green Synthesis of Chitosan-coated Tin Dioxide Nanoparticles Using *Moringa oleifera* Flower Extract Against Breast Cancer via the Caspase-dependent Apoptotic Pathway. *Pharmacognosy Magazine*, *21*(1), 305–314.

Bessalah, S., Faraz, A., Dbara, M., Khorcheni, T., Hammadi, M., Ajose, D. J., & Saeed, S. I. (2024). Antibacterial, anti-biofilm, and anti-inflammatory properties of gelatin–chitosan–moringa-biopolymer-based wound dressings towards *Staphylococcus aureus and Escherichia coli*. *Pharmaceuticals*, *17*(5), 545.

Briggs, A. M., Jordan, J. E., Sharma, S., Young, J. J., Chua, J., Foster, H. E., Haq, S. A., Huckel Schneider, C., Jain, A., & Joshipura, M. (2023). Context and priorities for health systems strengthening for pain and disability in low-and middle-income countries: a secondary qualitative study and content analysis of health policies. *Health Policy and Planning*, *38*(2), 129–149.

Dai, T., Tanaka, M., Huang, Y.-Y., & Hamblin, M. R. (2011). Chitosan preparations for wounds and burns: antimicrobial and wound-healing effects. *Expert Review of Anti-Infective Therapy*, *9*(7), 857–879.

Dasari, N., Jiang, A., Skochdopole, A., Chung, J., Reece, E. M., Vorstenbosch, J., & Winocour, S. (2021). Updates in diabetic wound healing, inflammation, and scarring. *Seminars in Plastic Surgery*, *35*(03), 153–158.

Deng, X., Gould, M., & Ali, M. A. (2022). A review of current advancements for wound healing: Biomaterial applications and medical devices. *Journal of Biomedical Materials Research Part*

B: Applied Biomaterials, *110*(11), 2542–2573.

Dewi, S. R. P. (2024). Bioinformatics analysis and biomolecular characterization of salivary alpha amylase as risk factor for dental caries. *Makassar Dental Journal*, *13*(2), 196–201.

Divya, S., Pandey, V. K., Dixit, R., Rustagi, S., Suthar, T., Atuahene, D., Nagy, V., Ungai, D., Ahmed, A. E. M., & Kovács, B. (2024). Exploring the phytochemical, pharmacological and nutritional properties of *Moringa oleifera*: A comprehensive review. *Nutrients*, *16*(19), 3423.

Fernández-Guarino, M., Hernández-Bule, M. L., & Bacci, S. (2023). Cellular and molecular processes in wound healing. *Biomedicines*, *11*(9), 2526.

Ganesh, S. K., Chakravorty, A., Raghavan, V., & Devi, C. S. (2025). Chitosan coated ZnO/Tio2/Gd2O3 nano composites for improved rapamycin delivery in non-small cell lung cancer. *International Journal of Biological Macromolecules*, *319*, 145439.

Gupta, A., Rattan, V., & Rai, S. (2019). Efficacy of Chitosan in promoting wound healing in extraction socket: A prospective study. *Journal of Oral Biology and Craniofacial Research*, *9*(1), 91–95.

Harti, A. S., Sutanto, Y. S., Agustin, W. R., Putriningrum, R., Irdianty, M. S., Saelan, S., & Ardiani, N. D. (2024). The Effectiveness of Anti-Inflammatory Cream Galenic Preparations Based on Snail Seromucoid, Durian Peel Extract Polysaccharides and Chitosan in the Wound Healing Process (*In Vivo*). *International Journal of Public Health Excellence (IJPHE)*, *3*(2), 729–740.

Hassan, M. E., Shehata, H. A., Fahmy, A., Badr, M., Tamer, T. M., & Omer, A. M. (2021). Development of biodegradable poly (vinyl alcohol)/chitosan cross linked membranes for antibacterial wound dressing applications. *Jordan Journal of Biological Sciences*, *14*(1).

Inayatullah, N., Kemala, T., & Suparto, I. H. (2022). Potential for antibacterial activity of chitosan-polyvinyl alcohol membrane loaded with green grass jelly leaf and moringa leaf extract as a wound dressing. *Jurnal Kimia Sains Dan Aplikasi*, *25*(4), 146–154.

Mamgain, A., Kenwat, R., & Paliwal, R. (2024). Biopolymer zein nanoparticles loaded with *Moringa Oleifera* extract for improved wound healing activity: Development, Qbd based optimization and *in vivo* study. *International Journal of Biological Macromolecules*, *263*, 130314.

Mohammad Shafie, N., Raja Shahriman Shah, R. N. I., Krishnan, P., Abdul Haleem, N., & Tan, T. Y. C. (2022). Scoping review: Evaluation of *Moringa oleifera* (Lam.) for potential wound healing in *In Vivo* studies. *Molecules*, *27*(17), 5541.

Nguyen, A. T., Aris, I. M., Snyder, B. D., Harris, M. B., Kang, J. D., Murray, M., Rodriguez, E. K., & Nazarian, A. (2024). Musculoskeletal health: an ecological study assessing disease burden and research funding. *The Lancet Regional Health–Americas*, *29*.

Olson, C. P., Kennedy, M. I., DePhillipo, N. N., Tagliero, A. J., LaPrade, R. F., & Kennedy, N. I. (2024). Effect of anti-inflammatory treatments on patient outcomes and concentrations of inflammatory modulators in the post-surgical and post-traumatic tibiofemoral joint setting: a narrative review. *Annals of Joint*, *9*, 9.

Pagano, C., Perioli, L., Baiocchi, C., Bartoccini, A., Beccari, T., Blasi, F., Calarco, P., Ceccarini, M. R., Cossignani, L., & di Michele, A. (2020). Preparation and characterization of polymeric microparticles loaded with *Moringa oleifera* leaf extract for exuding wound treatment. *International Journal of Pharmaceutics*, *587*, 119700.

Petroni, S., Tagliaro, I., Antonini, C., D'Arienzo, M., Orsini, S. F., Mano, J. F., Brancato, V., Borges, J., & Cipolla, L. (2023). Chitosan-based biomaterials: insights into chemistry, properties, devices, and their biomedical applications. *Marine Drugs*, *21*(3), 147.

Pranoto, A. E., Aprilia, A., Rahmitasari, F., Soesilo, D., Puspita, S., Riski, M., Ariestania, V., Lestari, I. O., Raharjo, P., & Wijaya, Y. H. (2025). Pendidikan Dan Pelatihan Kader Sebagai Salah Satu Pilar Penting Perubahan Perilaku Di Bidang Kesehatan Gigi Dan Mulut. *Jurnal Pengabdian Masyarakat Bangsa*, *2*(11), 5252–5256.

Rajkumar, D. S. R., Keerthika, K., & Vijayaragavan, V. (2024). Chitosan-based biomaterial in wound healing: a review. *Cureus*, *16*(2).

Santhosh, V. N., Ankola, A. V, Sankeshwari, R. M., Varghese, A. S., Ragu, K., Parimala, Y. K., Chavan, P. J., & Shankkari, S. (2025). Remineralization Potential of Casein Phosphopeptide–Amorphous Calcium Phosphate, Nanohydroxyapatite Crystals, and Bioactive Glass on Initial Enamel Lesions: A Systematic Review and Meta-analysis. *International Journal of Clinical Pediatric Dentistry*, *18*(5), 560.

Soylu, Z., Oktay, B., Erarslan, A., & Ahlatcıoğlu Özerol, E. (2025). Multifunctional polymeric wound dressings. *Polymer Bulletin*, *82*(11), 5325–5383. https://doi.org/10.1007/s00289-025-05753-z

Sutanti, V., Rachmawati, Y. L., El Milla, L., & Ningtyas, D. C. (2022). Pengaruh susu terhadap kekerasan enamel gigi: Studi Literatur. *E-Prodenta Journal of Dentistry*, *6*(2), 680–698.

Thang, N. H., Chien, T. B., & Cuong, D. X. (2023). Polymer-based hydrogels applied in drug delivery: an overview. *Gels*, *9*(7), 523.

Ul-Islam, M., Alabbosh, K. F., Manan, S., Khan, S., Ahmad, F., & Ullah, M. W. (2024). Chitosan-based nanostructured biomaterials: Synthesis, properties, and biomedical applications. *Advanced Industrial and Engineering Polymer Research*, *7*(1), 79–99.

Villegas-Vazquez, E. Y., Gómez-Cansino, R., Marcelino-Pérez, G., Jiménez-López, D., & Quintas-Granados, L. I. (2025). Unveiling the miracle tree: therapeutic potential of *Moringa oleifera* in chronic disease management and beyond. *Biomedicines*, *13*(3), 634.

Yaqoob, N., Imtiaz, F., Shafiq, N., Rehman, S., Munir, H., Bourhia, M., Almaary, K. S., & Nafidi, H.-A. (2024). Oleogels for the promotion of healthy skin care products: synthesis and characterization of Allantoin containing Moringa-based oleogel. *Current Pharmaceutical Biotechnology*, *25*(17), 2326–2336.

Zhang, S., Ali, M., Nawaz, F., Ali, N., Khan, A., Ali, F., Khan, M. H., Ahmad, S., Rahman, S., & Nawaz, A. (2025). Scaffolds of Chitosan-metallic hybrids as antimicrobial wound dressing. *Journal of Molecular Liquids*, *417*, 126541.