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Natural Fibre-Reinforced Polymethyl Methacrylate for Denture Bases: A Critical Review of Interfacial Engineering, Mechanical Performance, Physical Stability, and the Translational Potential of Kenaf

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ABSTRACT

Objectives: To critically evaluate plant-derived fibre reinforcement of polymethyl methacrylate (PMMA) denture base materials, with particular emphasis on fibre-matrix adhesion, surface modification, mechanical performance, water-related behaviour and surface quality and to assess the translational potential of kenaf (Hibiscus cannabinus) as denture base reinforcement. **Materials and Methods:** A focused critical narrative review was undertaken using PubMed/MEDLINE and targeted searches of peer-reviewed publisher and indexing records. The proposal literature was used as a seed set, and searches were updated to 26 August 2026. Priority was given to studies involving plant-fibre-reinforced dental PMMA and to mechanistic studies of kenaf surface treatment relevant to PMMA. Evidence was synthesised thematically rather than quantitatively. **Results:** Direct evidence for kenaf-reinforced denture PMMA remains sparse. A 2021 study reported an increase in flexural strength from 68.9 to 82.5 MPa after incorporating 2 wt% kenaf, but did not optimise the fibre surface treatment or evaluate a broad range of physical properties. More recent evidence from hemp, cellulose microfibres, and cellulose nanofibres indicates that plant-derived reinforcement can improve selected mechanical properties, but the

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responses are concentration, processing, and matrix dependent. Silane modification can improve cellulose-PMMA compatibility and dispersion; however, kenaf silanisation data are derived largely from non-dental polymer matrices. Higher fibre loading may increase agglomeration, void formation, water sorption, or surface roughness. **Conclusions:** Kenaf is a promising experimental reinforcement for PMMA, but current evidence is insufficient for clinical endorsement. The limiting factor is the interface, therefore future work should optimise silane chemistry and fibre loading using coupled chemical, morphological, mechanical and physical analyses followed by hydrothermal and fatigue ageing.

1. INTRODUCTION

Poly(methyl methacrylate) (PMMA) remains the dominant material for conventional denture bases because it combines acceptable aesthetics, low cost, reparability and relatively straightforward laboratory processing. Its long clinical history, however, does not imply that it is mechanically or physically ideal. Fracture under flexural fatigue or accidental impact, limited fracture toughness, water sorption and changes in surface quality remain recurrent concerns, particularly when denture bases are thin or contain local stress concentrators (Alqutaibi et al., 2023; Zafar, 2020).

A wide range of reinforcement strategies has therefore been investigated, including glass and carbon fibres, polypropylene, metal oxides, ceramic nanoparticles and hybrid fillers. These approaches demonstrate that reinforcement can improve selected properties, but they also show why the problem is not solved by maximising one mechanical value. A fibre may increase flexural strength while altering colour, roughness, solubility, handling or fatigue behaviour. For example, carbon fibre can provide favourable flexural performance but produces clinically undesirable dark discoloration, whereas glass-fibre systems require adequate impregnation and interfacial coupling to avoid voids and premature debonding (Gad et al., 2017; Yerliyurt et al., 2023).

Interest has consequently shifted toward plant-derived reinforcements. Natural fibres are renewable, generally low-density and capable of providing favourable specific stiffness and strength. In dental PMMA, oil palm cellulose, ramie, Hibiscus sabdariffa, hemp, and cellulose nanofibres have all been investigated. Yet the biological origin of these materials also introduces variability in composition, geometry and moisture affinity. Their abundant hydroxyl groups make lignocellulosic fibres hydrophilic, whereas PMMA is comparatively hydrophobic. The resulting interfacial mismatch can restrict wetting and stress transfer and may promote water uptake, fibre pull-out and void formation (Mohammed et al., 2023; Xu et al., 2013).

Kenaf (Hibiscus cannabinus) is especially attractive in the Malaysian context because it is a rapidly renewable bast fibre with high cellulose content and an established role in engineered polymer composites. The original research proposal underpinning this review identified an important translational gap: direct dental evidence for kenaf-PMMA was limited, and no study in the proposal literature systematically optimised silane treatment of kenaf before incorporation into a denture-base PMMA matrix. The key scientific question is therefore not simply whether kenaf is intrinsically strong, but whether its surface can be engineered to transfer stress efficiently across the fibre-PMMA interface without incurring unacceptable moisture- or surface-related penalties.

A 2026 systematic review has since strengthened the broader evidence base for plant-fibre reinforcement of denture PMMA, reporting that flexural strength and surface hardness generally improve, while evidence for impact, compressive and tensile properties remains limited or inconsistent; the authors also emphasised the absence of clinical trials and the need for ageing studies (Hammad Uddin et al., 2026). This new synthesis does not resolve the kenaf-specific interface problem. Accordingly, the present critical review focuses on the mechanistic and translational issues that determine whether kenaf can progress from a promising natural fibre to a clinically credible denture-base reinforcement.

2. MATERIALS AND METHODS

This paper was developed as a critical narrative review rather than a systematic review because the available evidence is limited and methodologically heterogeneous, particularly for kenaf-reinforced denture base PMMA. Relevant evidence is distributed across different plant-derived fibres, cellulose forms, surface treatments and polymer matrices, making quantitative pooling or narrowly defined systematic review unsuitable for the present objective. A critical narrative approach therefore allowed integration of direct dental PMMA studies with mechanistic evidence from related natural fibre and polymer systems to evaluate interfacial behaviour, material performance and translational relevance. A focused literature search was performed in PubMed/MEDLINE and supplemented by targeted searches of peer-reviewed publisher and indexing records. The reference list of the source research proposal was used as a seed set. Searches were updated to 26 August 2026 using combinations of the terms 'polymethyl methacrylate', 'PMMA', 'denture base', 'natural fibre', 'plant fibre', 'kenaf', 'Hibiscus cannabinus', 'hemp', 'ramie', 'cellulose', 'silane', 'surface treatment', 'flexural strength', 'water sorption' and 'surface roughness'.

Priority was given to peer-reviewed English-language studies that directly evaluated plant-derived fibre or cellulose reinforcement in dental or denture-base PMMA. Mechanistic studies involving kenaf in other polymer matrices were included only when they addressed surface treatment, silane coupling, fibre-matrix adhesion, moisture behaviour or concentration-dependent damage that was directly relevant to the proposed dental application. General PMMA and natural-fibre reviews were used to establish context and identify recurring methodological limitations.

Because the objective was critical interpretation rather than exhaustive quantitative pooling, study heterogeneity was examined qualitatively. Particular attention was paid to polymer type, fibre source and form, fibre dimensions and loading, pretreatment, interfacial characterisation, mechanical outcomes, water-related properties, surface roughness, ageing protocols and whether conclusions exceeded the experimental conditions.

3. RESULTS

3.1 Plant-derived fibre reinforcement of dental PMMA

The most consistent finding across the plant-fibre PMMA literature is that reinforcement is highly dependent on how the fibre is presented to the matrix. In a classic denture-base study, Xu et al. (2013) showed that short ramie fibres increased flexural modulus, but flexural strength was reduced or unstable as fibre content increased. Single-fibre pull-out testing indicated weak interfacial adhesion. The importance

of this result lies not in the absolute strength value but in the mechanism: a stiff vegetable fibre does not necessarily strengthen PMMA if the interface cannot transmit stress efficiently.

Oil-palm empty-fruit-bunch fibre provided a more favourable example. John et al. (2015) found that oil-palm cellulose and thinner fibres improved both flexural strength and modulus relative to conventional PMMA, supporting the concept that refining the natural reinforcement and controlling its physical form can improve performance. Hibiscus sabdariffa fibres also showed a concentration-dependent response. Okeke et al. (2018) reported the most favourable flexural and impact values at an intermediate loading of 7.5 wt% with flexural strength reaching 101.2 (SD 3.65) MPa against an unreinforced value of 83.55 (SD 0.62) MPa, with no further improvement at 10 wt% (88.67 MPa). These data argue against the assumption that increasing plant-fibre content produces a linear increase in strength. Impact strength showed a similar pattern, peaking at 7.5 wt% (32.01 kJ/m^2) against 13.12 kJ/m^2 unreinforced.

The same principle is seen in cellulose nanofibre systems. Kawaguchi et al. (2020) reported progressive increases in flexural strength and modulus when 5-23 wt% cellulose nanofibre was incorporated into an injection-moulded thermoplastic PMMA model. In contrast, Yamazaki et al. (2021) found that directly adding cellulose nanofibres to PMMA liquid did not improve the mechanical properties in their system. Differences in processing route, dispersion state and fibre-matrix interaction therefore appear capable of reversing the apparent benefit of the same broad class of reinforcement.

The most recent evidence extends this concentration-dependent behaviour to additively manufactured denture-base resins. Ren et al. (2026) found that low concentrations of cellulose nanofibre improved flexural strength and Vickers hardness, with 1.0 wt% giving the most balanced overall performance. At higher concentrations, water sorption increased slightly and scanning electron microscopy revealed greater agglomeration and void formation. Although a 3D-printed resin matrix is not equivalent to conventional heat-polymerised PMMA, the study reinforces a general composite principle relevant to kenaf: a useful concentration window exists between insufficient reinforcement and excess loading that disrupts the matrix.

Padmapiriyaa et al. (2026) reinforced heat-cured PMMA with 2.5% and 5% nanocellulose and found that the flexural strength increases from 53.66 MPa to 60.82 MPa but was not significant ($p = 0.095$). The authors also reported that impact strength improved significantly and there is linear increase ($p < 0.001$). The authors suggested that the variation in flexural strength may have been caused by agglomeration, as the study did not use ultrasonication or microscopy to confirm how well the nanocellulose fibres were dispersed.

Divergence between mechanical and physical outcomes is a recurring theme. Salih et al. (2017) found that tensile strength, modulus, fracture toughness and hardness of siwak-fibre reinforced acrylic improved with increasing fibre length and weight fraction while impact strength and elongation moved in the opposite direction. Table 1 summarises the primary studies and the interpretation each supports.

Table 1. Critical evidence map of plant-derived fibre and cellulose reinforcement in dental PMMA

Study	Reinforcement/ matrix	Treatment or loading	Key finding	Critical interpretation
Xu et al. (2013)	Ramie/ heat-cured denture PMMA	Untreated, short fibres of 1.5 and 3.0 mm; multiple volume fractions up to 10%	Flexural modulus increased in selected groups, but strength declined or fluctuated; pull-out testing indicated weak interface.	Shows that fibre stiffness is insufficient when interfacial adhesion is poor.
John et al. (2015)	Oil-palm empty-fruit-bunch fibre/ PMMA	Fibres of different thickness plus cellulose form	OPEFB cellulose and thinner fibre improved flexural strength and modulus relative to conventional PMMA; 0.5 mm 94.96 MPa and cellulose 95.60 MPa vs 79.15 MPa control	Supports refinement of fibre form as a determinant of reinforcement.
Salih et al. (2017)	Siwak/ denture base acrylic	NaOH treated; 2, 6, 12 mm; 3, 6, 9 wt%	Tensile, modulus, toughness and hardness improved with length and loading; impact and elongation fell	Mechanical outcomes within one study can move in opposite direction
Okeke et al. (2018)	Hibiscus sabdariffa/ PMMA	2.5–10 wt%; 3-mm fibres	Best flexural and impact performance occurred at 7.5 wt% (101.2 MPa), 2.5 and 5 wt% fell below the control group (83.55 MPa)	Non-monotonic, demonstrates a non-linear concentration-response relationship.
Kawaguchi et al. (2020)	Cellulose nanofibre/ thermoplastic PMMA	5–23 wt% CNF	Flexural strength and modulus increased with CNF content in the tested model. SEM showed interfacial delamination and no matrix penetration of the bundles.	Processing route can enable high cellulose loading, but matrix differs from conventional heat-cured PMMA.
Taczała et al. (2020)	Silanised cellulose microfibres/ dental PMMA	OTES or methacrylate-functional silane modification	Improved fibre dispersion, PMMA compatibility, mechanical performance and thermal stability.	Provides direct PMMA-specific support for silane-mediated interface engineering.
Johari et al. (2021)	Kenaf/ denture PMMA	2 wt%, 6-mm fibres; MMA pretreatment	Flexural strength increased from 68.9 to 82.5 MPa; altered crack propagation observed.	Proof of concept only: one loading, limited outcomes.
Bolayır et al. (2022)	Hemp/ PMMA prosthetic material	Multiple fibre lengths and concentrations	Mechanical behaviour changed with hemp addition; SEM, FTIR and modelling supported fibre-matrix interactions.	Relevant analogue showing that plant-fibre effects depend on geometry and interaction.

Study	Reinforcement/ matrix	Treatment or loading	Key finding	Critical interpretation
Sosiati et al. (2022)	Kenaf/ carbon/ PMMA hybrid	Chitosan nano and micro particles 1–5 vol%	Peak flexural strength 133.57 MPa; water uptake <6%; nanoparticles aggregated, microparticles did not	Hybridisation of reinforcement is viable, however the architecture is not a dough-molded denture base
Baysan et al. (2025)	Raw and chemically treated hemp / heat-cured PMMA	Raw versus lignin/pectin-removed fibres	No significant change in fracture strength or acrylic-tooth bond; water absorption decreased significantly.	Shows physical and mechanical outcomes can diverge.
Kuşçu et al. (2025)	Raw and lignin/pectin-free hemp / PMMA	1 wt%; different finishing/ polishing protocols	Hemp increased roughness after finishing; effective polishing reduced final roughness.	Removing non-cellulosic components restores polishability below plaque retention threshold
Ren et al. (2026)	Cellulose nanofibre / 3D-printed denture resin	0–2 wt% CNF	Low concentrations improved strength/ hardness; higher concentrations increased sorption and produced agglomeration/voids.	Contemporary evidence for an optimum loading window; matrix is not conventional heat-cured PMMA.
Padma-piriyaa et al. (2026)	Nanocellulose/ heat-cured PMMA	2.5 and 5%, no ultra-sonication or dispersion verification	Flexural strength increases from 53.66 to 60.82 MPa but not significant ($p = 0.095$), impact strength significant and dose-dependent	Expected gain was not reproducible; authors associate it to lack of dispersion control

Abbreviations: CNF, cellulose nanofibre; FTIR, Fourier-transform infrared spectroscopy; MMA, methyl methacrylate; OPEFB, oil-palm empty-fruit-bunch; OTES, octyltriethoxysilane; PMMA, poly(methyl methacrylate); SEM, scanning electron microscopy.

3.2 Direct evidence for kenaf-reinforced PMMA

Direct evidence for kenaf in denture-base PMMA is much narrower than the wider plant-fibre literature. Johari et al. (2021) incorporated 2 wt% kenaf fibre into PMMA after monomer pretreatment and reported an increase in flexural strength from 68.9 MPa in the control to 82.5 MPa in the kenaf group. Fractographic observations suggested altered crack propagation around the fibre-resin interface. This study provides an important proof of concept, but it should not be interpreted as an optimised material formulation.

Several limitations constrain the strength of the inference. Only a single kenaf loading was investigated, preventing identification of a dose-response relationship or an optimum concentration. The fibre was not subjected to a systematic coupling-agent protocol designed specifically to improve chemical compatibility with PMMA. The evaluated outcomes were also limited, so the study could not establish whether the gain in flexural strength was accompanied by acceptable impact behaviour, water sorption, solubility, surface roughness or resistance to hydrothermal ageing. Moreover, the reported flexural strength after

reinforcement remained below the approximately 90 MPa reference value frequently cited for conventional denture-base PMMA, although cross-study numerical comparisons must be made with caution because specimen geometry, resin system, and test conditions differ (Zafar, 2020).

The kenaf evidence is therefore best characterised as feasibility evidence. It demonstrates that kenaf can be incorporated into dental PMMA and can influence fracture behaviour, but it does not yet demonstrate that kenaf produces a clinically superior denture base. This distinction is central to the rationale for optimising surface treatment before expanding mechanical and physical testing.

3.3 Interfacial engineering and silane surface modification

Surface modification is the most compelling strategy for addressing the hydrophilic fibre-hydrophobic PMMA mismatch. Silane coupling agents are attractive because appropriately selected molecules can interact with hydroxyl-rich cellulose surfaces while presenting an organofunctional group compatible with the polymer phase. The mechanism is particularly relevant when the silane contains a methacrylate group that can participate in radical polymerisation with methyl methacrylate.

Direct dental evidence is available from cellulose microfibres. Taczała et al. (2020) modified cellulose with octyltriethoxysilane and with a methacrylate-functional silane. Surface modification reduced the hydrophilic character of the cellulose, improved dispersion within dental PMMA and improved mechanical performance. The methacrylate-functional silane was particularly attractive because it could contribute to polymerisation and cross-linking rather than merely making the fibre surface more hydrophobic. This study provides a stronger PMMA-specific rationale for silanisation than extrapolation from engineering composites alone.

Kenaf-specific silane literature nevertheless remains useful for defining hypotheses. A review by Nurazzi et al. (2021) concluded that silane treatment can improve interfacial bonding and moisture resistance in kenaf-reinforced polymer composites, although effects depend on fibre preparation, silane chemistry, concentration and matrix type. Jamadi et al. (2021), working with kenaf-reinforced polylactic acid rather than PMMA, reported the best tensile and flexural performance at an intermediate silane concentration after alkaline treatment, with deterioration at higher concentrations. The mechanistic lesson is important, but the numerical optimum cannot be transferred directly to denture-base PMMA because polymer chemistry, viscosity, polymerisation and processing differ.

Accordingly, silane concentration should be treated as an experimental variable rather than a value to be borrowed from another polymer system. Chemical confirmation using Fourier-transform infrared spectroscopy (FTIR), supported by microscopic evaluation of the fibre surface and the fractured composite interface, is necessary before any improvement in strength is attributed to enhanced chemical coupling.

3.4 Fibre loading, dimensions and dispersion

Fibre loading, length, aspect ratio, orientation and dispersion determine whether natural fibres behave as reinforcing elements or as defects. Longer fibres can provide a larger area for stress transfer and crack bridging, but they are more difficult to distribute uniformly. Very short milled fibres disperse more readily but increasingly behave as particulate fillers. Agglomerated fibres can trap air, interfere with PMMA packing and generate voids that act as crack initiators.

Evidence from ramie, Hibiscus sabdariffa, hemp and cellulose nanofibres consistently suggests a non-linear concentration-response relationship (Bolayır et al., 2022; Okeke et al., 2018; Ren et al., 2026; Xu et

al., 2013). This has two implications for kenaf. First, a study that compares only one reinforced group with one control group cannot establish an optimal formulation. Second, concentration should not be interpreted independently of fibre size and dispersion. If milling changes a bast fibre into approximately micrometre-sized particles, the critical variables become particle size distribution, surface area, wetting and agglomeration as much as conventional fibre length.

A robust kenaf-PMMA study should therefore report the source and anatomical fraction of the fibre, pretreatment, post-treatment moisture control, size distribution, loading basis (weight or volume), mixing method and evidence of dispersion. Without these details, reproducibility is limited and between-study comparisons become unreliable.

3.5 Water-related properties and surface quality

Mechanical improvement alone is insufficient for a denture-base material that functions continuously in saliva and undergoes repeated thermal change. Natural fibres contain cellulose, hemicellulose and other hydrophilic constituents capable of interacting with water. Moisture can swell the fibre, plasticise the polymer, enlarge interfacial gaps and promote progressive debonding. Reviews of natural-fibre composites therefore identify water absorption as a central durability problem rather than a secondary physical property (Mohammed et al., 2023).

Recent dental studies show that the direction of the water response is not uniform. Baysan et al. (2025) found that raw and chemically treated hemp fibre did not significantly change fracture strength or acrylic-tooth bond strength but significantly reduced water absorption in their PMMA system. This is encouraging, but it also illustrates that changes in physical and mechanical properties do not necessarily move together. A formulation can improve water behaviour without improving fracture performance.

Surface quality creates another clinically relevant trade-off. Kuşçu et al. (2025) reported that addition of 1% hemp fibre increased PMMA surface roughness after finishing, although appropriate polishing substantially reduced roughness. The authors attributed part of the effect to fibre aggregation and showed that polishing technique modified the final outcome. This finding is especially important for kenaf because exposed fibres, fibre pull-out or voids at the polished surface could compromise hygiene even if flexural strength improves.

For denture-base research, water sorption, solubility and surface roughness should therefore be considered co-primary material-performance domains rather than optional ancillary outcomes. Testing before and after thermocycling or prolonged water storage is preferable because an initially strong fibre-matrix interface may deteriorate only after repeated hydrothermal challenge.

3.6 Ageing and contemporary denture-resin evidence

Most plant-fibre PMMA studies remain short-term laboratory investigations. Hammad Uddin et al. (2026) identified only eight eligible experimental studies in their systematic review and concluded that evidence is strongest for flexural strength and surface hardness, while other mechanical properties remain insufficiently characterised. The review also highlighted the need for ageing protocols and clinical studies. These limitations are particularly important for a natural fibre whose water affinity is expected to influence long-term behaviour.

Recent work in digitally fabricated denture resins adds another caution. Ren et al. (2026) demonstrated that a cellulose nanofibre concentration that improved strength could also alter water sorption, colour

stability and microstructure. The implication is broader than the specific resin system: optimisation should seek the best overall material profile, not the maximum value of a single mechanical test. The same principle should guide conventional heat-polymerised kenaf-PMMA development.

4. DISCUSSION

4.1 Reinforcement should be judged as a material-property profile

The central conclusion from the available evidence is that plant-fibre reinforcement of PMMA is a multi-objective optimisation problem. A clinically useful denture base must resist bending, impact and fatigue while remaining dimensionally stable, polishable, hygienic, aesthetically acceptable and reproducible. The literature contains several examples in which one property improves while another is unchanged or worsens. Such trade-offs explain why a statistically significant increase in flexural strength should not be equated automatically with material superiority.

For kenaf, this issue is particularly relevant because its strongest justification is presently theoretical and mechanistic: it is renewable, cellulose-rich and capable of carrying load. The weakest link is the interface. If interfacial adhesion is poor, the fibre can be pulled out before it is fully loaded, and the reinforcing phase becomes a stress concentrator. If treatment is too aggressive, fibre damage may reduce intrinsic strength. If loading is too high, agglomeration and porosity may negate any gain in stiffness. The experimental aim should therefore be to identify the formulation that provides the most favourable balance across several properties rather than the formulation that maximises flexural strength alone.

4.2 Why interfacial optimisation is the critical next step

The proposal to optimise silanised kenaf is scientifically well founded, but the treatment sequence requires rigorous validation. Bleaching, alkaline treatment, drying and silanisation all modify the fibre surface. Each step can alter cellulose accessibility, lignin and hemicellulose content, surface energy, roughness and moisture content. These changes can affect both chemical coupling and mechanical integrity.

A methacrylate-functional silane is especially rational for PMMA because it may create a molecular bridge between hydroxyl-rich cellulose and a methacrylate-based polymerising phase, as demonstrated for modified cellulose microfibres in dental PMMA (Taczała et al., 2020). However, successful silanisation should not be inferred solely from the treatment recipe. FTIR should confirm relevant chemical changes; scanning electron microscopy should assess surface morphology and fibre-matrix contact; and fractured specimens should be inspected for pull-out, interfacial gaps and voids. Mechanical improvement should then be interpreted together with this chemical and morphological evidence.

The common tendency to select a silane concentration from a study in PLA, polyester or polyethylene should be avoided. Those studies are valuable for defining a plausible concentration range, but an 'optimal' concentration is matrix-specific. A dental PMMA study should therefore test several concentrations and select the surface treatment based on convergent evidence rather than on flexural strength alone.

4.3 Clinical translation, standards and reproducibility

Clinical translation also requires attention to standards and ageing. ISO 20795-1:2013 provides a framework for denture-base polymers (International Organization for Standardization, 2013), but a reinforced experimental composite should be evaluated beyond minimum flexural criteria and the relevant

question is whether the reinforced material outperforms a well-processed conventional PMMA and whether it continues to do so after ageing. Impact strength, fracture toughness and fatigue behaviour are relevant because denture fractures arise from both accidental dropping and repeated functional loading. Neither of which is well predicted by a single three-point bend test. Water sorption, solubility and surface roughness should be assessed under conditions approximating oral exposure and ageing such as thermocycling should be used to challenge the fibre-matrix interface.

A further translational issue is natural-fibre variability. Fibre composition depends on cultivar, plant maturity, bast versus core fraction, extraction, retting, storage and chemical pretreatment. For a biomedical material, batch-to-batch consistency must be demonstrated. Reporting only 'kenaf fibre' without chemical composition, source and size distribution is insufficient for reproducibility. Future studies should therefore include fibre characterisation and, where feasible, replicate key experiments across independent fibre batches.

Two further risks are documented in fibre-reinforcement studies but evidence is sparse. The first is tooth-base junction. Taczała-Warga et al. (2022) studied bonding of acrylic tooth to cellulose-fibre-reinforced denture base and found the durability of that joint to be preparation dependent and environment dependent. Mechanical preparation with carbide bur raised shear resistance by 116.5% in dry specimens and by 155.4% after immersion in artificial saliva, but by only 46.6% after 5000 cycles of thermocycling. The thermocycling result indicated that this junction is particularly vulnerable to debonding.

The second risk is biological. Manoharan et al. (2024) incorporated 5 wt% microcrystalline cellulose derived from oil-palm empty fruit bunch to heat-cured PMMA, a formulation reported to raise flexural strength and modulus. They reported that Candida albicans biofilm formation was 1.43 times higher than on conventional PMMA. Biofilm was heterogenous, with the presence of hyphae and denser extracellular polysaccharide matrix. This result is not a matter of antifungal activity but it indicates that an organic, hydrophilic filler that improves mechanical performance may simultaneously present a more colonizable surface.

Biological safety also warrants attention. A favourable toxicological profile of the plant itself does not establish the safety of a processed fibre-PMMA composite. Residual processing chemicals, leachable components, microbial contamination and surface changes after ageing may alter biological behaviour. Cytotoxicity and microbial adhesion should therefore follow successful mechanical and physical optimisation before clinical investigation.

4.4 Sustainability: plausible advantage, not yet demonstrated

The sustainability argument for kenaf is attractive but should be framed cautiously. Renewable origin does not automatically make a composite environmentally superior. A denture base containing a small percentage of natural fibre remains predominantly a methacrylate polymer, and fibre processing may require bleaching agents, alkali, silane, heat, drying and milling. Life-cycle advantage depends on the combined effects of cultivation, processing, material yield, service life, reparability and end-of-life management.

Earlier life-cycle work on natural-fibre composites suggests that lower fibre density and renewable sourcing can provide environmental advantages over glass-fibre systems, but the magnitude of benefit is application-dependent (Joshi et al., 2004). For dental use, the most meaningful sustainability gain may come not from the small mass fraction of PMMA displaced by kenaf, but from extending prosthesis service life without

increasing repair or replacement. Until durability and life-cycle data are available, kenaf-PMMA is more accurately described as a potentially more sustainable material strategy rather than a proven sustainable denture base.

Table 2. Methodological variables that should be controlled in future kenaf-PMMA studies.

Domain	Why it matters	Recommended control or analysis
Fibre source and batch	Bast/core fraction, cultivar, harvest, extraction and storage change cellulose/lignin/hemicellulose composition.	Document source; characterise independent batches; report fibre chemistry where feasible.
Surface treatment	Insufficient treatment leaves a hydrophilic interface; excessive treatment can damage fibres.	Compare untreated and several silane concentrations; confirm chemistry by FTIR.
Fibre size and loading	High loading or long fibres can agglomerate; very fine fibres behave increasingly as particulate fillers.	Report size distribution and loading basis; use microscopy to quantify dispersion/voids.
Moisture control	Residual moisture interferes with wetting and may increase porosity or hydrolytic degradation.	Standardise drying and storage; measure water sorption/solubility before and after ageing.
Mechanical testing	Flexural strength alone cannot predict impact or fatigue fracture.	Include flexural modulus, impact strength and, where feasible, fracture toughness/fatigue.
Ageing	Short-term dry tests may overestimate performance of hydrophilic composites.	Use thermocycling, prolonged water storage and repeated loading before biological/clinical progression.
Surface quality	Exposed fibres and pull-out may increase roughness and microbial retention.	Standardise finishing/polishing; assess Ra after ageing; consider microbial adhesion in later phases.

5. CONCLUSION

Kenaf fibre is a credible candidate for experimental reinforcement of PMMA denture-base resin, but the evidence is not yet sufficient to support clinical adoption. Direct kenaf-PMMA evidence remains limited to proof-of-concept work, while the broader plant-fibre literature demonstrates substantial dependence on fibre treatment, loading, geometry, dispersion and processing route.

The most defensible research direction is interfacial engineering. Methacrylate-compatible silane treatment has a strong mechanistic rationale for improving cellulose-PMMA compatibility, but the concentration and treatment sequence must be optimised specifically for kenaf and dental PMMA rather than imported from another polymer system. Mechanical performance must then be interpreted together with water sorption, solubility, surface roughness, fractography and ageing.

The key translational criterion is therefore not the highest flexural strength, but a reproducible property profile that remains acceptable after hydrothermal and mechanical challenge. If that threshold can be achieved, locally sourced kenaf could contribute to a stronger and potentially more sustainable denture-base composite. At present, it should be regarded as a promising research platform rather than an established alternative to conventional PMMA.

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7. DECLARATION OF GENERATIVE AI IN THE WRITING PROCESS

During preparation of this manuscript, generative AI was used to assist with structural organisation, language refinement and preliminary synthesis of the literature. All scientific statements, numerical data and references were subsequently checked against the cited sources and critically reviewed by the authors. The authors take full responsibility for the content of the manuscript.

8. ETHICS STATEMENT

Not applicable. This critical narrative review used information from previously published literature and did not involve human participants, identifiable patient information or experimental animals.

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10. CONFLICT OF INTEREST

All authors declare no conflict of interest.

11. AUTHORS' CONTRIBUTIONS

Nur Eida Sazali conducted the literature search, synthesized the evidence, and drafted and revised the manuscript. **Rohana Ahmad** conceptualized the review and provided overall supervision. **Aiemeeza Rajali** and Nur Atikah Mustafa contributed to the review design, interpretation, and manuscript review. **Siti Norasmah Surip** contributed to the review methodology and provided co-supervision, particularly in polymer and materials science. **Suzana Ratim** provided technical and methodological input on polymer-related aspects**. Yuli Nugraeni** and **Fatima** contributed ideas and methodological input. All authors critically reviewed and approved the final manuscript.

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