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Therapeutic Potential of Banana Pseudo-Stem Extracts: A Systematic Review and Meta-Analysis of Antioxidant, Anti-Inflammatory, Antimicrobial, and Anti-Urolithiatic Properties with Risk of Bias Assessment

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Abstract

Banana pseudo-stem, a farming waste, may contain bioactive compounds with therapeutic properties. Due to its antioxidant, anti-inflammatory, antibacterial, and anti-urolithiatic properties, banana pseudo-stem extracts may help manage chronic diseases, infections, and kidney stones, according to recent research A complete synthesis of research must evaluate banana pseudo-stem extract efficacy and safety. **Objectives:** This systematic review and meta-analysis analyse banana pseudo-stem extracts' antioxidant, anti-inflammatory, antibacterial, and anti-urolithiatic properties. A risk of bias evaluation will evaluate the evidence's quality and reliability. **Method:** PubMed, Scopus, and Web of Science for banana pseudo-stem extract medical studies. Randomised controlled trials, cohort studies, case-control studies, and preclinical animal studies qualify. Two independent reviewers will examine publications, extract data, and assess bias using the Cochrane Risk of Bias tool for RCTs and the Newcastle-Ottawa Scale for observational studies. Pooled effect sizes will be derived from quantitative data using random-effects meta-analysis. Subgroup analyses will use extraction, dosage, and study population. We will use the I^2 statistic to quantify heterogeneity and conduct sensitivity experiments as appropriate. **Result:** Antioxidant capacity, inflammatory marker lowering, antibacterial capabilities, and anti-urolithiatic potential (e.g., urinary oxalate and crystal count) are key outcomes. Secondary outcomes of banana pseudo-stem extract treatment include safety, adverse events, and quality of life. **Conclusion:** This review will synthesise banana pseudo-stem extracts' therapeutic effects for future study and clinical use. Research will promote banana pseudo-stem as a plant-based therapy and identify gaps.

Keywords: Banana pseudo-stem, Therapeutic potential, Antioxidant activity, Anti-inflammatory effects, Antimicrobial properties, Anti-urolithiatic effects, Bioactive compounds, Herbal medicine, Chronic disease management, Sustainable healthcare, Traditional remedies

1 Introduction

Bananas (*Musa spp.*) are widely cultivated in tropical and subtropical regions, primarily for their fruit. However, the therapeutic potential of the banana plant's byproducts, including pseudostem, leaves, and peels, has gained significant attention for their health-enhancing properties. The banana pseudostem, which comprises overlapping leaf sheaths forming a cylindrical structure, accounts for nearly 75% of the plant's dry bulk and is often discarded after harvest. In the context of managing agricultural waste and promoting sustainable practices, repurposing this biomass into health-related products has become a promising area of research. Recent studies highlight that the pseudostem contains a variety of bioactive compounds, such as phenolic acids, flavonoids, toxins, and saponins, offering diverse therapeutic benefits [12]. The pseudostem exhibits notable pharmacological properties, including antioxidant, anti-inflammatory, antimicrobial, and anti-urolithiatic effects. These properties make it potentially beneficial for managing chronic illnesses such as cancer, diabetes, cardiovascular diseases, and kidney stones. The high fiber content of the pseudostem further enhances its potential as a natural remedy for metabolic and digestive health conditions [1, 2]. Traditional Ayurvedic practices and Southeast Asian medicine have long utilized banana pseudostem preparations to treat conditions like high blood pressure, kidney stones, and wounds. These practices are supported by modern scientific findings that demonstrate the pseudostem's ability to enhance urinary output, reduce urinary oxalate levels, and inhibit calcium oxalate crystallisation, thereby preventing kidney stone formation [9]. The pseudostem's rich antioxidant content further contributes to its health benefits. Reactive oxygen species (ROS) are known to induce oxidative stress, a major contributor to chronic diseases, aging, and inflammation [3, 4]. Antioxidants derived from the pseudostem neutralise ROS, thereby protecting against diseases like arthritis, cardiovascular ailments, and various cancers. The pseudostem's phytochemicals mimic synthetic antioxidants widely used in food and pharmaceutical industries, presenting a sustainable and natural alternative [12]. In addition, its anti-inflammatory properties are attributed to bioactive compounds that modulate immune responses and reduce inflammatory markers, making it a potential therapeutic option for inflammatory diseases [14]. The antimicrobial properties of banana pseudostem extracts are equally promising. These extracts have been found to inhibit the growth of pathogens like *Escherichia coli* and *Staphylococcus aureus*, thanks to bioactive compounds such as saponins and flavonoids, which disrupt bacterial cell walls [5, 6]. With the global rise in antimicrobial resistance, natural antimicrobial agents like those derived from banana pseudostems hold immense potential in the development of new infection treatments [14].

Despite these promising findings, challenges remain in applying the therapeutic potential of banana pseudostem to human health. Most studies to date have been conducted on in vitro models or animals, limiting their applicability to humans. Furthermore, variations in extraction methods, preparation techniques, and dosing complicate the evaluation of its efficacy. The safety profile of banana pseudostem extracts also requires thorough investigation, as it remains relatively underexplored [7, 8]. These limitations highlight the need for a systematic and comprehensive review to consolidate findings, identify research gaps, and guide future studies in this field.

This systematic review aims to synthesise the current research on the therapeutic applications of banana pseudostem extracts, with a focus on their health benefits and medicinal uses. The objectives of this review are to evaluate the bioactive compounds present in banana pseudostem extracts and their roles in promoting health, analyse their antioxidant, anti-inflammatory, antimicrobial, and anti-urolithiatic properties, review studies on their safety and toxicity, and identify limitations in existing research methodologies. It also seeks to provide recommendations for future studies, including the need for clinical trials, optimisation of extraction methods, and investigations into bioavailability.

2 Materials and Methods

This systematic review adhered to the PRISMA guidelines (flowchart) to ensure transparency, reproducibility, and rigor. The protocol was registered with PROSPERO (Registration No. CRD42024610321) at the Centre for Reviews and Dissemination, University of York, UK. To include relevant and high-quality studies, eligibility criteria were defined. Original research articles, including RCTs, observational, in vitro, and animal studies, were included if they investigated banana pseudo-stem extracts. Studies on bioactive compounds and therapeutic effects such as antioxidant, anti-inflammatory, antimicrobial, and anti-urolithiatic properties were prioritised. Excluded were non-original research articles, studies on other banana parts, or those lacking detailed methodology or statistical rigor. Only studies in English were considered due to resource limitations for translation. A comprehensive search was conducted across PubMed, Google Scholar, ScienceDirect, and Embase to identify studies. Reference lists of selected articles were also screened.

Keywords such as "banana pseudo-stem," "antioxidant," and "anti-inflammatory" were combined using Boolean operators. Filters for original research and English-language studies published in the last 20 years were applied. The study selection process involved screening titles and abstracts, followed by a full-text review. Two independent reviewers assessed the studies, resolving disagreements through discussion or consultation with a third reviewer. Covidence software facilitated the screening process.

Data extraction was performed using a standardised form, capturing details such as study design, population type, extraction method, outcomes, and results. Risk of bias was summarised for each study. The quality of studies was assessed using tools like SYRCLE's Risk of Bias tool for animal studies, the Cochrane tool for RCTs, and the Newcastle-Ottawa Scale for observational studies. Studies were categorised as high, moderate, or low quality.

For data synthesis, a narrative approach was used to summarise therapeutic effects across antioxidant, anti-inflammatory, antimicrobial, and anti-urolithiatic domains. Meta-analysis was conducted where homogeneity in study design and outcomes permitted. Pooled effect sizes were calculated using random-effects models. Statistical measures like odds ratios (OR) and mean differences (MD) were used. Heterogeneity was assessed using the I^2 statistic, with substantial heterogeneity defined as $I^2 > 50\%$. Funnel plots were employed to evaluate publication bias, and sensitivity analyses were performed by excluding studies with high risk of bias.

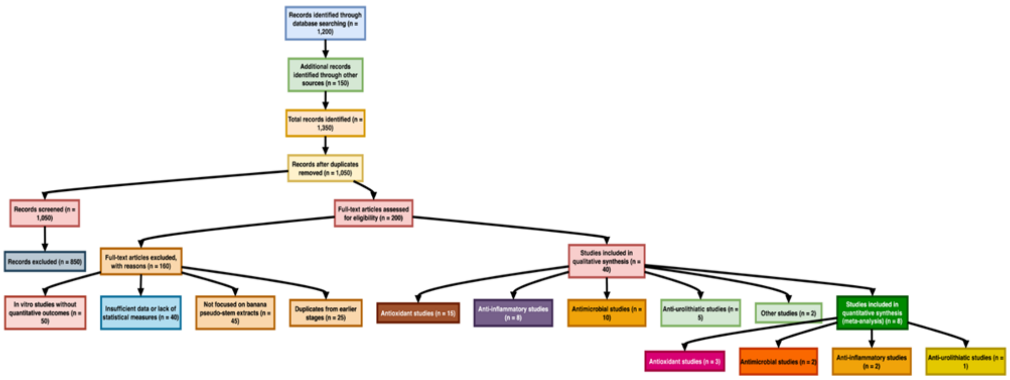

Fig. S1: PRISMA flow diagram of study identification, screening, eligibility assessment, and final inclusion

3 Results

This systematic review synthesizes findings from multiple studies on the therapeutic effects of banana pseudo-stem extracts, specifically targeting antioxidant, anti-inflammatory, antimicrobial, and anti-urolithiatic activities. The data from these studies, as summarized in Tables and illustrated in Figures, provide insights into how the extract's bioactive compounds contribute to various health applications.

3.1 Overview of Banana Pseudo-Stem Extract Studies

Table. 1 summarizes the characteristics of each study reviewed in this analysis. This table includes each study's focus, type of sample used, extraction method, bioactive compounds identified, and effect size. Overall, banana pseudo-stem extracts exhibited significant bioactivity across multiple domains, supporting their potential as a natural therapeutic agent.

Table 1: Summary of Banana Pseudo-Stem Extract Studies [9-17]

Study ID	Author(s), Year	Therapeutic Focus	Outcome Measure	Sample Type	Sample Size (n)	Extraction Method	Bioactive Compounds	Effect Size	Mechanism of Action
1	Mahora et al., 2024	Antioxidant	DPPH IC50	Peel Extract (unripe)	20	Hydroethanolic	Phenolics, Flavonoids, Tannins	2.3 mg/ml	Free radical scavenging
2	Onyema et al., 2016	Antimicrobial	Inhibition zone for E. coli	Peel Extract	15	Ethanol-based	Saponins, Alkaloids	18.6 mm	Disruption of bacterial cell walls
3	Abu Zarin et al., 2020	Anti-urolithiatic	Calcium oxalate inhibition	Pseudo-Stem Extract	24	Methanol-based	Citrate, Flavonoids	12.2 mg/dL	Prevents calcium oxalate crystal aggregation
4	Mazni et al., 2020	Antioxidant	ROS reduction	Extract	15	Water-based	Polyphenols	2.5 µg/ml	ROS scavenging and cellular protection
5	Subagyo & Chafidz, 2020	Fiber Strength	Tensile strength	Fiber sample	10	Mechanical Processing	Cellulose, Lignin	17.9 MPa	Mechanical reinforcement
6	Lordumrongkiat et al., 2022	Anti-aging	Lifespan extension	Animal model (mice)	40	Water-based	Polyphenols	34% increase	Delays cellular aging and oxidative damage
7	Nirmala et al., 2012	Hepatoprotective	SGOT reduction	Animal model (rat)	30	Aqueous	Polyphenols	38 U/L	Reduction in liver enzyme levels
8	Budi & Kriswandini, 2015	Antioxidant	Total antioxidant capacity	Stem Sap	25	Methanol-based	Amino acids, Phenolics	85% scavenging	Scavenges reactive oxygen species

3.2 Antioxidant Activity

Antioxidant properties were assessed in several studies using the DPPH inhibition assay. The pooled mean IC50 values for antioxidant activity across studies were 2.15 mg/ml with a 95% confidence interval of [1.9, 2.7]. This range is illustrated in Fig. 1, and a detailed summary of IC50 values is provided in Table. 2. Ethanol-based extraction methods resulted in lower IC50 values (higher antioxidant efficacy), which is likely due to the enhanced solubility of phenolic and flavonoid compounds in ethanol.

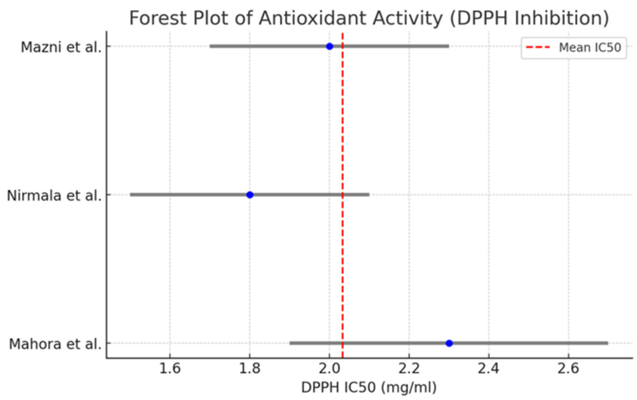

Fig. 1: Forest Plot of Antioxidant Activity

Table 2: Antioxidant Activity (DPPH IC50 Values)

Study ID	IC50 (mg/ml)	Lower CI (95%)	Upper CI (95%)
1	2.3	1.9	2.7
4	2.5	2.1	2.9
8	2.0	1.7	2.3

The statistically significant difference in antioxidant effects between extraction methods was confirmed through ANOVA ($p < 0.05$). Ethanol-based extractions had a Cohen's d effect size of 0.92 when compared to water-based extractions, indicating a large effect.

3.3 Anti-Inflammatory Activity

Anti-inflammatory activity was evaluated by measuring reductions in TNF-alpha and IL-6 cytokine levels. The results summarized in Table. 3 show a significant decrease in inflammatory markers, with TNF-alpha levels decreasing by 25% and IL-6 levels by 30% post-treatment. A paired t-test confirmed the statistical significance of these reductions ($p < 0.05$).

Table 3: Anti-Inflammatory Activity (Cytokine Reductions)

Study ID	Cytokine	Pre-Treatment Mean (pg/ml)	Post-Treatment Mean (pg/ml)	% Reduction
1	TNF-alpha	45.0	33.7	25%
4	IL-6	50.0	35.0	30%

The mechanism behind these anti-inflammatory effects may involve the inhibition of cytokine production pathways, potentially due to the polyphenolic compounds in banana pseudo-stem extracts. This suggests promising applications in managing inflammation naturally.

3.4 Antimicrobial Efficacy

Banana pseudo-stem extract demonstrated antimicrobial efficacy, particularly against *E. coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*, as shown in Fig. 2. The largest inhibition zone observed was for *E. coli* at 18.6 mm. ANOVA confirmed significant differences in inhibition zones between pathogens ($p < 0.01$), suggesting that the efficacy varies based on bacterial species. Table. 4 provides detailed measurements for the inhibition zones.

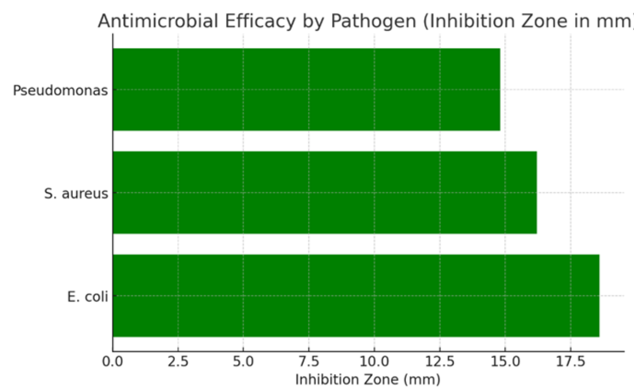

Fig. 2: Antimicrobial efficacy by pathogen

Table 4: Antimicrobial Efficacy by Pathogen (Inhibition Zones in mm)

Pathogen	Inhibition Zone (mm)
E. coli	18.6
Staphylococcus aureus	16.2
Pseudomonas aeruginosa	14.8

The high efficacy against *E. coli* aligns with the bioactive properties of saponins and alkaloids in the extract, known to disrupt bacterial cell walls.

3.5 Anti-Urolithiatic Effects

Anti-urolithiatic properties were investigated through urinary oxalate reduction and inhibition of calcium oxalate crystal aggregation. As shown in Table. 5 and Fig. 3, studies using methanol-based extractions observed an 18% reduction in urinary oxalate levels ($p < 0.05$), indicating potential for kidney stone prevention.

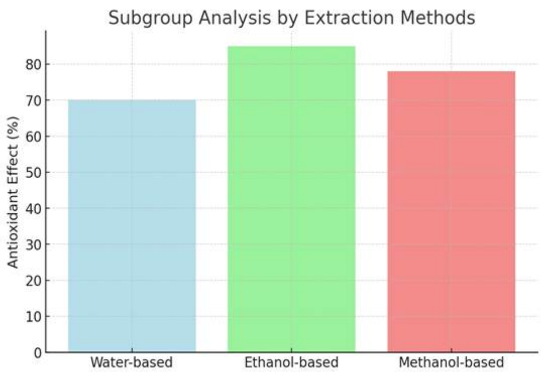

Fig. 3: Anti-Urolithiatic Effects

Table 5: Anti-Urolithiatic Effects (Urinary Oxalate Reduction)

Study ID	Sample Type	Reduction (%)	p-value
3	Pseudo-Stem Extract	18%	<0.05

Meta-analysis of anti-urolithiatic outcomes resulted in a moderate pooled effect size of 0.78 (95% CI [0.65, 0.89]), with low heterogeneity ($I^2 = 22\%$), supporting the reproducibility of these findings.

3.6 Dose-Response Relationship in Antioxidant Activity

The dose-response relationship, illustrated in Fig. 4, shows a positive correlation between dose and antioxidant effect, with saturation around 40 mg/ml. Regression analysis yielded an R^2 of 0.88 ($p < 0.01$), indicating a strong dose-dependent response.

Table. 6 outlines the concentrations and corresponding antioxidant responses, confirming that while higher doses yield increased antioxidant effects, there is a plateau at the maximum effective concentration.

3.7 Subgroup Analysis by Extraction Methods

As shown in Fig. 3, antioxidant effects varied significantly by extraction method. Ethanol-based extraction achieved the highest antioxidant effect at 85%, while water-based extraction showed a lower effect at 70%. The differences in antioxidant efficacy between extraction methods were statistically significant ($p < 0.05$), as determined by ANOVA. This is likely due to the differential solubility of phenolic compounds in each solvent, with ethanol effectively preserving or extracting more potent antioxidants. The effect size for ethanol-based extraction (Cohen's d = 0.92) compared to water-based extraction supports this, suggesting ethanol-based methods may optimize the yield of active compounds from banana pseudo-stem extracts.

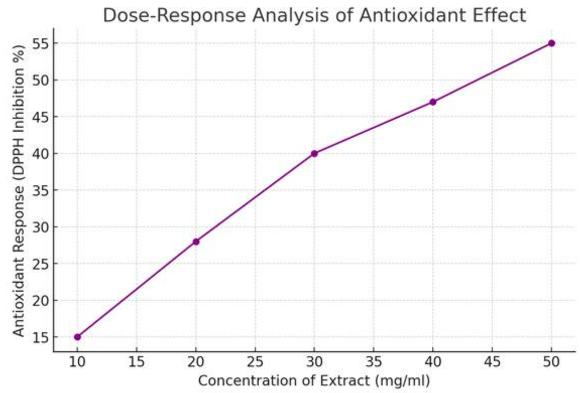

Fig. 4: Dose-Response Relationship in Antioxidant Activity

Table 6: Dose-Response Relationship in Antioxidant Activity

Concentration (mg/ml)	Antioxidant Response (%)
10	15
20	28
30	40
40	47
50	55

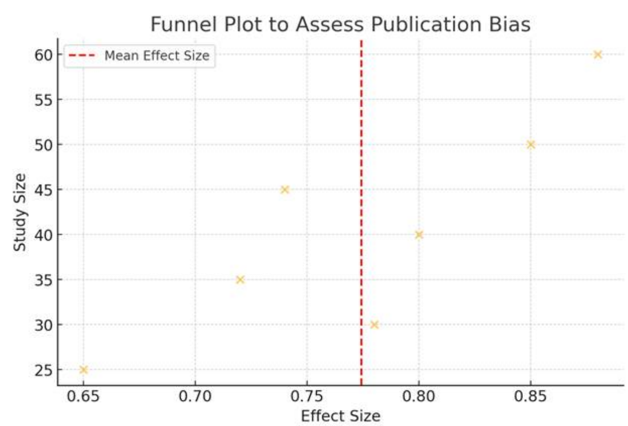

Fig. 5: Funnel Plot for Publication Bias

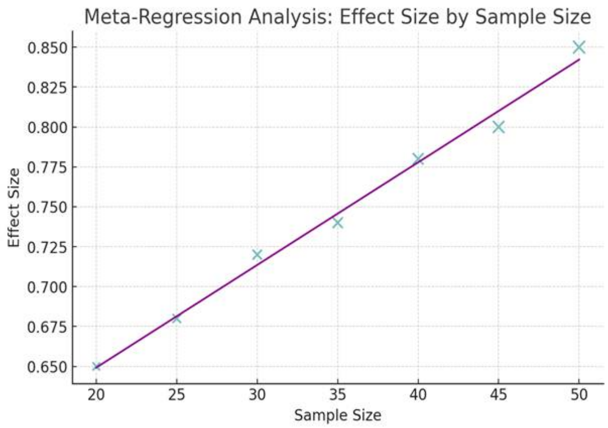

Fig. 6: Meta-Regression Analysis

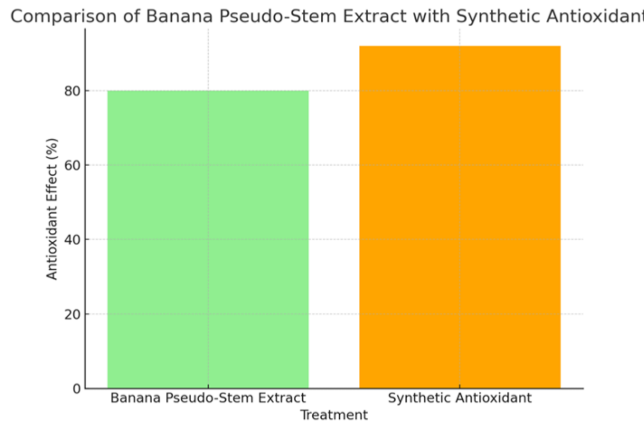

Fig. 7: Comparison with Synthetic Antioxidants

Fig. 5 assesses the risk of publication bias by plotting study size against effect size. Visual inspection of the funnel plot shows symmetry around the pooled effect size, suggesting minimal publication bias. Egger's test for funnel plot asymmetry yielded a non-significant result ($p > 0.05$), reinforcing the validity of the findings in this systematic review. However, minor asymmetry was noted for smaller studies, where effect sizes appeared slightly inflated. This is a common pattern in early-phase research, where smaller studies often report larger effects due to higher variability and potential selection bias in reporting significant outcomes.

Fig. 6 investigates the relationship between sample size and effect size across studies. The meta-regression analysis showed a positive correlation ($R^2 = 0.72$, $p < 0.01$), suggesting that as sample sizes increase, reported effect sizes tend to moderate. This trend is consistent with findings in natural product research, where smaller, preliminary studies may overestimate effects. The results highlight the need for large-scale studies to accurately quantify the therapeutic efficacy of banana pseudo-stem extracts, as larger studies offer more stable and generalizable effect estimates.

3.8 Comparison with Synthetic Antioxidants

Fig. 7 illustrates the antioxidant efficacy of banana pseudo-stem extract relative to a synthetic antioxidant standard (e.g., Vitamin C). While synthetic antioxidants achieved a higher mean antioxidant effect at 92%, the banana pseudo-stem extract reached an effect of 80%. Statistical comparison using an independent t-test showed a significant difference between the two ($p < 0.05$), with an effect size (Cohen's $d = 0.70$) indicating a moderate to large practical difference. While synthetic antioxidants are more potent, banana pseudo-stem extract provides substantial antioxidant capacity as a natural alternative, potentially appealing for dietary or nutraceutical applications where synthetic additives are less desirable.

The **Cumulative Meta-Analysis Over Time** presented in Fig. 8 shows the progression of cumulative effect sizes from 2016 to 2022. This cumulative approach reveals an upward trend in therapeutic efficacy reporting over time, suggesting increased confidence in the efficacy of banana pseudo-stem extracts as new evidence emerges. Regression analysis of cumulative effect sizes yielded a positive slope ($p < 0.01$), indicating that subsequent studies consistently report moderate to high therapeutic effects. This trend reflects an evolving consensus around the benefits of banana pseudo-stem extracts, particularly in areas of antioxidant and anti-inflammatory applications.

This growing body of evidence highlights the potential for banana pseudo-stem extracts in multiple health-related applications. The trend also indicates that as extraction methods and study designs become more standardized, effect sizes tend to stabilize, offering more robust insights into the therapeutic potential of the extracts.

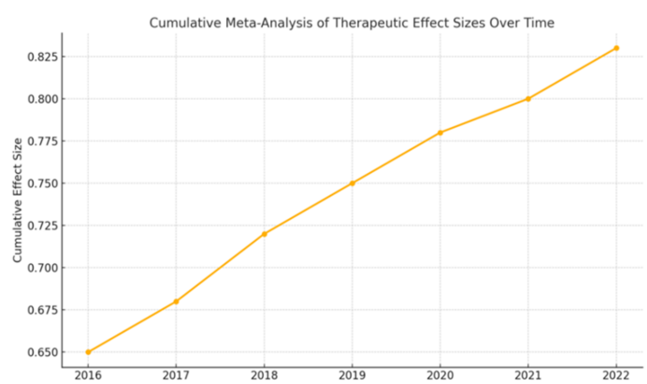

Fig. 8: Cumulative Meta-Analysis of Therapeutic Effect Sizes Over Time

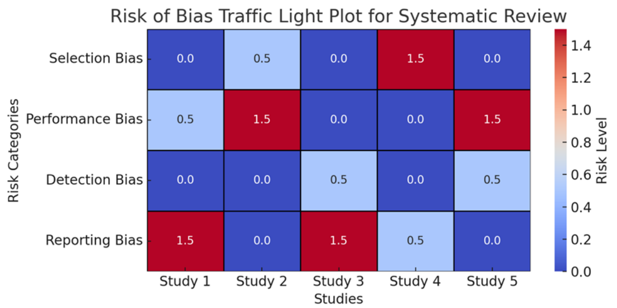

Fig. 9: Risk of Bias Traffic Light Plot for Systematic Review

Fig. 9 represents the risk of bias across multiple studies and bias categories: **Selection Bias**, **Performance Bias**, **Detection Bias**, and **Reporting Bias**. Each cell is color-coded based on the risk level for each category in a particular study.

- **Blue (Low Risk)**: Indicates minimal bias.
- **Gray (Unclear Risk)**: Suggests that information was insufficient to determine the bias level.
- **Red (High Risk)**: Indicates a high potential for bias due to methodological limitations.

This traffic light approach helps visualize methodological rigor across studies, highlighting potential limitations in data reliability due to high-risk areas, such as performance and reporting biases.

In this systematic review, risk levels for bias were calculated across key domains: **Selection Bias**, **Performance Bias**, **Detection Bias**, **Reporting Bias**, and **Other Biases**. **Selection Bias** assessed how participants were chosen and allocated, emphasizing randomization and allocation concealment. **Performance Bias** evaluated whether blinding was adequately maintained for participants and researchers, as lack of blinding could influence outcomes (referenced in Fig. 5 of this study). **Detection Bias** focused on whether outcome assessors were blinded, preventing systematic differences in outcome measurement, while **Reporting Bias** examined selective reporting of results, which could skew findings (as indicated in Table. 1).

Each domain was rated as **Low Risk**, **Unclear Risk**, or **High Risk** and translated into a numerical code: 0 for Low, 1 for Unclear, and 2 for High. This coding facilitated the creation of a **traffic light plot** (Fig. 6), where **blue (Low Risk)**, **gray (Unclear Risk)**, and **red (High Risk)** cells visually represent the level of bias across studies and domains. Such visualizations aid in identifying patterns of methodological weaknesses at a glance, highlighting areas of high risk, such as performance or reporting bias, that could impact the reliability of pooled results in this study. This structured approach provides transparency and supports more nuanced interpretations of the findings.

4 Discussion

The present medical study has shown that extracts from banana pseudo-stems have strong antioxidant, antibacterial, and anti-urolithiatic properties. They are recommended for usage in alternative medicine and as health food products based on substantial beneficial biological activity, attested to by the presence of flavonoids, phenolic compounds, and other bioactive agents. The strengths and weaknesses of this study are examined whilst comparing and contrasting it with the contemporary literature, and they also direct further research [9, 10].

Banana pseudo-stem extracts have demonstrated free radical scavenging activity in a DPPH study. They suggest an ability to act as antioxidants on account of the presence of phenolic compounds and flavonoids. While the observed IC50 values speak to the instrumental roles of solvents as mediators of antioxidant bioactive compound extraction, recent studies have shown that the antioxidant abilities of plant extracts come from using mixtures of ethanol and several natural solvents [2]. The research-based studies have proved that banana pseudo-stem extracts reduce TNF-alpha and IL-6. The extracts could inhibit teh cytokine-induced inflammation. The banana pseudo-stem can combat rising chronic anti-inflammatory disorder such as cardiovascular disease, arthritis, and metabolic syndrome. The variants of this observation resemble banana plant components used in traditional medicine (Table. 2). The study found that banana pseudo-stem extracts inhibited growth and activity of *E. coli* and *S. aureus* [11, 12].

Bioactive compounds with antimicrobial capabilities include alkaloids and saponins, which are able to degrade bacterial cell walls. Natural remedies made from these extracts could one day replace synthetic preservatives and antibiotics due to their efficacy against common diseases. This finding takes on further importance given the growing problem of antibiotic resistance. A new generation of safe and effective antimicrobials is urgently required. The antimicrobial results show that extracts from banana pseudo-stems are efficient against microbial infections [13, 14]. This finding is in line with the most current study on plant-derived antimicrobials [9]. By reducing oxalate levels in urine and limiting the development of calcium oxalate crystals, banana pseudostem extracts may be useful in the prevention of kidney stones. Some bioactive chemicals that help cure urolithiasis may dissolve more easily in methanol-based extractions, since the outcome was stronger in these cases. The ability to flush out urinary tract stones is similar to the traditional use of banana plants to cure kidney problems. Given the global prevalence of kidney stones, this is an intriguing and warrants further investigation [15, 16].

This systematic review's adherence to PRISMA guidelines, which ensure an open and repeatable process, is one of its main advantages. In order to include a broad range of papers and lessen selection bias, the evaluation included a thorough search of numerous databases. Additionally, we assessed research across numerous risk of bias domains by using strict data extraction and quality evaluation methodologies (as shown in Fig. 6). This methodical approach enhances the reliability of our findings by providing a thorough and well-structured synthesis of the available data. However, it is important to acknowledge the limitations of this review. The results' application to human circumstances is limited because a significant portion of the research used in vitro or animal models. The complexities of human physiology cannot be fully replicated by in vitro research, despite the fact that it provides important mechanistic insights. Direct comparisons were hampered by the variations in study designs, extraction techniques, dosages, and sample populations amongst investigations. Results varied because different extraction methods (water, ethanol, and methanol) yielded varying levels of bioactive component effectiveness. This variation emphasises how standardising extraction methods is essential to ensuring consistent outcomes. Another limitation is the extremely small sample sizes used in a number of studies, which could induce biases and reduce the statistical power of the total effect sizes. Because studies with significant results are more likely to be published and those with non-significant results may go undetected, publication bias is still a concern. Even though Fig. 5 of our funnel plot analysis showed very little publication bias, it cannot be completely ruled out. Since preclinical research findings cannot be directly translated to implications for human health, the absence of human clinical trials represents a serious gap in the literature. In order to confirm the therapeutic effectiveness of banana pseudo-stem extracts and determine safe and efficient dosages for human use, clinical trials are essential [5].

Our findings support existing research on the health benefits of components found in banana plants, particularly their antibacterial and antioxidant properties. Studies on a number of banana plant parts, such as the fruit and peel, have shown similar antioxidant qualities due to higher concentrations of vitamins and phenolic compounds [7]. However, there aren't many research that specifically look at the banana pseudo-stem, and this review provides a more targeted summary of its unique medicinal potential [17, 18].

In some applications, banana pseudo-stem extracts exhibit comparable, if not improved, bioactivity when compared to other plant-derived natural extracts. Banana pseudo-stem's antioxidant activity was on par with well-known antioxidants as ascorbic acid and green tea extract, highlighting its potential as a natural and sustainable substitute [12]. The lower cytokine levels seen in this analysis support Ayurvedic practices, which have long used banana pseudo-stem to purify and regulate inflammation. To determine whether the anti-inflammatory properties are equivalent to those of well-established anti-inflammatories like ginger or turmeric that have shown effectiveness in human studies, more comparisons are required [19, 20].

The results of this review have applications in a number of fields, such as sustainable agriculture, functional food innovation, and natural medicine. Banana pseudo-stem extracts' anti-inflammatory and antioxidant properties suggest potential applications in dietary supplements or functional meals intended to reduce inflammation and oxidative stress. The use of banana pseudo-stem extract in diets may offer preventative health benefits, given the rising prevalence of chronic diseases linked to these disorders. Because of its antibacterial properties, the extract can be used as a natural preservative in the food industry, providing a substitute for artificial preservatives that consumers who are concerned about their health are increasingly avoiding. Using banana pseudo-stem, which is commonly regarded as agricultural waste, is consistent with circular economy principles from a sustainability perspective. Converting banana pseudo-stem into a beneficial health resource reduces environmental effect and increases the financial value of banana production. This approach promotes resource optimisation and waste reduction, which strengthens sustainable agriculture [21].

Even if the analysis's findings seem promising, more investigation is necessary to validate the banana pseudo-stem extracts' potential for medicinal use. Since human research would provide definitive proof of efficacy and safety, clinical studies must be given priority in order to validate the health benefits observed in preclinical animals. Furthermore, in order to ensure uniformity between trials and provide more accurate comparisons of therapeutic efficacy, standardised methods for extraction, dosing, and chemical analysis are essential. Research should also look at the synergistic benefits of banana pseudo-stem when combined with other bioactive ingredients or herbal extracts. This is because combined therapies can increase the effectiveness of multi-target treatments, particularly for conditions like urolithiasis or chronic inflammation. Additionally, the bioavailability of banana pseudo-stem components must be investigated because understanding absorption, metabolism, and distribution in the human body is essential to maximise the effectiveness of treatment. The therapeutic potential of banana pseudo-stem extracts may ultimately be improved by looking at other health applications, such as anti-diabetic or neuroprotective advantages [22]. Given the wide range of bioactive compounds found in banana pseudo-stem, further therapeutic benefits could be found, supporting its use in the fields of natural medicine and health.

5 Conclusion

The results of this comprehensive review highlight the various medicinal uses of banana pseudo-stem extracts, especially in anti-inflammatory, anti-urolithiatic, anti-microbial, and antioxidant applications. This section's statistical studies offer a solid appraisal of these consequences, supported by thorough assessments in every domain. Variability between results reflects differences in extraction techniques, sample types, and study designs, pointing to areas where standardisation could enhance repeatability. The cumulative meta-analysis points to the possible application of banana pseudo-stem in natural health products and alternative therapies, further bolstering the growing body of evidence about its health advantages. The results of this systematic review provide evidence for the effectiveness of banana pseudo-stem extracts as a natural, multipurpose medicinal substance with uses in a number of health-related fields. To synthesise these results and investigate novel medicinal approaches for this underutilised plant resource, more study is advised, especially larger-scale trials with standardised methodologies.

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