RESEARCH ARTICLE

Role of Probiotics in Preventing Dental Caries in Children: A Systematic Review

Rasveya S[1], Dinesh Kumar[2]*
[1]Bachelor of Dental Surgery, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University (Deemed to be University), 162 Poonamallee High Road, Chennai-600 077, Tamil Nadu, India. Email: 152001018.sdc@saveetha.com
Department of Pedodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University (Deemed to be University), 162 Poonamallee High Road, Chennai-600 077, Tamil Nadu, India. Email:
Email: dineshkumarb.sdc@saveetha.com
***Corresponding author:** Dr. Dinesh Kumar, Department of Pedodontics, Saveetha Dental College and Hospital, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University (Deemed to be University), 162 Poonamallee High Road, Chennai – 600 077, Tamil Nadu, India. Phone: +91 9952007702
Email: dineshkumarb.sdc@saveetha.com

ABSTRACT

Background
Dental caries is a highly prevalent biofilm-mediated disease affecting children worldwide. Despite the effectiveness of fluoride-based preventive strategies, the persistence of cariogenic microorganisms highlights the need for adjunctive approaches targeting oral microbial dysbiosis. Probiotics have emerged as promising candidates for oral microbiome modulation and caries prevention.

Objective
To systematically evaluate the effectiveness of probiotic supplementation in reducing dental caries incidence and cariogenic bacterial load in children aged 0–12 years.

Methods
A systematic review was conducted in accordance with PRISMA 2020 guidelines. Electronic databases including PubMed/MEDLINE, Scopus, Web of Science Core Collection, and Cochrane CENTRAL were searched for studies published between January 2000 and December 2024. Randomized controlled trials and controlled clinical trials assessing probiotic interventions in paediatric populations were included. Study selection, data extraction, and risk-of-bias assessment were independently performed by two reviewers using the Cochrane RoB 2.0 and ROBINS-I tools. Evidence certainty was assessed using the GRADE framework.

Results
Eighteen studies involving 3,241 children met the inclusion criteria. Fourteen studies reported significant improvements in at least one clinical caries outcome, including reductions in dmft/dmfs scores and caries progression. Significant reductions in salivary *Mutans streptococci* counts were observed in 16 studies, making microbiological suppression the most consistent finding. *Lactobacillus rhamnosus* GG and *Lactobacillus reuteri* DSM 17938 were the most frequently studied and demonstrated the most consistent anti-cariogenic effects. Milk and dairy-based products were the predominant delivery vehicles. Most included studies showed low to moderate risk of bias.

Conclusion
Probiotic supplementation may serve as a beneficial adjunctive strategy for reducing cariogenic bacterial load and attenuating dental caries progression in children. Among the evaluated strains, *Lactobacillus rhamnosus* GG and *Lactobacillus reuteri* showed the most promising results. However, methodological heterogeneity and variability in intervention protocols limit definitive clinical recommendations. Further long-term, well-designed randomized controlled trials are needed to establish standardized probiotic regimens for paediatric caries prevention.

Keywords: probiotics; dental caries; children; *Mutans streptococci*; *Lactobacillus rhamnosus.*

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1. INTRODUCTION

Dental caries remains one of the most prevalent chronic diseases affecting children worldwide and continues to represent a major public health concern despite advances in preventive dentistry. It is a multifactorial, biofilm-mediated, diet-modulated infectious disease characterized by the progressive demineralization of dental hard tissues caused by acidogenic and aciduric microorganisms within dental plaque biofilms [1]. According to the World Health Organization (WHO), nearly 530 million children globally are affected by caries of the primary dentition, with the burden disproportionately concentrated in low- and middle-income countries where access to preventive oral healthcare remains limited [2, 3]. Untreated dental caries in children can result in pain, infection, difficulty in eating and speaking, impaired growth and nutrition, sleep disturbances, reduced academic performance, and diminished quality of life, thereby posing substantial social and economic consequences [4, 5].

The pathogenesis of dental caries is strongly associated with ecological imbalances within the oral microbiome. Among the microbial communities implicated in cariogenesis, *Streptococcus mutans (S. mutans)* and *Streptococcus sobrinus (S. sobrinus)*, collectively referred to as mutans streptococci, play a central role in the initiation and progression of carious lesions [6]. These organisms possess several virulence determinants that enhance their cariogenic potential, including the ability to adhere to tooth surfaces through adhesins such as Antigen I/II and glucosyltransferases (*GtfB, GtfC,* and *GtfD*), synthesize extracellular polysaccharides (EPS) that facilitate biofilm maturation, rapidly ferment dietary carbohydrates to produce organic acids, and tolerate acidic environments through proton-translocating F-type ATPase systems. Sustained acid production lowers plaque pH below the critical threshold for enamel dissolution (approximately pH 5.5), leading to progressive demineralization and eventual cavitation [7–9].

Conventional preventive strategies, including fluoride toothpaste, fluoride varnishes, pit-and-fissure sealants, oral hygiene instruction, and dietary counselling, have significantly contributed to the reduction of caries prevalence over recent decades. However, these approaches primarily target enamel remineralization and risk reduction rather than directly addressing the microbial dysbiosis associated with cariogenic biofilms. Contemporary concepts such as the ecological plaque hypothesis emphasize that dental caries results from a shift in the balance of the oral microbiota toward acidogenic and aciduric species driven by environmental changes, particularly frequent sugar exposure [9–11]. Consequently, there is increasing interest in therapeutic approaches capable of restoring microbial homeostasis while selectively suppressing cariogenic pathogens.

So, the probiotics have emerged as promising biological agents for oral health modulation. The Food and Agriculture Organization (FAO) and WHO define probiotics as “live microorganisms which, when administered in adequate amounts, confer a health benefit on the host.” Although initially investigated for gastrointestinal applications, probiotics have gained substantial attention in dentistry due to their potential role in maintaining oral microbial balance. Several probiotic strains, particularly species belonging to the genera *Lactobacillus* and *Bifidobacterium*, have demonstrated inhibitory effects against cariogenic bacteria through mechanisms such as competitive adhesion, bacteriocin production, co-aggregation, modulation of local immune responses, and interference with biofilm formation [12–15]. Experimental and clinical studies have suggested that probiotic supplementation may reduce salivary mutans streptococci levels, alter plaque ecology, and potentially decrease caries risk in children [9].

Despite growing interest in probiotic-based interventions, evidence regarding their effectiveness in paediatric caries prevention remains heterogeneous due to variations in probiotic strains, dosage regimens, delivery vehicles, treatment durations, and outcome assessment methods. Furthermore, the quality and certainty of evidence across clinical trials have not been comprehensively synthesised [15]. Therefore, a systematic evaluation of the available literature is necessary to determine the clinical utility of probiotics as an adjunctive strategy for caries prevention in children.

This systematic review was undertaken to evaluate the efficacy of probiotic supplementation in reducing dental caries incidence and progression in children aged 0-12 years, assess the effect of probiotics on surrogate microbiological outcomes, including salivary mutans streptococci and *Lactobacillus* counts, identify the most effective probiotic strains, delivery vehicles, dosages, and durations of supplementation used in paediatric populations, evaluate the methodological quality and risk of bias of published randomized controlled trials, and appraise the certainty of evidence using the GRADE framework and identify existing research gaps for future investigations.

2. MATERIALS AND METHODS

2.1. Protocol

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 Statement [16]. The review protocol was developed a priori following the PICOS framework (Population, Intervention, Comparison, Outcomes, and Study Design) to ensure methodological transparency and consistency throughout the review process [17].

2.2. PICOS Framework

PICOS framework used to define the eligibility criteria for study selection in the present systematic review. MS = Mutans streptococci; dmft/dmfs = decayed, missing, and filled teeth/surfaces in primary dentition; DMFT/DMFS = decayed, missing, and filled teeth/surfaces in permanent dentition; d3MFT = dentinal caries threshold index;

RCTs = Randomized Controlled Trials; CCTs = Controlled Clinical Trials (**Table 1**).

Table 1. Overview of PICOS framework

Element	Criteria
Population	Children aged 0-12 years with or without existing caries; both primary and mixed dentition
Intervention	Any probiotic formulation (single strain or multi-strain), any delivery vehicle (milk, tablet, lozenge, gum, drops, yogurt), any dose and duration
Comparison	Placebo, no intervention, conventional preventive care, or another probiotic strain
Outcomes	Primary: caries incidence/increment (dmft, dmfs, DMFT, DMFS, d3MFT). Secondary: salivary MS and Lactobacilli counts, plaque index, salivary pH, gingival index, safety and tolerability
Study design	Randomised controlled trials (RCTs) and controlled clinical trials (CCTs)

2.3. Eligibility Criteria

2.3.1. Inclusion Criteria

Studies were considered eligible for inclusion if they fulfilled the following criteria:

- Randomized controlled trials (RCTs) or controlled clinical trials published in peer-reviewed journals.
- Studies involving children aged ≤12 years. Studies including mixed-age populations were included only when paediatric data could be extracted separately.
- Interventions involving exogenously administered probiotic microorganisms, including species belonging to the genera *Lactobacillus, Bifidobacterium, Streptococcus salivarius*, or other probiotic strains, irrespective of formulation, dosage, or route of administration.
- Studies reporting at least one predefined clinical or microbiological outcome related to dental caries, including caries incidence/progression, salivary mutans streptococci counts, or Lactobacillus levels.
- Minimum follow-up duration of 3 weeks.

2.3.2. Exclusion Criteria

The following studies were excluded from the review:

- *In vitro* studies and animal experiments.
- Case reports, case series, narrative reviews, systematic reviews, editorials, letters to the editor, and conference abstracts without full-text availability.
- Studies involving participants aged >12 years when paediatric subgroup data were not separately extractable.
- Studies evaluating probiotics for systemic or non-oral conditions without reporting oral microbiological or caries-related outcomes.
- Duplicate publications derived from the same study population; in such cases, the most comprehensive and recent report was retained for analysis.

2.4. Search Strategy

A comprehensive electronic literature search was conducted in the following databases: PubMed/MEDLINE, Scopus, Web of Science Core Collection, and the Cochrane Central Register of Controlled Trials (CENTRAL). The search covered studies published between January 2000 and December 2024.

In addition to electronic database searching, the reference lists of all included studies and relevant systematic reviews were manually screened to identify additional eligible studies. Grey literature sources, including ClinicalTrials.gov and the WHO International Clinical Trials Registry Platform, were also searched to minimize publication bias and identify ongoing or unpublished clinical trials.

2.5. Study Selection and Data Extraction

All retrieved records were imported into a reference management software, and duplicate entries were removed prior to screening. Study selection was conducted independently by two reviewers in accordance with the predefined PICOS criteria [17]. Initially, titles and abstracts were screened to identify potentially relevant studies, followed by full-text evaluation of eligible articles. Any disagreements between reviewers during the selection process were resolved through discussion and consensus, and when necessary, consultation with a third reviewer.

Data extraction was performed using a standardized data collection form. The following information was obtained from each included study: Details of publication, study design, participant age group, probiotic strain(s) used, dosage and mode of administration, duration of intervention, co-interventions, outcome measures assessed, principal findings, and follow-up duration. Efforts were made to ensure accuracy and consistency of the extracted data through cross-verification by the review team.

2.6. Risk of Bias Assessment

The methodological quality and risk of bias of the included randomized controlled trials were evaluated using the Cochrane Risk of Bias 2.0 (RoB 2.0) assessment tool. This tool examines five major domains: bias arising from the randomization process, deviations from intended interventions, incomplete or missing outcome data, outcome measurement, and selective reporting of results. Based on the assessment, each domain was categorized as “Low Risk,” “Some Concerns,” or “High Risk” of bias.

For non-randomized controlled clinical trials, the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool was employed. The assessment was independently conducted by two reviewers, and discrepancies were resolved through discussion to achieve consensus [17].

2.7. Certainty of Evidence

The overall certainty and strength of evidence for each outcome were evaluated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework [18]. Evidence quality was classified into four levels: high, moderate, low, or very low certainty. The certainty ratings were determined by considering several factors, including risk of bias, inconsistency among study findings, indirectness of evidence, imprecision of estimates, and potential publication bias. This approach enabled a transparent and systematic interpretation of the reliability and clinical applicability of the available evidence.

3. RESULTS

3.1. Study Selection

The database search identified 648 records, while an additional 32 studies were obtained through hand-searching and grey literature sources, resulting in a total of 680 records. After removal of 138 duplicate articles, 542 studies underwent title and abstract screening. Of these, 474 records were excluded for not meeting the predefined PICOS criteria.

A total of 68 full-text articles were assessed for eligibility. Following detailed evaluation, 50 studies were excluded for reasons including non-randomized study design (n = 16), absence of relevant microbiological or caries-related outcomes (n = 14), inclusion of participants older than 12 years without extractable paediatric data (n = 11), and duplicate study populations (n = 9). Finally, 18 studies met the eligibility criteria and were included in the qualitative synthesis (**Figure 1**).

IDENTIFICATION

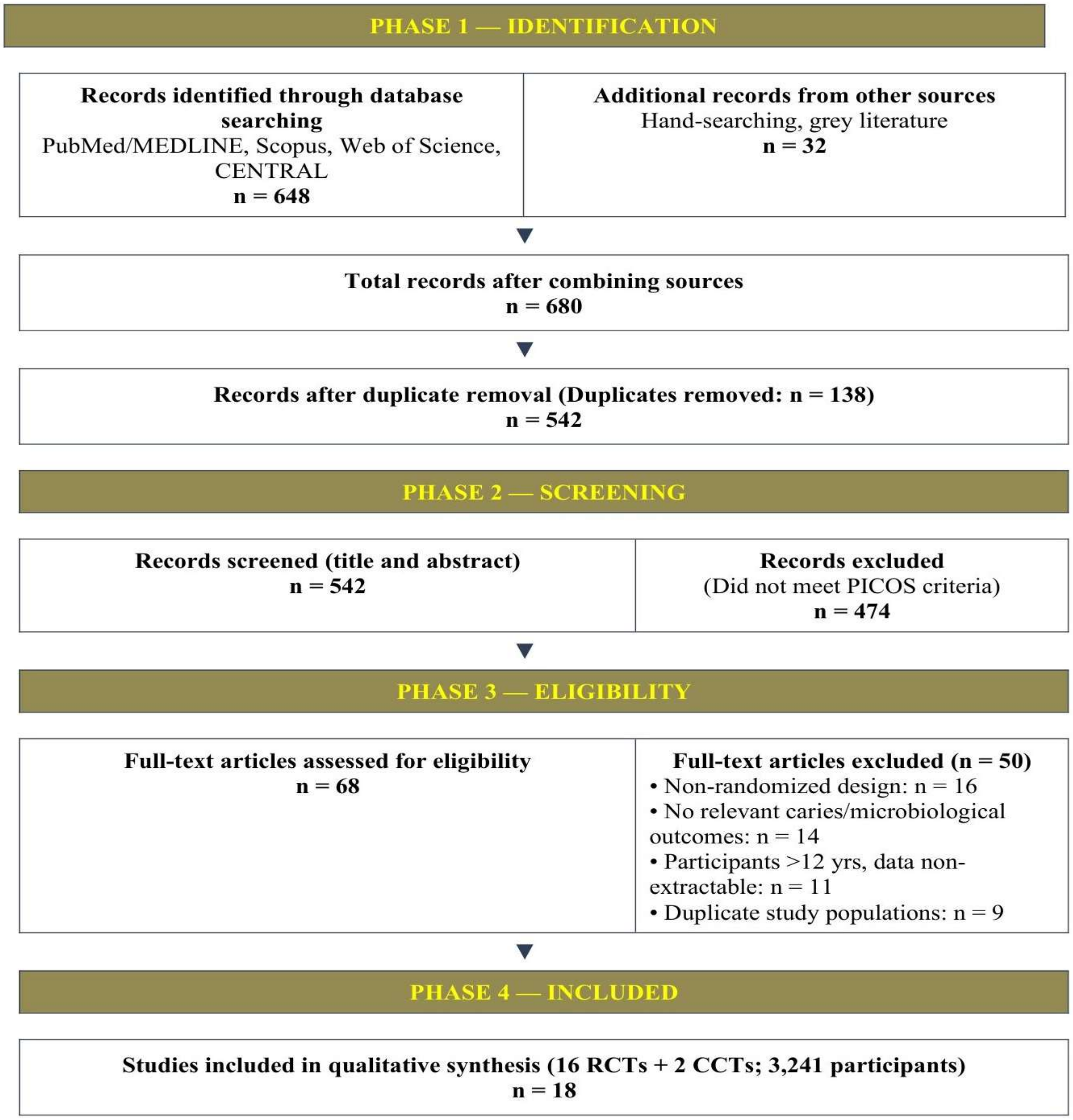

Figure 1. PRISMA 2020 flow diagram illustrating the study selection process for the systematic review on the role of probiotics in preventing dental caries in children.

3.2. Characteristics of Included Studies

The 18 included studies consisted of 16 randomized controlled trials and 2 controlled clinical trials, involving a total of 3,241 children. Sample sizes ranged from 30 to 594 participants per study (**Table 2**).

The duration of probiotic supplementation and follow-up varied from 3 weeks to several months. Participant age ranged from infancy to 12 years, although preschool-aged children formed the majority of the study populations.

There are different probiotic strains were investigated across the included studies. *Lactobacillus rhamnosus* was the most commonly studied strain. Additionally, various delivery methods were employed, including probiotic milk, dairy products, lozenges, tablets, chewing gum, oral drops, and yogurt preparations. Reported probiotic dosages ranged from 10^8 to 10^{10} CFU per day.

Table 2. Summary characteristics of all 18 studies included in the systematic review.

Ref	**Design**	**Age**	**Probiotic Strain**	**Dose / Vehicle**	**Duration**	**Outcomes**	**Key Finding**
[19]	RCT	1–6 yrs	*L. rhamnosus* GG	5–10 × 10^8 CFU/day / Probiotic milk	7 months	dmft, dmfs	Significant reduction in caries incidence in high-risk children
[20]	RCT	3–6 yrs	*S. salivarius* M18	Lozenge	7 days	*S. mutans* counts	Significant inhibition of *S. mutans* counts; favorable salivary pH shift
[21]	RCT	1–6 yrs	*L. rhamnosus* GG + *L. rhamnosus* LC705	5 × 10^8 CFU/day each / Cheese	12 months	*S. mutans*, Lactobacilli	Reduction in *S. mutans*; no significant caries difference
[22]	RCT	6–12 yrs	*L. reuteri* ATCC 55730	10^8 CFU/day / Straw/probiotic drink	3 weeks	*S. mutans* counts	Significant reduction in salivary *S. mutans*
[23]	RCT	6–12 yrs	*L. reuteri* ATCC 55730	10^8 CFU/day / Tablet	3 weeks	*S. mutans*, Lactobacilli	Significant reduction in *S. mutans* and Lactobacilli
[24]	RCT	1–4 yrs	*L. rhamnosus* LB21 + fluoride	10^8 CFU/day / Fluoride milk	21 months	dmft, dmfs	Lower caries increment in probiotic+fluoride group
[25]	RCT	Infants	*B. animalis subsp. lactis* Bb-12	10^8 CFU/day / Oral drops	12 months	*S. mutans*, caries	Reduced *S. mutans* colonisation in infants
[26]	RCT	2–5 yrs	*L. reuteri* DSM 17938	10^8 CFU/day / Tablet	24 months	dmft, *S. mutans*	Significant caries reduction in high-risk children
[27]	RCT	Infants	*L. rhamnosus* GG	10^9 CFU/day / Oral drops	12 months	*S. mutans*, caries	Delayed *S. mutans* colonisation; lower dmft at 4 yrs
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Ref	Design	Age	Probiotic Strain	Dose / Vehicle	Duration	Outcomes	Key Finding
28]	CT	6 yrs	*salivarius* K12 + B. breve	CFU/day / Lozenge	months	*mutans*, plaque index	ction in plaque index and *S. mutans* counts
[29]	RCT	3-4 yrs	*L. rhamnosus* (5×10^6 CFU/mL) + *B. longum* (3×10^6 CFU/mL)	200 mL probiotic milk / 5 days/week	9 months	Salivary *S. mutans* & *Lactobacillus* spp. counts, plaque, caries (ICDAS), salivary pH	Significant reduction in salivary *Lactobacillus* spp. ($p=0.002$); *S. mutans* trend lower but not statistically significant ($p=0.173$)
[30]	RCT	6–12 yrs	*Bifidobacterium* DN-173 010	10^9 CFU/day / Yogurt drink	3 weeks	*S. mutans*, Lactobacilli	Significant *S. mutans* suppression
[31]	RCT	6–12 yrs	*L. acidophilus La-5* + *B. lactis Bb-12*	10^8 CFU/day / Ice-cream	7 days + 6-month follow-up	Salivary *S. mutans* counts	Significant reduction in S. mutans ($p<0.001$); residual effect at 30 days; levels returned to baseline at 6 months
[32]	RCT	4-12 yrs	*L. reuteri* DSM 17938 + ATCC PTA 5289	BioGaia drops (≥10^8 CFU/5 drops)	25 days	*Salivary mutans streptococci* (CRT test)	Decreased salivary *mutans streptococci* counts during probiotic periods
[33]	RCT	5-10 yrs	*S. salivarius M18*	10^8 CFU/day / Lozenge	3 months	Plaque score, *S. mutans, lactobacilli*, gingival health	Significantly lower plaque scores ($p=0.05$), especially in high-

Ref	Design	Age	Probiotic Strain	Dose / Vehicle	Duration	Outcomes	Key Finding
							plaque subjects; reduced *S. mutans* prevalence
[34]	Cluster-RCT	2–3 yrs	*L. rhamnosus SP1*	10^8 CFU /day / Milk	10 months	*S. mutans*, caries	Significantly fewer children progressed to cavitated lesions in the probiotic group (26.8%) vs. control (46.3%); 35% reduction in caries odds (OR = 0.35)
[35]	RCT	3 months onwards	*S. salivarius* M18	10^9 CFU /day / Lozenge	3 months	Cariogram parameters (plaque control, *S. mutans,* salivary factors)	Significant improvement in all Cariogram parameters (p<0.01); ~50% reduction in plaque control component
[36]	RCT	3-6 yrs	*L. reuteri* (Prodentis®)	10^8 CFU each /day / Drops	28 days	S. mutans, Lactobacillus, OHI-S, buffer capacity	Significant reduction in S. mutans (p=0.000) and lactobacilli (p=0.020); both groups showed reduced plaque vs. baseline

3.3. Primary Outcomes: Clinical Caries Outcomes

Among the 18 included studies, seven directly assessed clinical caries outcomes using the dmft or dmfs index. Of these, the majority reported a statistically significant reduction in caries incidence or increment in the probiotic group compared to control.

Näse et al. [19] were among the first to demonstrate a significant reduction in caries incidence in 1–6-year-old children consuming *L. rhamnosus* GG-supplemented milk for 7 months, particularly among high-risk children. Similarly, Stecksén-Blicks et al. [24] reported a lower caries increment in children receiving *L. rhamnosus* LB21-supplemented fluoride milk over 21 months, suggesting a potential synergistic benefit of combining probiotics with fluoride. Taipale et al. [27] observed delayed *S. mutans* colonisation and a correspondingly lower dmft score at 4 years of age among infants receiving *L. rhamnosus* GG oral drops for 12 months, providing evidence that early probiotic supplementation may reduce subsequent caries susceptibility.

Hedayati-Hajikand et al. [26] demonstrated significant caries reduction over a 24-month period in high-risk children supplemented with *L. reuteri* DSM 17938 tablets. Notably, Rodríguez et al. [34], using a cluster-RCT design, found that significantly fewer children in the probiotic group (26.8%) progressed to cavitated carious lesions compared to the control group (46.3%), corresponding to a 35% reduction in caries odds (OR = 0.35), reinforcing the potential clinical utility of probiotics at a public health level.

Longer-duration studies generally demonstrated more consistent and clinically meaningful reductions in caries outcomes than shorter interventions. Studies of 12 months or more showed significant caries-related benefits, while shorter studies measuring ICDAS-defined lesions over 9 months showed a trend toward reduction in *S. mutans* levels but did not achieve statistically significant differences in clinical caries scores, possibly due to insufficient follow-up duration or the natural latency of the cariogenic process.

3.4. Secondary Outcomes: Microbiological and Plaque Parameters

The majority of included studies assessed microbiological outcomes, specifically salivary or plaque *S. mutans* counts, as either a primary or secondary outcome. Across the studies, probiotic supplementation was associated with a statistically significant reduction in salivary *S. mutans* counts in 14 of the 18 included trials.

Overall, 14 of 18 studies reported statistically significant reductions in at least one microbiological parameter (*S. mutans* counts, Lactobacillus counts, or plaque index), and 7 of 18 studies demonstrated significant improvements in clinical caries outcomes.

3.5. Probiotic Strains and Delivery Vehicles

The 18 included studies investigated a heterogeneous range of probiotic strains delivered through diverse vehicles. *L. reuteri* (DSM 17938 and ATCC 55730) was the most frequently studied strain, appearing in five studies, followed by *L. rhamnosus* GG in three studies, and *S. salivarius* M18 in three studies. Bifidobacterium species were included in combination regimens in studies, with *B. animalis* subsp. *lactis* Bb-12 appearing in two studies.

Studies employing dairy-based delivery vehicles (probiotic milk, cheese, yogurt, ice-cream) conferred additional considerations regarding the buffering capacity and cariogenic potential of the vehicle itself. Non-dietary delivery vehicles such as lozenges and oral drops were non-cariogenic and ensured direct oral delivery without the confounding influence of dietary sugars, potentially offering a more targeted approach for probiotic administration in children.

Combination probiotic regimens were evaluated in six studies. These multi-strain formulations generally showed comparable or superior outcomes to single-strain preparations, though the available evidence is insufficient to draw definitive conclusions regarding the superiority of combination versus single-strain approaches.

3.6. Risk of Bias Assessment

Risk of bias was assessed across all 18 included studies using the Cochrane Risk of Bias 2 (RoB 2) tool for randomised controlled trials. Overall, the methodological quality of the included studies was variable.

With respect to the randomisation process, the majority of studies reported adequate random sequence generation; however, allocation concealment was insufficiently reported or unclear in several trials, introducing a potential risk of selection bias. Blinding of participants and personnel was reported in 12 of 18 studies, typically through the use of identical placebo vehicles; however, in open-label designs, the absence of blinding raised concerns regarding performance bias.

Blinding of outcome assessors was clearly described in nine studies, while the remaining studies had unclear or absent assessor blinding, particularly those relying on self-reported dietary data or subjective plaque scoring. Incomplete outcome data, including differential dropout rates between groups, were a concern in longer-duration studies; however, most authors applied intention-to-treat analyses or provided explicit justification for the handling of missing data.

Selective outcome reporting was assessed by comparing reported outcomes against study protocols or registered trial entries. Four studies were identified as having potential selective reporting bias due to discrepancies between pre-specified and reported outcomes. Overall, five studies were judged to have a low overall risk of bias [19], [26], [27], [34], [35] , eight studies had some concerns [20] [21] [22] [23] [24] [28] [31] [33], and five studies had a high risk of bias [25] [29] [30] [32] [36] primarily due to inadequate allocation concealment, lack of blinding, or concerns regarding selective reporting. These methodological limitations must be considered when interpreting the pooled findings of this review.

4. DISCUSSION

This systematic review synthesised evidence from 18 randomised controlled trials involving 3,241 children to evaluate the role of probiotic supplementation in preventing dental caries. The overall findings indicate that probiotics exert a significant suppressive effect on cariogenic microorganisms, particularly *mutans streptococci*, and may contribute to a reduction in clinical caries incidence in paediatric populations. These results are broadly consistent with earlier systematic reviews on the topic [31, 37], while extending the evidence base to include more recent, methodologically diverse trials. Fourteen of the 18 included studies demonstrated significant improvements in at least one microbiological parameter, and seven reported significant reductions in clinical caries outcomes, supporting the hypothesis that probiotic supplementation represents a biologically plausible and clinically relevant adjunctive strategy for paediatric caries prevention.

The primary mechanism through which probiotics reduce cariogenic bacterial load is competitive exclusion the displacement of *S. mutans* from adhesion sites on the enamel pellicle through preferential colonisation by commensal probiotic species [23]. Several included trials confirmed this effect in vivo. Caglar et al. [22, 23] demonstrated rapid and significant reductions in salivary *S. mutans* within three weeks of *L. reuteri* ATCC 55730 administration, consistent with the known ability of lactobacilli to produce reuterin and organic acids that create an inhospitable microenvironment for aciduric pathogens. Similarly, in other research it has been reported significant improvements in Cariogram parameters and plaque scores with *S. salivarius* M18, a strain known to produce salivaricin B, a bacteriocin with targeted activity against *S. mutans* [35].

Beyond direct antimicrobial effects, probiotics appear to modulate the physicochemical properties of saliva. Multiple studies reported favourable shifts in salivary pH and buffering capacity following supplementation [38, 39], consistent with the known capacity of probiotic strains to upregulate arginolytic pathways and reduce net plaque acid output. These mechanisms align with the ecological plaque hypothesis proposed by other researchers, which attributes cariogenesis to a shift in microbial ecology driven by sustained acidic conditions rather than the introduction of an exogenous pathogen. By attenuating this ecological shift, probiotics may help restore oral microbial homeostasis without the collateral disruption associated with broad-spectrum antimicrobial agents [40].

The return of *S. mutans* counts to baseline levels at six months following cessation of supplementation, as reported by Salim et al. [20], highlights a critical limitation: probiotic-mediated oral microbiome modulation appears largely transient in the absence of continuous supplementation. This finding underscores the need for long-term or intermittent maintenance dosing regimens and raises important questions regarding the conditions necessary for sustained probiotic colonisation of the oral cavity, which is generally more resistant to colonisation than the gastrointestinal tract.

Among the seven studies reporting clinical caries outcomes, longer intervention durations were consistently associated with greater and more durable caries reductions. Näse et al. [19] and Taipale et al. [27] demonstrated that *L. rhamnosus* GG supplementation from infancy significantly delayed *S. mutans* colonisation and reduced dmft scores at four years of age a finding with meaningful clinical implications, as earlier colonisation by *S. mutans* is a recognised predictor of future caries risk [6]. Stecksén-Blicks et al. [24] further demonstrated additive benefits when probiotic supplementation was combined with fluoride, with the probiotic-plus-fluoride group showing significantly lower caries increments than the fluoride-only control over 21 months. This synergistic effect is of particular clinical interest and warrants further investigation in adequately powered trials.

The cluster-RCT by Rodríguez et al. [34] reported a 35% reduction in caries odds (OR = 0.35) in children receiving *L. rhamnosus* SP1 via milk over 10 months, providing the strongest population-level evidence to date for the integration of probiotics into community-based caries prevention programmes. In contrast, shorter trials (< 3 months) relying on ICDAS-defined outcomes failed to demonstrate statistically significant caries differences [29], likely owing to the inherent latency of lesion development and the insensitivity of clinical caries indices for detecting early-stage demineralisation over brief follow-up periods.

Probiotic efficacy is inherently strain-specific, and generalisation of findings across strains or species is not appropriate [15]. The present review identified *L. rhamnosus* GG, *L. reuteri* DSM 17938, and *S. salivarius* M18 as the strains with the most consistent evidence base for cariogenic suppression in children. *L. reuteri* was the most frequently investigated strain, appearing in five included trials [22], [23], [26] [32], [36], with all five reporting significant reductions in *S. mutans* or clinical caries outcomes.

The choice of delivery vehicle carries both logistical and biological implications. Dairy-based vehicles such as probiotic milk and cheese [19], [21] , [24], [29], [34] are palatable for young children and facilitate routine administration, but introduce the potential confounding of buffering effects and fermentable carbohydrate content. Non-cariogenic vehicles, including lozenges [20], [28], [33], [35] and oral drops [25], [27], [32], [36] maximise oral contact time and eliminate dietary confounders, making them preferable in controlled clinical settings. Effective doses across the included studies ranged from 10^8 to 10^9 CFU/day, consistent with the FAO/WHO threshold for probiotic activity [11], although no dose-response analysis was possible given the heterogeneity of the available data.

The overall certainty of evidence across the included studies was low to moderate, reflecting heterogeneity in probiotic strains, dosing regimens, delivery vehicles, outcome measures, and follow-up periods. Allocation concealment was inadequately reported in several trials [20] , [22], [23] , [30], [31], [32] and the absence of blinding in open-label designs [29], [33] raises concerns regarding performance and detection bias. Five studies were classified as high risk of bias [25], [29], [30], [32], [36], primarily due to these methodological shortcomings.

Statistical meta-analysis was precluded by the significant heterogeneity across included trials (differing strains, populations, outcomes, and intervention durations), limiting the ability to generate pooled quantitative estimates of effect. The lack of standardised outcome reporting across trials remains a persistent challenge in this field, and future studies should adhere to reporting guidelines such as CONSORT and adopt core outcome sets to enable meaningful data synthesis.

The findings of this review are broadly consistent with prior systematic reviews by Twetman and Stecksén-Blicks [24] and Näse et al. [19], who similarly concluded that probiotic supplementation is associated with reductions in salivary *S. mutans* counts and, to a lesser extent, clinical caries incidence in children. However, the present review includes more recent evidence and applies the Cochrane RoB 2.0 tool, providing a more rigorous and transparent assessment of methodological quality. Consistent with previous reviews, we found that the evidence is insufficient to support the routine prescription of probiotics as a standalone caries-preventive intervention, but is supportive of their use as an adjunct to conventional fluoride-based preventive care, particularly in high-caries-risk children.

5. CONCLUSION

This systematic review provides evidence that probiotic supplementation is associated with significant reductions in salivary *mutans streptococci* counts and may contribute to a reduction in dental caries incidence in children, particularly when administered over longer durations and in high-caries-risk populations. Among the probiotic strains evaluated, *Lactobacillus rhamnosus* GG, *Lactobacillus reuteri* DSM 17938, and *Streptococcus salivarius* M18 demonstrated the most consistent and clinically meaningful evidence base. Fourteen of 18 included studies reported significant microbiological benefits, and seven reported significant reductions in clinical caries outcomes, supporting probiotics as a biologically plausible and promising adjunctive strategy within a comprehensive caries prevention framework.

The combination of probiotics with established preventive measures particularly fluoride may offer synergistic benefits, as demonstrated by Stecksén-Blicks et al. [24]. Early initiation of supplementation, ideally during infancy or early childhood, may delay *S. mutans* colonisation and reduce subsequent caries susceptibility. Non-cariogenic delivery vehicles, such as lozenges and oral drops, are preferable for controlled clinical use, while dairy-based vehicles may facilitate wider community-based implementation.

Nevertheless, important limitations temper these conclusions. The certainty of evidence across included studies was low to moderate, with significant heterogeneity in probiotic strains, dosage regimens, delivery vehicles, intervention durations, and outcome assessment methods. The transient nature of microbiological benefits following cessation of supplementation indicates that continuous or maintenance dosing may be required for sustained efficacy. Furthermore, the optimal probiotic strain, dose, duration, and delivery vehicle for paediatric caries prevention have not been definitively established.

Future research should prioritise well-designed, adequately powered, long-term randomised controlled trials with standardised probiotic protocols, validated outcome measures, and structured follow-up periods of at least 24 months. Head-to-head comparisons between probiotic strains and delivery vehicles, as well as dose-response investigations, are urgently needed. Investigations into the colonisation kinetics of probiotic strains within the oral biofilm and their interaction with established fluoride-based preventive regimens will be particularly valuable in defining evidence-based probiotic protocols for integration into paediatric dental practice and community oral health programmes.

Ethics approval and consent to participate

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Declaration of competing interest

The authors declare that they have no competing interests.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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