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The Athlete's Breath: Strain-Specific Probiotic Evidence for Managing Intra-Oral Halitosis in Adults — A Critical Narrative Review

Authors:

Natalia Le Hong¹ [NLH]

5th Military Clinical Hospital with Polyclinic - Independent Public Healthcare Institution, Krakow, Poland

<https://orcid.org/0009-0000-0540-8222>

e-mail: natalialehong@gmail.com

Weronika Jagiello [WJ]

5th Military Clinical Hospital with Polyclinic - Independent Public Healthcare Institution, Krakow, Poland

<https://orcid.org/0009-0000-5200-9208>

e-mail: weronikajagiello@o2.pl

Natalia Dymel [ND]

5th Military Clinical Hospital with Polyclinic - Independent Public Healthcare Institution, Krakow, Poland

<https://orcid.org/0009-0009-3928-5393>

e-mail: natalia6545@gmail.com

Karolina Kukuczka [KKu]

Independent Researcher, Krakow, Poland

<https://orcid.org/0009-0006-6436-3718>

e-mail: carolina.kaa@onet.pl

Gabriela Karpińska [GK]

HCP Medical Center Ltd., Poznan, Poland

<https://orcid.org/0009-0007-2185-2586>

e-mail: g.karpinska13@gmail.com

¹ Corresponding Author: e-mail: natalialehong@gmail.com

Kamila Kędzior [KKe]

Independent Researcher, Krakow, Poland

<https://orcid.org/0009-0007-4562-3825>

e-mail: kedziorkamila97@gmail.com

Sonia Krzykawska [SK]

University Dental Clinic in Krakow, Krakow, Poland

<https://orcid.org/0009-0001-3577-014X>

e-mail: sonia.krzykawska2001@gmail.com

Abstract

Probiotics have been proposed as adjuncts for intra-oral halitosis, while exercise-related oral dryness, sports nutrition, and a substantial burden of oral disease make oral health relevant to sports medicine. Aim. To critically review strain-specific clinical evidence for probiotics in adult intra-oral halitosis and consider implications for sports dentistry. Material and methods. A targeted, non-systematic PubMed/MEDLINE update, recent systematic reviews, citation tracing, and a contextual search of athlete oral-health literature were used through 6 September 2026. Randomized between-group effects were prioritized. Results. Fifteen placebo- or matched-control randomized trials (844 participants) and one 117-participant active-comparator trial were examined. Selected strains improved some VSC or organoleptic outcomes, whereas other trials were null, transient, or analytically uncertain. No athlete-specific efficacy trial was identified. Conclusions. Evidence does not support a uniform probiotic class effect or routine recommendation. In sports dentistry, probiotics should be regarded only as evidence-limited, strain-specific adjuncts to cause-directed oral care.

Key words: halitosis; oral malodor; probiotics; volatile sulfur compounds; organoleptic assessment; oral microbiome; sports dentistry

1. Introduction

Halitosis is a clinically relevant condition characterized by unpleasant odor in exhaled breath and may adversely affect interpersonal communication, self-confidence, and oral health-related quality of life. Although malodor can originate from respiratory, gastrointestinal, metabolic, or other extra-oral sources, most genuine cases have an intra-oral origin. Tongue coating, plaque-retentive niches, gingival inflammation, and periodontitis are among the principal oral contributors. Contemporary clinical guidance therefore emphasizes etiological classification and cause-directed diagnosis rather than treating halitosis as a single homogeneous disorder (De Geest et al. 2016; Nakhleh et al. 2018; Shang et al. 2026).

The biological basis of intra-oral halitosis is predominantly microbial. Proteolytic microorganisms colonizing the dorsum of the tongue and periodontal niches metabolize sulfur-containing amino acids and other organic substrates, producing volatile and non-volatile odorants. Hydrogen sulfide (H₂S) and methyl mercaptan (CH₃SH) are the volatile sulfur compounds most closely associated with intra-oral malodor. Dimethyl sulfide (DMS) can also be detected in exhaled breath, but elevated DMS is more strongly associated with extra-oral, blood-borne halitosis and therefore requires different etiological interpretation (Tangerman and Winkel 2007; De Geest et al. 2016; Suzuki et al. 2019).

Conventional management focuses on removal of odor-producing substrates and treatment of the underlying oral condition. Tongue cleaning, oral-hygiene reinforcement, professional periodontal therapy when indicated, and selected chemical neutralizing or antimicrobial approaches remain the foundation of care (De Geest et al. 2016; Shang et al. 2026). Probiotics have been proposed as a complementary ecological strategy: a viable microorganism may interfere with malodor-associated microbial networks, compete for adhesion sites or nutrients, produce inhibitory metabolites, or modify local environmental conditions (Suzuki et al. 2019). The central clinical question is whether these plausible microbiological effects translate into a perceptible and durable reduction in malodor.

Relevance to sports dentistry is clinically plausible because oral health in athletes is shaped by sport-specific exposures, including frequent carbohydrate or acidic-product intake, hydration demands, and exercise-related oral dryness. Recent literature has emphasized that preventable oral disease is common in athletic populations and may affect well-being, training, and perceived performance; Quality in Sport has likewise framed oral health

as a component of athlete welfare and readiness (Schulze and Busse 2024; Lewalski et al. 2026). Evidence specific to halitosis and probiotic treatment in athletes, however, is sparse. Sports-related implications should therefore be treated as contextual extrapolation rather than as evidence of athlete-specific probiotic efficacy.

Clinical trials have evaluated *Streptococcus salivarius*, *Weissella cibaria*, *Ligilactobacillus salivarius*, *Levilactobacillus brevis*, *Lacticaseibacillus paracasei*, *Lactiplantibacillus plantarum*, and multi-strain formulations. Previous systematic reviews have reached divergent conclusions, ranging from insufficient evidence for a clear clinical benefit to pooled short-term improvements in VSC or organoleptic outcomes (López-Valverde et al. 2022; Tay et al. 2022; Huang et al. 2022; Passadakis et al. 2025; Yang et al. 2026). A critical narrative synthesis is therefore warranted not merely to ask whether “probiotics” work as a broad category, but to examine strain-specific effects, the non-interchangeability of sensory and biochemical outcomes, the validity of randomized treatment estimates, and the clinical relevance of newer trials not fully represented in earlier meta-analyses.

Research objective. The objective of this critical narrative review was to evaluate the biological rationale, strain-specific clinical evidence, outcome measurement, methodological limitations, and clinical relevance of probiotic interventions for intra-oral halitosis in adults, with emphasis on randomized treatment contrasts and the distinction between biochemical and clinically perceptible outcomes, and to consider potential implications for sports dentistry and physically active adults while clearly separating direct halitosis-trial evidence from sport-specific contextual evidence.

2. Research materials and methods

2.1. Review design and scope

This article was designed as a critical narrative review rather than a systematic review. Its purpose was interpretive: to examine clinically informative human evidence, identify reasons for discordant trial results, and distinguish robust randomized treatment effects from within-group change.

2.2. Information sources and literature update

Targeted PubMed/MEDLINE searches combined terms for halitosis, oral malodor, bad breath, volatile sulfur compounds, probiotics, and named oral probiotic strains with clinical-trial terminology. Searches were supplemented by recent systematic reviews, backward and forward citation tracing, and targeted verification of newly published reports; the final update was performed on 6 September 2026. A supplementary contextual search combined terms for athletes, sport, exercise, sports dentistry, oral health, saliva, oral microbiota, and probiotics to identify literature relevant to applicability in physically active populations. Priority was given to peer-reviewed adult randomized trials in which intra-oral halitosis was objectively assessed by standardized organoleptic testing and/or instrumental VSC measurement. No exhaustive multi-database search, duplicate screening, or formal study-selection audit was undertaken, and the search was not designed to establish language-independent completeness.

2.3. Evidence selection and interpretation

The review does not claim exhaustive study identification and does not present a PRISMA flow diagram, formal duplicate screening, study-level RoB 2 adjudication, GRADE ratings, or a meta-analysis. The core evidence table focuses on randomized trials with clinically interpretable halitosis outcomes; recent randomized studies conducted in populations not selected for clinically established halitosis or using a substantially different malodor-assessment framework are discussed as indirect evidence rather than treated as equivalent efficacy trials. Organoleptic and instrumental outcomes are treated as related but non-interchangeable constructs; randomized between-group, baseline-adjusted, or treatment-by-time effects are prioritized where available; and within-group change alone is not interpreted as proof of probiotic efficacy. This is particularly important because study participation, repeated testing, oral-hygiene reinforcement, chewing or lozenge vehicles, and concomitant periodontal treatment can improve malodor independently of the probiotic microorganism. Sports-focused oral-health literature was used only for contextual interpretation and external-validity considerations and was not counted as direct evidence of probiotic efficacy for halitosis.

3. Research results

3.1. Biological rationale and probiotic mechanisms

Intra-oral malodor emerges from a complex ecological process rather than from a single pathogen. The tongue dorsum and periodontal niches support microbial communities capable of degrading sulfur-containing substrates and generating H₂S, CH₃SH, and other odorants. Their abundance and metabolic activity are influenced by substrate availability, oxygen tension, pH, salivary flow, tongue coating, inflammatory exudate, and oral-hygiene behavior (De Geest et al. 2016; Suzuki et al. 2019). Consequently, an intervention that changes microbial composition without changing local substrate supply or inflammation may produce limited clinical benefit.

This ecological perspective also explains why periodontal treatment and tongue cleaning can have strong effects even when a probiotic itself has little specific efficacy. Mechanical disruption of biofilm and removal of retained organic material directly reduce the substrate and anaerobic niches required for odor production. Probiotic effects, if present, should therefore be interpreted as incremental effects beyond optimized cause-directed care rather than as substitutes for it.

For terminology, this review uses the consensus definition of a probiotic as a live microorganism that, when administered in adequate amounts, confers a health benefit on the host (Hill et al. 2014). Heat-killed or otherwise inanimate microbial preparations are not treated as probiotics; when they occur as additional trial arms, they are considered contextual comparators rather than evidence for live-probiotic efficacy. Proposed mechanisms of live oral probiotics include competitive inhibition of adhesion, coaggregation with or exclusion of malodor-associated organisms, bacteriocin production, hydrogen peroxide generation, modification of local pH and redox conditions, and suppression of metabolic pathways involved in VSC production (Suzuki et al. 2019). These mechanisms are biologically plausible but strain-specific.

The broad label “probiotic” therefore has limited mechanistic precision: *W. cibaria* CMU, *S. salivarius* K12, *L. salivarius* WB21 or G60, *L. brevis* CD2, *L. paracasei* strains, and multi-strain products should not be assumed to be therapeutically equivalent. Taxonomic nomenclature has changed substantially; updated genus names are used where appropriate, while strain designations and bibliographic titles retain the nomenclature of the original publications (Zheng et al. 2020). Strain identity, viability, dose, delivery vehicle, administration frequency, treatment duration, and background care are all potential determinants of exposure and effect, and a favorable result with one strain cannot be generalized automatically to another product.

3.2. Measurement of halitosis and clinical interpretation

Organoleptic testing measures odor intensity as perceived by an examiner and remains clinically important because it captures the sensory manifestation of malodor rather than a single chemical component. Its limitations include examiner dependence, the need for standardized sampling conditions, and the ordinal nature of many scoring systems (Kim et al. 2009; Nakhleh et al. 2018). Organoleptic improvement is therefore more directly related to examiner-perceived odor intensity than a change in a single biochemical marker, but it should not be equated automatically with patient-perceived benefit unless supported by patient-reported outcomes. Trials using organoleptic endpoints should report examiner blinding, training or calibration, and, where more than one examiner is involved, intra- and inter-rater reliability.

Instrumental methods are complementary rather than interchangeable. Portable sulfide monitors provide a composite signal for sulfur-containing gases and generally do not resolve individual VSC species, whereas portable gas chromatography can separately quantify H₂S, CH₃SH, and DMS (Tangerman and Winkel 2008; Nakhleh et al. 2018). These methods offer objective biochemical information but measure only part of the odor mixture. Moreover, DMS requires etiological caution because it is more strongly associated with extra-oral blood-borne halitosis than with typical intra-oral malodor (Tangerman and Winkel 2007). A statistically significant decrease in one measured VSC therefore does not necessarily mean that overall breath odor has improved to a degree perceptible to an examiner or patient.

Discordance between sensory and instrumental outcomes is a recurring feature of probiotic trials. Suzuki et al. reported a favorable crossover effect of *L. salivarius* WB21 on total VSC and CH₃SH without a corresponding

organoleptic treatment difference (Suzuki et al. 2014). Choi et al. similarly found between-group reductions in total VSC and H₂S without clear organoleptic superiority (Choi et al. 2026). Conversely, Kim et al. reported a favorable sensory outcome despite the absence of a clear randomized VSC advantage (Kim et al. 2020). These findings demonstrate that organoleptic and instrumental outcomes should not be collapsed into a single generic “halitosis” endpoint.

3.3. Randomized clinical evidence

The core evidence selected for detailed discussion includes 15 placebo- or matched-control randomized trials involving 844 randomized participants and one additional 117-participant pragmatic active-comparator trial published in 2026. Thus, the 16 core trials randomized 961 participants in total, but this number is descriptive rather than a pooled denominator because clinical phenotypes, designs, interventions, outcome methods, background care, and estimands differ materially. Sample sizes were generally modest, treatment periods ranged from approximately two weeks to three months, and populations included tongue-coating-associated halitosis, VSC-defined oral malodor, periodontal-associated halitosis, and older adults with clinically diagnosed halitosis. Table 1 summarizes the principal randomized findings and key interpretive limitations.

Table 1. Core randomized trials of probiotic interventions for intra-oral halitosis selected for detailed discussion

Study / design	Intervention and comparator	Halitosis assessment	Main randomized finding and key limitation
Suzuki et al. (2014) 26; crossover; oral malodor	<i>Ligilactobacillus salivarius</i> WB21 Comparator: Matching placebo; 14 d/period	OLT; total and individual VSC	Direct crossover comparison favored total VSC and CH ₃ SH; no organoleptic treatment difference. Carry-over/period handling should be considered when interpreting the estimate.
Marchetti et al. (2015) 20; parallel; halitosis	<i>Levilactobacillus brevis</i> CD2 lozenges Comparator: Matching placebo; 14 d	OLT; OralChroma / multi-sensor	Small exploratory trial; no clear conventional OLT or VSC superiority. Precision was limited by sample size.
Penala et al. (2016) 32; parallel; chronic periodontitis + halitosis	Local probiotic mouthwash + subgingival probiotic after SRP Comparator: Placebo + identical SRP; 1–3 mo follow-up	Organoleptic	Adjunctive organoleptic outcome favored probiotic. Interpretation is specific to periodontal therapy plus local probiotic delivery, not probiotic monotherapy.
Soares et al. (2019) 60; parallel; severe periodontitis + halitosis	<i>Limosilactobacillus reuteri</i> + <i>Ligilactobacillus salivarius</i> + <i>L. acidophilus</i> Comparator: Xylitol placebo + periodontal	Organoleptic / instrumental parameters	Reported halitosis parameters favored the probiotic adjunct, but directly comparable randomized numerical effect estimates were incompletely reported.

	therapy; 90 d		
He et al. (2020) 28; parallel; halitosis	<i>Streptococcus salivarius</i> K12 Comparator: Placebo lozenge; 30 d	OLT; Halimeter VSC	Longitudinal group-by-time comparisons did not establish probiotic superiority for OLT or VSC despite within-group improvement.
Mousquer et al. (2020) 45; multi-arm; oral halitosis + tongue coating	<i>Ligilactobacillus salivarius</i> G60, probiotic-only arm Comparator: Placebo gum; 10–14 d	OLT; Halimeter	Probiotic-only randomized contrast did not support superiority. The synbiotic arm cannot be used to infer probiotic monotherapy efficacy.
Lee DS et al. (2020) 92 randomized; 68 in efficacy analysis; parallel; post-SRP	<i>Weissella cibaria</i> CMU Comparator: Matching placebo after SRP; 8 wk	OLT; VSC	Week-4 separation was not sustained at week 8. Post-randomization exclusions materially weaken the treatment estimate.

Study / design	Intervention and comparator	Halitosis assessment	Main randomized finding and key limitation
Kim et al. (2020) 60; parallel; halitosis	<i>Weissella cibaria</i> CMU Comparator: Placebo; 8 wk	Sensory score; OralChroma VSC	Sensory outcome favored probiotic; randomized VSC comparison did not show clear superiority, illustrating sensory–biochemical discordance.
Han et al. (2023) 100; parallel; VSC-defined halitosis	<i>Weissella cibaria</i> CMU Comparator: Matching placebo; 8 wk	Total VSC; H ₂ S + CH ₃ SH	Lower unadjusted VSC values were not supported by the adjusted longitudinal treatment effect after accounting for baseline imbalance.
Wuri et al. (2023) 68; multi-arm; halitosis	<i>Lacticaseibacillus paracasei</i> ET-22 Comparator: Placebo; 28 d; heat-killed arm separate	VSC	The report emphasized within-group VSC change; a direct randomized live-probiotic treatment estimate was not clearly reported and is therefore considered uncertain.

Ding et al. (2024) 43 randomized; 33 completed; parallel; halitosis	<i>Lactiplantibacillus plantarum</i> CCFM1214 + <i>Ligilactobacillus salivarius</i> CCFM1215 Comparator: FOS-matched control (2.0 g FOS; active arm 1.9 g FOS + live strains); 4 wk	VSC	Direction favored the probiotic combination, but marked asymmetric attrition substantially reduces confidence in the estimate.
Choi et al. (2026) 80 randomized; 70 completed; parallel; VSC-defined halitosis	<i>Lactobacillus gasseri</i> HHuMIN D + <i>Lactacaseibacillus paracasei</i> OK Comparator: Matching placebo; 12 wk	OLT; OralChroma VSC	Between-group effects favored probiotic for total VSC and H ₂ S (P<0.05); CH ₃ SH, DMS and OLT did not show the same pattern. Product-related industry involvement should be considered when interpreting replication needs.
Lee SK et al. (2026) 80; parallel; gingivitis/incipient periodontitis + halitosis	<i>Weissella cibaria</i> CMU Comparator: Placebo; 8 wk	OLT; total/individual VSC	Total VSC favored probiotic at week 8 (P=0.001); OLT also favored probiotic (P=0.015). Registration KCT0009810 was retrospective and the trial has a companion periodontal report.
Mei et al. (2026) 80; four-arm; halitosis	<i>Streptococcus salivarius</i> K12, probiotic-only arm Comparator: Control / placebo framework; 4 wk + 4-wk follow-up	OLT; VSC; self-reported halitosis	Within-group VSC reduction was reported for probiotic treatment, but a directly interpretable probiotic-only between-group OLT effect was not clearly demonstrated; the combined tongue-brushing + probiotic arm showed the strongest pattern.

Study / design	Intervention and comparator	Halitosis assessment	Main randomized finding and key limitation
Samnieng et al. (2026) 30; crossover; older adults with halitosis	<i>Lactacaseibacillus paracasei</i> TISTR 2688 Comparator: Matching placebo; 14 d/period	OralChroma H ₂ S, CH ₃ SH, DMS	Within-period VSC reductions occurred during probiotic exposure, but a direct crossover treatment-effect estimate was not clearly reported. DMS should not be interpreted as an exclusively intra-oral marker.
Bolos et al. (2026) 117; three-arm pragmatic parallel trial; persistent intra-oral halitosis, OLT ≥2	<i>Streptococcus salivarius</i> K12 lozenges Comparator: Standard care vs K12 vs zinc	Portable sulfide VSC; OLT; HALT; OHIP-14	Mean VSC change was -47.3±42.2 ppb with K12 vs -12.7±33.9 with standard care; overall between-group P<0.001, with zinc producing the largest reduction. Active comparators and 4-wk follow-up limit inference about placebo-specific efficacy and durability.

	mouthrinse; 4 wk		
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Note. OLT, organoleptic test; VSC, volatile sulfur compounds; H₂S, hydrogen sulfide; CH₃SH, methyl mercaptan; DMS, dimethyl sulfide; SRP, scaling and root planing; FOS, fructooligosaccharides. The first 15 rows are placebo- or matched-control trials; Bolos et al. used standard care and zinc mouthrinse as comparators. When a direct randomized treatment estimate or confidence interval was not clearly reported in the accessible article, this is stated rather than inferred from within-group P values. Updated bacterial genus names are used where appropriate; bibliographic titles retain original nomenclature.

3.3.1. *Ligilactobacillus salivarius* and *Levilactobacillus brevis*

The placebo-controlled crossover trial by Suzuki et al. provides an instructive example of outcome discordance. *L. salivarius* WB21 reduced total VSC and CH₃SH relative to placebo, but the organoleptic score did not show a corresponding treatment difference (Suzuki et al. 2014). This pattern is compatible with a biochemical effect on selected sulfur metabolism without clear evidence of perceptible sensory benefit. By contrast, Mousquer et al. found that *L. salivarius* G60 monotherapy did not clearly outperform placebo for oral halitosis and tongue coating (Mousquer et al. 2020). The study also included a synbiotic arm, but improvement in that arm cannot be used to infer the efficacy of probiotic monotherapy.

Marchetti et al. evaluated *L. brevis* CD2 lozenges in a small randomized placebo-controlled study using organoleptic and multi-sensor approaches (Marchetti et al. 2015). The trial was exploratory and did not provide clear conventional OLT/VSC superiority. Taken together, these studies argue against treating “lactobacilli” as a single therapeutic category. Strain, formulation, delivery vehicle, and analytical method appear to matter, and favorable findings with one strain cannot be generalized to another.

3.3.2. *Streptococcus salivarius* K12

S. salivarius K12 is one of the most frequently studied oral probiotic strains, but its clinical evidence is mixed. In the placebo-controlled trial by He et al., substantial improvement occurred over time, yet the longitudinal group-by-time comparison did not demonstrate superiority of K12 for either organoleptic or VSC outcomes (He et al. 2020). This illustrates why within-group change should not be interpreted as a treatment effect.

Mei et al. later evaluated K12, tongue brushing, and their combination in a four-arm randomized trial (Mei et al. 2026). The published report described VSC reductions during probiotic treatment, but the probiotic-only between-group sensory effect was not clearly established; the combined intervention showed the strongest and more persistent pattern. In a 2026 pragmatic trial, Bolos et al. randomized 117 adults with persistent intra-oral halitosis and baseline OLT ≥ 2 to standardized care, K12 lozenges, or zinc mouthrinse (Bolos et al. 2026). Mean VSC reduction after four weeks was greater with K12 than with standard care, although zinc produced the largest improvement. Because the comparator was active standard care rather than placebo and follow-up was short, this trial strengthens the short-term strain-specific signal but does not establish placebo-specific efficacy or durability. Overall, K12 may exert clinically relevant short-term effects in some settings, but the randomized evidence remains insufficient to claim a consistent, durable sensory benefit.

3.3.3. *Weissella cibaria* CMU

The evidence for *W. cibaria* CMU is comparatively extensive but internally inconsistent. Lee DS et al. reported an early separation between probiotic and placebo groups after scaling and root planing, yet the week-4 signal was not sustained at the week-8 end-of-treatment assessment; interpretation is further complicated by substantial post-randomization exclusions (Lee et al. 2020). Kim et al. reported a favorable sensory outcome whereas the randomized VSC comparison did not show clear superiority (Kim et al. 2020). Han et al. found lower unadjusted VSC values in the probiotic group, but adjusted longitudinal analysis did not support a treatment effect after accounting for baseline imbalance (Han et al. 2023).

More recent evidence is more favorable. Lee SK et al. reported week-8 treatment effects favoring *W. cibaria* CMU for total VSC (P=0.001) and OLT (P=0.015) in adults with gingival inflammation or incipient periodontitis (Lee et al. 2026). Trial-family structure is important: Lee DS et al. and Kang et al. derive from the KCT0005078 cohort, whereas Lee SK et al. and Jeon et al. derive from KCT0009810; companion reports should therefore not be counted as independent randomized cohorts (Lee et al. 2020; Kang et al. 2020; Lee et al. 2026; Jeon et al. 2026). Both KCT0005078 and KCT0009810 were retrospectively registered as reported in the primary publications, limiting independent assessment of prospective outcome specification (Kang et al. 2020; Lee et al. 2026). Overall, *W. cibaria* CMU has one of the larger strain-specific evidence bases in this field, but null or transient findings and trial-family dependencies preclude a claim of established efficacy across populations.

3.3.4. Lacticaseibacillus paracasei and multi-strain formulations

Newer trials have expanded evidence beyond traditional oral probiotic strains. Wuri et al. evaluated *L. paracasei* ET-22 and reported VSC reduction during probiotic use, but the published presentation emphasized within-group change and did not provide a clearly interpretable randomized live-probiotic treatment estimate suitable for a strong efficacy conclusion (Wuri et al. 2023). Samnieng et al. studied *L. paracasei* TISTR 2688 in a crossover design in older adults and observed reductions in H₂S, CH₃SH, and DMS during probiotic exposure; however, a direct crossover treatment-effect estimate was not clearly reported, and DMS requires caution because it is not specific to intra-oral malodor (Tangerman and Winkel 2007; Samnieng et al. 2026).

Multi-strain interventions have produced several favorable signals. Choi et al. found adjusted effects favoring a combination of *L. gasseri* HHuMIN D and *L. paracasei* OK for total VSC and H₂S, while CH₃SH, DMS, and organoleptic outcomes did not show the same pattern (Choi et al. 2026). Ding et al. reported a favorable direction for VSC outcomes with *L. plantarum* CCFM1214 plus *L. salivarius* CCFM1215, but the control contained a nearly equivalent amount of FOS and marked asymmetric attrition materially limits confidence in the result (Ding et al. 2024). These studies reinforce two points: multi-strain formulations may influence selected biochemical outcomes, and clinical benefit cannot be inferred simply from the number of statistically significant VSC comparisons.

3.3.5. Probiotics as adjuncts in periodontal-associated halitosis

Periodontal inflammation is a biologically plausible contributor to intra-oral malodor because inflamed periodontal niches provide protein-rich substrates and anaerobic conditions that may increase odorant production (De Geest et al. 2016). Several trials have therefore evaluated probiotics as adjuncts to scaling and root planing or periodontal therapy. Penala et al. reported lower organoleptic halitosis scores with local probiotic therapy added to scaling and root planing (Penala et al. 2016). Soares et al. reported favorable halitosis parameters with a multi-species lactobacillus preparation adjunctive to periodontal treatment, although numerical randomized effect estimates were incompletely reported (Soares et al. 2019). Lee SK et al. observed favorable organoleptic and VSC effects of *W. cibaria* CMU in a gingival-inflammatory context (Lee et al. 2026).

These findings are clinically interesting but should not be interpreted as proof that periodontal phenotype predicts probiotic response. The periodontal trials used different strains, delivery systems, treatment durations, background therapies, and outcome methods. Phenotype is therefore confounded with multiple intervention and design characteristics. The most defensible interpretation is that adjunctive benefit in periodontal-associated halitosis is plausible and hypothesis-generating, not yet confirmed as a reproducible effect modifier.

3.3.6. Additional recent randomized evidence

The final update also identified randomized reports that were not treated as equivalent core efficacy evidence because their populations, comparator structures, or outcome frameworks differed materially. Enioutina et al. studied volunteers with persistent oral malodor using a different malodor-assessment framework (Enioutina et al. 2024); Vasoglou et al. reported two placebo-controlled orthodontic trials in patients treated with aligners or fixed appliances rather than participants selected for clinically established halitosis (Vasoglou et al. 2026); and Cirio et al. reported a secondary VSC analysis in healthy adults not selected for halitosis, with no statistically significant between-group VSC advantage of H. coagulans gum over matched placebo (Cirio et al. 2026). Huang and Li studied 61 adults who met objective VSC criteria for halitosis, but the trial evaluated acute effects of several commercial or multi-ingredient fresh-breath products; the main effervescent formulation combined live

microorganisms with non-probiotic active ingredients, so a probiotic-specific effect could not be isolated (Huang and Li 2024). These studies are relevant to external validity, short-term product effects, and outcome interpretation but were not counted among the 16 core trials summarized in Table 1.

4. Discussion

4.1. Heterogeneity and the absence of a uniform probiotic class effect

A central finding of this synthesis is that probiotics should not be treated as a pharmacologically homogeneous class. Clinical trials differ in strain identity, single- versus multi-strain composition, delivery vehicle, treatment duration, background care, clinical phenotype, and outcome instrument. Some trials demonstrate favorable randomized effects on selected outcomes, whereas others show null, transient, or analytically uncertain contrasts. Cross-trial heterogeneity is compatible with strain- or formulation-specific effects, but it does not itself prove effect modification because these characteristics are not randomized across studies.

4.2. Statistical significance versus clinical significance

Improvement from baseline in the probiotic group is not evidence of a probiotic-specific effect when the comparator group improves similarly. This is particularly relevant in halitosis research because study participation commonly entails oral-hygiene reinforcement, repeated examination, behavior change, and sometimes professional periodontal treatment. He et al. and Mousquer et al. illustrate how substantial improvement can coexist with a null randomized comparison (He et al. 2020; Mousquer et al. 2020). Conversely, a statistically significant reduction in a selected VSC does not necessarily imply that malodor is perceptibly improved.

A further limitation is the lack of a consistently validated minimal clinically important difference across the instrumental methods represented in these trials. Biochemical effect sizes should therefore be interpreted alongside calibrated sensory outcomes and, where available, patient-reported benefit. The most clinically persuasive evidence would demonstrate a prespecified between-group effect with confidence intervals that exclude both no effect and a clinically trivial effect, and would also show persistence after treatment withdrawal.

4.3. Durability and safety

Most studies assess outcomes during active probiotic administration or shortly thereafter. This is an important limitation because transient suppression of odor-producing metabolism is not equivalent to durable ecological modification. Detection of an administered strain during treatment does not demonstrate stable colonization after withdrawal. An intervention that is beneficial only while continuously taken may still have value, but its clinical role, cost, adherence requirements, and expected duration of use differ from those of an intervention that induces persistent change.

Safety reporting was generally less detailed than efficacy reporting. No consistent short-term serious safety signal was reported in the trials reviewed; for example, Mousquer et al. described adverse effects as mild and transient, and Lee DS et al. did not identify a safety issue attributable to the probiotic formulation (Mousquer et al. 2020; Lee et al. 2020). However, small sample sizes, short treatment periods, and inconsistent adverse-event ascertainment are insufficient to characterize uncommon or long-term harms. The appropriate conclusion is therefore that no consistent short-term safety signal has emerged, not that long-term safety is established.

4.4. Methodological limitations of the clinical literature

The principal limitation of the evidence base is not simply that trials are small; several sources of uncertainty occur simultaneously. Sample sizes range from 20 participants in the smallest parallel trial to 117 in the newer pragmatic trial, with many trials enrolling fewer than 80 participants. Small samples increase imprecision and make baseline imbalances more consequential. Han et al., for example, required adjusted longitudinal interpretation because baseline VSC values were imbalanced (Han et al. 2023).

Missing outcome data and analysis populations are also important. In the Lee DS et al. trial, 92 participants were randomized but only 68 were retained in the efficacy analysis after post-randomization exclusions (Lee et al.

2020). Ding et al. randomized 43 participants but only 33 completed follow-up, with marked asymmetry between treatment groups (Ding et al. 2024). Such patterns can bias treatment estimates when missingness is related to treatment, prognosis, or outcome.

A third problem is analytical and measurement heterogeneity. Reports variably present raw endpoints, change scores, ANCOVA-adjusted endpoints, generalized linear models, longitudinal treatment-by-time interactions, or only within-group tests. Crossover studies require paired, period-aware analyses and explicit consideration of carry-over, yet a direct crossover treatment effect was not always clearly reported (Samnieng et al. 2026). Organoleptic endpoints additionally depend on examiner blinding, calibration, and reproducibility, which are not consistently reported. Multiple outcomes and time points increase the risk that isolated favorable findings receive disproportionate emphasis. Future trials should prespecify one primary halitosis endpoint, one principal treatment-end time point, and a statistical estimand that directly compares randomized groups.

Finally, clinical phenotype and study sponsorship require careful interpretation. Tongue-coating-associated malodor, periodontal-associated halitosis, older-adult populations, and VSC-defined halitosis may not respond identically, but the current literature is too small and confounded across strains and designs to establish reliable phenotype-specific treatment effects. Several product-specific studies involved manufacturer-affiliated authors, manufacturer-supplied study products, or product-related industry support, including the ET-22, Choi et al., CMU, and orthodontic trial reports (Kang et al. 2020; Wuri et al. 2023; Choi et al. 2026; Lee et al. 2026; Vasoglou et al. 2026). Commercial involvement does not invalidate a trial, but it increases the importance of prospective registration, prespecified outcomes, complete reporting, transparent analysis, and independent replication. For periodontal secondary outcomes measured at multiple teeth or sites, future analyses should also account explicitly for within-patient clustering rather than treating sites as independent observations.

4.5. Relation to previous systematic reviews

The inconsistent conclusions of previous systematic reviews are understandable in light of the underlying heterogeneity. López-Valverde et al. did not demonstrate a convincing overall pooled benefit in the limited randomized evidence available at that time (López-Valverde et al. 2022). Tay et al. emphasized heterogeneity and insufficient evidence for clear clinical benefit (Tay et al. 2022). Huang et al. reported modest short-term reductions in organoleptic scores and VSC concentrations (Huang et al. 2022), whereas Passadakis et al. and Yang et al. reached comparatively more favorable conclusions while still acknowledging small samples and heterogeneous interventions (Passadakis et al. 2025; Yang et al. 2026).

Differences in review conclusions may arise from population definitions, inclusion of periodontal patients, strain composition, treatment duration, outcome selection, follow-up timing, and statistical handling. Another source of divergence is the interpretation of within-group significance: a significant pre-post change in the probiotic arm can overstate efficacy when the corresponding randomized comparison is null or uncertain. Newer 2026 trials add clinically relevant information, including placebo-controlled studies and the pragmatic K12 trial by Bolos et al., but they do not eliminate heterogeneity or establish a class-wide effect (Choi et al. 2026; Lee et al. 2026; Mei et al. 2026; Samnieng et al. 2026; Bolos et al. 2026). The specific contribution of the present review is therefore critical interpretation of strain-specific evidence and estimands rather than another pooled class-level effect.

4.6. Clinical implications

Routine clinical recommendation of probiotics for intra-oral halitosis cannot currently be supported. Clinical management should begin with diagnosis of the malodor source and treatment of modifiable oral causes, including tongue coating, inadequate oral hygiene, gingival inflammation, and periodontal disease (Shang et al. 2026). If a patient elects to use a probiotic, it should be framed as an evidence-limited, strain-specific adjunct to optimized cause-directed care rather than as established therapy or a substitute for conventional treatment.

Clinicians should avoid extrapolating evidence from one strain to another commercial product. Consistent with probiotic nomenclature standards, products used clinically or in research should provide strain-level identification, viable dose, and administration instructions (Hill et al. 2014). A favorable VSC result should not be presented as proof that breath odor will improve perceptibly. If an adjunctive probiotic is tried, a defined treatment period, continued standard oral care, and reassessment using a clinically meaningful sensory or patient-reported outcome are more defensible than indefinite continuation without demonstrated individual benefit.

4.7. Relevance to sports dentistry and physically active populations

The sport-specific relevance of this evidence is plausible but indirect. Athletes may have repeated exposure to fermentable carbohydrates and acidic sports products, dehydration, and transient oral dryness, while oral disease remains common in high-performance sport (Schulze and Busse 2024; Lewalski et al. 2026). The burden is well quantified: in a cross-sectional study of 302 athletes attending the dental clinic of the London 2012 Olympic Games, with data available for 278, dental caries was reported in 55%, dental erosion in 45%, gingivitis in 76%, and periodontitis in 15%, and 18% of athletes reported an impact of oral health on training and performance (Needleman et al. 2013). A systematic review of 34 studies in elite athletes reported dental caries in 15–75% and dental erosion in 36–85%, with sports-related dental trauma in 14–47% depending on sport and setting, although the methodological quality of the included studies was generally low (Ashley et al. 2015). A later review confirmed caries prevalences of 20–84%, erosion of 42–59%, gingivitis of 58–77%, and periodontal disease of 15–41%, and identified sports diet as a modifiable contributor (Schulze and Busse 2024).

Several athlete-specific exposures plausibly increase the risk of intra-oral malodor. During exercise-induced dehydration, salivary clearance may be reduced: in a field study of 21 participants completing a 120-minute slow-distance exercise session, salivary flow rate and oral mucosal moisture were lower after exercise, and the change in oral mucosal moisture correlated with sweat rate (Tanabe et al. 2024). Reduced salivary clearance favors tongue-coating accumulation and anaerobic proteolysis on the tongue dorsum, the dominant source of intra-oral halitosis discussed earlier; reduced salivary output is therefore a plausible permissive factor for malodor in this setting. Frequent intake of fermentable carbohydrates and acidic sports drinks supports acidogenic ecological shifts and caries and erosion risk; together with periodontal inflammation and reduced salivary clearance, it may create an oral environment in which malodor is harder to control (Schulze and Busse 2024).

A systematic review of oral microbiota and sports practice identified only five eligible studies and reported differences in microbial composition between physically active and less active groups, including increased *Rothia*, *Stenotrophomonas*, and *Veillonella* and decreased *Gemella* in athletes, but the authors could not establish a causal effect of sport on the oral microbiome because of limited and heterogeneous evidence (Dubois et al. 2025). Because probiotic effects are strain-specific and ecology-dependent, compositional differences of this kind mean that effect sizes documented in general adult populations cannot be assumed to transfer directly to athletes. These findings justify considering oral ecology within sports dentistry, but they do not show that athletes have a higher prevalence of halitosis or that probiotics are more effective in athletes.

None of the core randomized halitosis trials reviewed here specifically recruited athletes with clinically confirmed intra-oral halitosis or tested training load, hydration strategy, sports nutrition, or athletic status as treatment-effect modifiers. Therefore, current probiotic evidence can be transferred to sports populations only cautiously. In athletes and other physically active adults, cause-directed diagnosis, hydration and oral-hygiene optimization, and treatment of tongue coating or periodontal inflammation remain primary; a probiotic, if used, should remain an evidence-limited adjunct rather than a performance-oriented intervention.

4.8. Limitations of this narrative review

This narrative review has important limitations. The literature search was targeted rather than exhaustive, and study selection, extraction, and interpretation were not performed independently by duplicate reviewers. No formal study-level risk-of-bias adjudication or quantitative meta-analysis was undertaken. Consequently, relevant studies may have been missed, and the selection and emphasis of evidence remain susceptible to reviewer judgment. The supplementary sports-dentistry contextual search was also non-systematic and was not designed to estimate halitosis prevalence or probiotic efficacy in athletes. The manuscript should therefore be interpreted as a critical narrative synthesis rather than as an exhaustive estimate of treatment effects.

The review also relies on the quality and completeness of primary-study reporting. For several trials, directly comparable between-group effect estimates and confidence intervals were not clearly available, and some reports emphasized within-group changes. Rather than reconstructing unreported estimands, such findings were classified as uncertain. The targeted update additionally identified randomized studies in non-halitosis-selected populations; these were treated as indirect evidence to avoid conflating biomarker changes in healthy or orthodontic participants with treatment effects in clinically confirmed intra-oral halitosis.

4.9. Future research

Future efficacy trials should use adequately powered, prospectively registered randomized designs with concealed allocation and intention-to-treat analyses. Recruitment should require standardized confirmation of intra-oral halitosis and distinguish clinically relevant phenotypes such as dominant tongue coating, gingival inflammation, periodontitis, or characteristic baseline VSC profiles. Strain identity, viability, dose, delivery vehicle, administration frequency, adherence, background oral care, funding, conflicts of interest, and adverse events should be reported in sufficient detail for replication.

Outcome selection requires particular improvement. Organoleptic assessment and instrumental VSC measurement should be reported as complementary but separate endpoints. Investigators should prespecify one primary halitosis endpoint and one principal treatment-end time point, report randomized between-group effects with confidence intervals, and distinguish statistical significance from clinical relevance. OLT should use blinded, trained and calibrated examiners with intra- and, where applicable, inter-rater reliability reported. Instrumental testing should identify the device and whether it yields a composite sulfide signal or compound-specific VSC concentrations. Where no validated minimal clinically important difference exists, a statistically significant biochemical change should not automatically be described as clinically meaningful.

The field should also move from generic “probiotic versus placebo” questions toward strain- and phenotype-specific hypotheses. Direct comparisons or prospectively stratified analyses could test whether response differs by dominant clinical phenotype. For periodontal and microbiome secondary outcomes that include multiple teeth, sites, or samples per participant, the patient-level clustering structure should be incorporated explicitly in the statistical analysis to avoid pseudoreplication. Microbiome and metabolomic studies may help explain mechanisms, but they should complement rather than replace randomized clinical outcomes. Long-term follow-up after treatment withdrawal is essential to determine whether any benefit reflects transient metabolic suppression or durable ecological change. An athlete-specific evidence gap also remains: future prospectively registered trials could enroll physically active adults with confirmed intra-oral halitosis and prespecify hydration status, training load, mouth-breathing, sports-product exposure, and background oral care as contextual variables, while avoiding post hoc claims of sport-specific effect modification.

5. Conclusions

The clinical literature does not support a uniform therapeutic effect of probiotics on intra-oral halitosis in adults. Favorable randomized effects have been reported for selected strains, formulations, and VSC outcomes, but organoleptic benefits are inconsistent and several trials show null, transient, or methodologically uncertain treatment contrasts. The discrepancy between biochemical and sensory outcomes is clinically important and argues against equating a reduction in selected sulfur compounds with a perceptible improvement in breath odor.

Probiotics are best regarded as investigational or evidence-limited adjuncts to cause-directed management rather than established stand-alone therapy. For sports dentistry, the current evidence is indirect; no athlete-specific efficacy advantage can be claimed. The most important unresolved question is whether any defined viable strain or formulation, at an appropriate dose and duration, produces a reproducible, clinically perceptible and durable benefit for a defined patient phenotype beyond optimized conventional oral care.

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Author contributions.

Conceptualization: [NLH], [WJ];

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Validation: [NLH], [ND], [GK];

Formal analysis: [NLH], [WJ], [SK];

Investigation: [NLH], [ND], [SK];

Resources: [NLH], [WJ], [GK];

Data curation: [NLH], [KKu], [KKe];

Writing - original draft preparation: [NLH], [ND], [KKe];

Writing - review and editing: [NLH], [WJ], [ND], [GK];

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References

1. Ashley P, Di Iorio A, Cole E, Tanday A, Needleman I. Oral health of elite athletes and association with performance: a systematic review. *Br J Sports Med.* 2015;49(1):14-19. <https://doi.org/10.1136/bjsports-2014-093617> <https://doi.org/10.3390/microorganisms14050990>
2. Bolos A, Bolos OC, Maghet E, Danila AI, Briceag R, Bumbu BA. Clinical and microbiological effects of *Streptococcus salivarius* K12 lozenges and zinc mouthrinse on persistent intra-oral halitosis. *Microorganisms.* 2026;14(5):990. <https://doi.org/10.3390/microorganisms14050990>
3. Choi JH, Song S, Jang MJ, Haque MA, Lee HE, Kim DH, Kim YJ, Cho JW, Moon JS, Heo K, Park MS, Ku S. A randomized, double-blind, placebo-controlled study on probiotic treatment for halitosis: novel insights into glucose and phosphorus metabolism. *Probiotics Antimicrob Proteins.* 2026;18(2):1722-1735. <https://doi.org/10.1007/s12602-025-10603-5>
4. Cirio S, Mantegazza G, Salerno C, Guglielmetti S, Allam A, Campus G, Cagetti MG. A chewing gum containing *Heyndrickxia coagulans* SNZ1969 and volatile sulphur compounds: an exploratory secondary analysis of a double-blind randomized controlled trial. *Nutrients.* 2026;18(16):2735. <https://doi.org/10.3390/nu18162735>
5. De Geest S, Laleman I, Teughels W, Dekeyser C, Quirynen M. Periodontal diseases as a source of halitosis: a review of the evidence and treatment approaches for dentists and dental hygienists. *Periodontol 2000.* 2016;71:213-227. <https://doi.org/10.1111/prd.12111>
6. Ding L, Wang Y, Jiang Z, Tang X, Mao B, Zhao J, Chen W, Zhang Q, Cui S. Effects of *Lactiplantibacillus plantarum* CCFM1214 and *Ligilactobacillus salivarius* CCFM1215 on halitosis: a double-blind, randomized controlled trial. *Food Funct.* 2024;15(16):8386-8394. <https://doi.org/10.1039/D4FO02280G>
7. Dubois M, Delcourt B, Ortis M, Bougault V, Doglio A, Bertrand MF. Correlation Between the Oral Microbiota and Sports Practice: A Systematic Review. *Cureus.* 2025;17(1):e78168. <https://doi.org/10.7759/cureus.78168>
8. Enioutina EY, Keddington RJ, Hauck KG, Chavez A, Clifford JJ, Cao TA, Smith B, Job KM, Balch A. Results of a pilot trial assessing the effects of proper oral hygiene and a probiotic dietary supplement on oral health in volunteers with oral malodor. *Microorganisms.* 2024;12(9):1821. <https://doi.org/10.3390/microorganisms12091821>
9. Han HS, Yum H, Cho YD, Kim S. Improvement of halitosis by probiotic bacterium *Weissella cibaria* CMU: a randomized controlled trial. *Front Microbiol.* 2023;14:1108762. <https://doi.org/10.3389/fmicb.2023.1108762>

- 10.He L, Yang H, Chen Z, Ouyang X. The effect of *Streptococcus salivarius* K12 on halitosis: a double-blind, randomized, placebo-controlled trial. *Probiotics Antimicrob Proteins*. 2020;12(4):1321-1329. <https://doi.org/10.1007/s12602-020-09646-7>
- 11.Hill C, Guarner F, Reid G, Gibson GR, Merenstein DJ, Pot B, Morelli L, Canani RB, Flint HJ, Salminen S, Calder PC, Sanders ME. Expert consensus document: the International Scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic. *Nat Rev Gastroenterol Hepatol*. 2014;11(8):506-514. <https://doi.org/10.1038/nrgastro.2014.66>
- 12.Huang G, Li N. Efficacy of probiotic tablets in the reduction of halitosis: a randomised, single blind, controlled clinical trial. *Oral Health Prev Dent*. 2024;22:639-646. <https://doi.org/10.3290/j.ohpd.b5866901>
- 13.Huang N, Li J, Qiao X, Wu Y, Liu Y, Wu C, Li L. Efficacy of probiotics in the management of halitosis: a systematic review and meta-analysis. *BMJ Open*. 2022;12(12):e060753. <https://doi.org/10.1136/bmjopen-2022-060753>
- 14.Jeon HW, Yang KI, Yu SJ, Kang MS, Lee WP. Clinical efficacy of the probiotic *Weissella cibaria* CMU in adults with gingivitis: a randomized, double-blind, placebo-controlled clinical trial. *J Med Food*. 2026;29(6):319-331. <https://doi.org/10.1177/1096620X261430298>
- 15.Kang MS, Lee DS, Lee SA, Kim MS, Nam SH. Effects of probiotic bacterium *Weissella cibaria* CMU on periodontal health and microbiota: a randomised, double-blind, placebo-controlled trial. *BMC Oral Health*. 2020;20:243. <https://doi.org/10.1186/s12903-020-01231-2>
- 16.Kim DH, Kang MS, Yeu JE, Lee MG, Cho JW. Inhibitory effect of the probiotic bacteria, *Weissella cibaria* CMU on halitosis: a randomized placebo-controlled study. *J Korean Acad Oral Health*. 2020;44(4):246-252. <https://doi.org/10.11149/jkaoh.2020.44.4.246>
- 17.Kim DJ, Lee JY, Kho HS, Chung JW, Park HK, Kim YK. A new organoleptic testing method for evaluating halitosis. *J Periodontol*. 2009;80(1):93-97. <https://doi.org/10.1902/jop.2009.080389>
- 18.Lee DS, Lee SA, Kim M, Nam SH, Kang MS. Reduction of halitosis by a tablet containing *Weissella cibaria* CMU: a randomized, double-blind, placebo-controlled study. *J Med Food*. 2020;23(6):649-657. <https://doi.org/10.1089/jmf.2019.4603>
- 19.Lee SK, Lim KO, Yang KI, You SJ, Kang MS, Lee WP. Oral probiotic *Weissella cibaria* improves halitosis and reduces periodontal pathogens: a randomized, double-blind, placebo-controlled trial. *BMC Oral Health*. 2026;26(1):649. <https://doi.org/10.1186/s12903-026-08003-4>
- 20.Lewalski T, Słuchocka J, Florczyk M, Lewalski O, Płuciennik L, Jeruc K. Oral Health in Athletes: An Overlooked Determinant of Performance, Recovery, and Safety. *Quality in Sport*. 2026;53:69891. <https://doi.org/10.12775/QS.2026.53.69891>
- 21.López-Valverde N, López-Valverde A, Macedo de Sousa B, Rodríguez C, Suárez A, Aragonese JM. Role of probiotics in halitosis of oral origin: a systematic review and meta-analysis of randomized clinical studies. *Front Nutr*. 2022;8:787908. <https://doi.org/10.3389/fnut.2021.787908>
- 22.Marchetti E, Tecco S, Santonico M, Vernile C, Ciciarelli D, Tarantino E, Marzo G, Pennazza G. Multi-sensor approach for the monitoring of halitosis treatment via *Lactobacillus brevis* (CD2)-containing lozenges: a randomized, double-blind placebo-controlled clinical trial. *Sensors (Basel)*. 2015;15(8):19583-19596. <https://doi.org/10.3390/s150819583>
- 23.Mei L, Yan F, Cheng L, Na A, Cannon RD, Guan G. Tongue brushing and oral probiotics for the treatment of halitosis: a randomized controlled trial. *J Breath Res*. 2026;20(1):016012. <https://doi.org/10.1088/1752-7163/ae3edc>
- 24.Mousquer CR, Della Bona A, Milani DC, Callegari-Jacques SM, Ishikawa K, Mayer MPA, Rösing CK, Fornari F. Are *Lactobacillus salivarius* G60 and inulin more efficacious to treat patients with oral halitosis and tongue coating than the probiotic alone and placebo? A randomized clinical trial. *J Periodontol*. 2020;91(6):775-783. <https://doi.org/10.1002/JPER.19-0089>

- 25.Nakhleh MK, Quatredeniens M, Haick H. Detection of halitosis in breath: between the past, present, and future. *Oral Dis.* 2018;24(5):685-695. <https://doi.org/10.1111/odi.12699>
- 26.Needleman I, Ashley P, Petrie A, Fortune F, Turner W, Jones J, Niggli J, Engebretsen L, Budgett R, Donos N, Clough T, Porter S. Oral health and impact on performance of athletes participating in the London 2012 Olympic Games: a cross-sectional study. *Br J Sports Med.* 2013;47(16):1054-1058. <https://doi.org/10.1136/bjsports-2013-092891> https://doi.org/10.4103/jispcd.jispcd_19_25
- 27.Passadakis G, Neophytou C, Davidopoulou S, Papadimitriou K. Effectiveness of probiotics in managing oral halitosis: a systematic review of randomized controlled trials. *J Int Soc Prev Community Dent.* 2025;15(4):301-312. https://doi.org/10.4103/jispcd.jispcd_19_25
- 28.Penala S, Kalakonda B, Pathakota KR, Jayakumar A, Koppolu P, Lakshmi BV, Pandey R, Mishra A. Efficacy of local use of probiotics as an adjunct to scaling and root planing in chronic periodontitis and halitosis: a randomized controlled trial. *J Res Pharm Pract.* 2016;5(2):86-93. <https://doi.org/10.4103/2279-042X.179568>
- 29.Samnieng P, Sopapornamorn P, Suwannakul S. Effectiveness of probiotic supplementation in reducing halitosis among older adults: a randomized, double-blind, placebo-controlled crossover trial. *Sci Rep.* Published online August 15, 2026. <https://doi.org/10.1038/s41598-026-66697-6>
- 30.Schulze A, Busse M. Sports Diet and Oral Health in Athletes: A Comprehensive Review. *Medicina (Kaunas).* 2024;60(2):319. <https://doi.org/10.3390/medicina60020319>
- 31.Shang X, Chen X, Lv C, Wang Z, Chen B, Shao J, Liang Y, Song A, Guo H, Yu Y, Liu H, Du M, Zhang J, Kang W, Li J, Ma B, Yan F, Pan Y, Chen F, Xu Y, Luan Q, Zhao L, Sun Y, Song Z, Liu Y, Cao Z, Xia J, Zhao C, Li A, Sun J, Wang Z, Luo L, Ren X, Xu S, Ma D, Xie Y, Zhu G, Zhong L, Lin J, Chen F, Peng X, Li X, Ding P, Xu J, Luo K, Li A, Lin L, Tian B, Chen Y, Li X, Feng Q, Deng J, Yuan C, Ding G, Zhu H, Pan K, Wang X, Qiu C, Ren G, Liu M, Sun X, Ge S, Zhang R, Li L, Lu S, Tian T, Chen Q, Wang H, Wang D, Wang X, Zhang C, Zhou X, Ge S. Clinical practice guidelines on the diagnosis and treatment of halitosis. *Int Dent J.* 2026;76(2):109436. <https://doi.org/10.1016/j.identj.2026.109436>
- 32.Soares LG, de Carvalho EB, Tinoco EMB. Clinical effect of Lactobacillus on the treatment of severe periodontitis and halitosis: a double-blinded, placebo-controlled, randomized clinical trial. *Am J Dent.* 2019;32(1):9-13.
- 33.Suzuki N, Yoneda M, Tanabe K, Fujimoto A, Iha K, Seno K, Yamada K, Iwamoto T, Masuo Y, Hirofuji T. Lactobacillus salivarius WB21-containing tablets for the treatment of oral malodor: a double-blind, randomized, placebo-controlled crossover trial. *Oral Surg Oral Med Oral Pathol Oral Radiol.* 2014;117(4):462-470. <https://doi.org/10.1016/j.oooo.2013.12.400>
- 34.Suzuki N, Yoneda M, Takeshita T, Hirofuji T, Hanioka T. Induction and inhibition of oral malodor. *Mol Oral Microbiol.* 2019;34(3):85-96. <https://doi.org/10.1111/omi.12259>
- 35.Tanabe G, Hasunuma T, Takeuchi Y, Churei H, Hayashi K, Togawa K, Moriya N, Ueno T. Assessment of exercise-induced dehydration status based on oral mucosal moisture in a field survey. *Dent J (Basel).* 2024 Dec 25;13(1):5. <https://doi.org/10.3390/dj13010005> <https://doi.org/10.1088/1752-7155/2/1/017010>
- 36.Tangerman A, Winkel EG. Intra- and extra-oral halitosis: finding of a new form of extra-oral blood-borne halitosis caused by dimethyl sulphide. *J Clin Periodontol.* 2007;34(9):748-755. <https://doi.org/10.1111/j.1600-051X.2007.01116.x>
- 37.Tangerman A, Winkel EG. The portable gas chromatograph OralChroma: a method of choice to detect oral and extra-oral halitosis. *J Breath Res.* 2008;2(1):017010. <https://doi.org/10.1088/1752-7155/2/1/017010>
- 38.Tay JRH, Ng E, Lai CWM, Lim LP, Ong MMA. The efficacy of probiotics in the management of intra-oral halitosis: a systematic review. *Clin Oral Investig.* 2022;26:4687-4700. <https://doi.org/10.1007/s00784-022-04522-w>
- 39.Vasoglou G, Mylonopoulou IM, Angelopoulos G, Kloukos D, Pandis N, Sifakakis I. Impact of oral probiotics on oral health and halitosis in orthodontic patients treated with aligners or conventional fixed appliances vs placebo: two randomized clinical trials. *Eur J Orthod.* 2026;48(3):cjag028. <https://doi.org/10.1093/ejo/cjag028>

- 40.Wuri G, Liu F, Sun Z, Fang B, Zhao W, Hung WL, Liu WH, Zhang X, Wang R, Wu F, Zhao L, Zhang M. *Lactobacillus paracasei* ET-22 and derived postbiotics reduce halitosis and modulate oral microbiome dysregulation: a randomized, double-blind placebo-controlled clinical trial. *Food Funct.* 2023;14(16):7335-7346. <https://doi.org/10.1039/D3FO02271D>
- 41.Yang Y, Ge J, Chen Y, Liu H. Efficacy and safety of probiotic therapy for halitosis: a systematic review and meta-analysis of randomized controlled trials. *J Breath Res.* 2026;20(1):016004. <https://doi.org/10.1088/1752-7163/ae23f0>
- 42.Zheng J, Wittouck S, Salvetti E, Franz CMAP, Harris HMB, Mattarelli P, O'Toole PW, Pot B, Vandamme P, Walter J, Watanabe K, Wuyts S, Felis GE, Gänzle MG, Lebeer S. A taxonomic note on the genus *Lactobacillus*: description of 23 novel genera, emended description of the genus *Lactobacillus* Beijerinck 1901, and union of *Lactobacillaceae* and *Leuconostocaceae*. *Int J Syst Evol Microbiol.* 2020;70(4):2782-2858. <https://doi.org/10.1099/ijsem.0.004107>