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The Impact of Probiotic Supplementation on Physical Performance: A Systematic Review of Studies from 2021-2026

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ABSTRACT

Background: Physical activity promotes health and positively modulates the gut microbiota. Evidence suggests a "gut-muscle axis" through which probiotic supplementation may enhance athletic performance. Results across direct performance indicators remain inconclusive due to variations in strains and dosages.

Aim: This review aims to evaluate studies on the impact of probiotic supplementation on physical performance.

Materials and Methods: A systematic literature search was conducted in PubMed and Scopus databases. The search strategy followed PRISMA guidelines. Studies published between 2021 to 2026 were included based on the PICO framework: healthy adults, oral probiotic intervention, placebo control, and validated physical performance outcomes.

Results: The analysis indicates that probiotics significantly improve muscular strength, explosive power, and aerobic capacity, particularly when administered as multi-strain formulations or in synergy with other nutrients. Probiotics also effectively attenuate exercise-induced muscle damage, accelerating the recovery. Single-strain interventions and protocols in elite athletes often showed limited effects. High-dose protocols lasting over 8 weeks were the most beneficial.

Conclusions: Probiotic supplementation is an effective strategy to support athletic performance and recovery, with its potential significantly amplified through synbiotic combinations. Mechanisms include increased short-chain fatty acid production and reduced oxidative stress and inflammation. Future research must address current limitations, including the lack of female cohorts, small sample sizes, and the need for standardized postbiotic protocols.

Keywords: *gut microbiota; probiotics; athletic performance; gut-muscle axis; postbiotics.*

INTRODUCTION

Regular physical activity is widely recognized for its role in preventing chronic diseases, reducing premature mortality, and conferring multiple health benefits 1. It also supports neurocognitive function and enhances musculoskeletal and metabolic health 2. Recent research has increasingly investigated the effects of physical activity on the human gut microbiota and the relationships between them. It has been shown that exercise may be a promising way to improve gut microbiota, with physically active individuals showing greater microbial diversity and ["]{dir="rtl"}health-promoting gut species", along with higher concentrations of short-chain fatty acids (SCFA) and SCFA-producing organisms 3, 4. Studies have provided strong evidence that modulation of the gut microbiota by probiotic supplementation can positively influence sports performance and may lead to an improvement in performance-related physical conditions, such as muscle pain and body composition 5, 6, 7. Additionally, supplementation with probiotics appears to aid recovery after exercise and restore ["]{dir="rtl"}normal" gut microbiota 4. Therefore, in recent years, there has been growing interest in sports science in the role of the gut microbiota in optimizing both health and athletic performance.

The human intestinal microbiota is recognized as one of the most complex ecosystems in the human body, comprising approximately 10 microbial cells. Bacteria are the most predominant population, with the highest concentrations being found in the human colon 8, 9. The biodiversity and overall composition of this microbiome play a fundamental role in modulating immune responses, metabolic pathways, and intestinal integrity, therefore maintaining systemic homeostasis 10, 11.

A key concept describing the link between the gut and the musculoskeletal system is the "gut-muscle axis." This concept indicates that the gut microbiota may mediate the effects of nutrition on muscle cells 12. Furthermore, the gut microbiota interacts with skeletal muscle through inflammatory immunity, autophagy, protein anabolism, energy, lipids, neuromuscular connectivity, oxidative stress, mitochondrial function, and endocrine and insulin resistance, thus affecting the physiological functions of the body 13. A properly balanced microbiome may have an impact on muscle protein synthesis and reduce inflammatory markers and reactive oxygen species production, thereby further attenuating macromolecular damage 14. Abnormal composition of the intestinal microflora influences the development of circulatory, nervous, or immune system diseases 15.

As defined by the FAO/WHO, probiotics are "live microorganisms that, when administered in adequate amounts, confer a health benefit on the host." According to the International Society of Sports Nutrition (ISSN), probiotic supplementation has been linked to numerous health advantages, with gastrointestinal and immune support being the most extensively researched.

Despite the growing body of literature, the impact of probiotics on direct performance indicators, such as muscular strength, anaerobic power, and aerobic capacity, remains inconclusive. Existing studies differ significantly in supplementation duration, dosage, and the specific bacterial strains used. Consequently, there is an evident need to systematize the latest scientific findings, especially focusing on randomized controlled trials, which offer the highest methodological rigor.

Accordingly, this thesis provides a systematic review of current literature on the effects of probiotic supplementation on physical performance and exercise parameters in athletes. By analyzing data across multiple athletic performance domains, this review aims to provide an evidence-based summary of the topic.

MATERIALS AND METHODS

1. Search Strategy and Information Sources

A systematic literature search was performed to identify studies evaluating the impact of probiotic supplementation on athletic performance. The search was performed across two major electronic databases, PubMed and Scopus, encompassing publications from 2021 to 2026. The search strategy relied on a combination of comprehensive free-text terms and Boolean operators (AND, OR). The search included keywords such as: *["]{dir="rtl"}microbiota"*, *["]{dir="rtl"}microbiome"*, *["]{dir="rtl"}probiotics"*, *["]{dir="rtl"}probiotic supplementation"*, *["]{dir="rtl"}athletic performance"*, *["]{dir="rtl"}exercise performance"*, *["]{dir="rtl"}endurance"*, *["]{dir="rtl"}aerobic capacity"*, and *["]{dir="rtl"}athletes"*. The search was restricted to randomized controlled trials (RCTs) involving human subjects and published in English. All identified records were screened in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Figure 1).

2. Study Selection and Eligibility Criteria

To maintain high methodological rigor, the selection process followed strict inclusion and exclusion criteria based on the PICO (Population, Intervention, Comparison, Outcome) framework:

Population (P): Healthy adults (aged 18-65), including both professional athletes and physically active individuals.

Intervention (I): Oral probiotic supplementation (single or multi-strain formulas).

Comparator (C): Placebo control with identical procedures and matched co-interventions.

Outcomes (O): Physical performance outcomes assessed with validated performance tests.

Exclusion criteria were defined as follows:

Participants with chronic conditions (e.g., IBS, diabetes, obesity), a sedentary lifestyle, and those outside the age range of 18-65.

Interventions lacking specific data on bacterial strains or dosage (e.g., diet modifications, fermented foods, or kefir).

Absence of a control group.

Studies focusing exclusively on gut microbiota composition or blood biomarkers without accompanying physical performance data.

3. Data Extraction and Synthesis

Data from the included studies were extracted using a standardized form. The following information was recorded: primary author, year of publication, participant characteristics (sample size, sex, age, and baseline fitness level) and intervention details (specific probiotic strains, dosage, and duration)(Table 1 and Table 2).

+---+-----------+----+------------------------+---+------------------+ | N | Author | Ye | Participants / Sample | S | Age (years) | | o | | ar | size (n) | e | | | . | | | | x | | +===+===========+====+========================+===+==================+ | | Cao et | 20 | PRO: n= 36 | M | PRO: 20.25 ± | | [| al. | 24 | | | 1.03 | | 1 | | | PLA: n= 36 | | | | 6 | | | | | PLA: 20.19 ± | | | | | healthy college | | 0.79 | |] | | | students | | | +---+-----------+----+------------------------+---+------------------+ | | Imanian | 20 | PRO: n= 11 | M | PRO: | | [| et al. | 24 | | | 23.09 ± 3.26 | | 1 | | | PLA: n= 11 | | | | 7 | | | | | PLA: | | | | | PRO+CAS: n= 11 | | 23.09 ± 3.61 | |] | | | | | | | | | | | CAS: n= 11 | | PRO+CAS: | | | | | | | | 22.36 ± 2.15 | | | | | soccer players | | | | | | | | | CAS: | | | | | | | | 22.72 ± 2.00 | +---+-----------+----+------------------------+---+------------------+ | | Schreiber | 20 | PRO: n= 11 | M | PRO: 25.9±4.6 | | [| et al. | 21 | | | | | 1 | | | PLA: n= 16 | | PLA: 29.5±6.2 | | 8 | | | | | | | | | | | elite cyclists | | | |] | | | | | | +---+-----------+----+------------------------+---+------------------+ | | Tarik et | 20 | PRO: n= 28 | M | PRO: 21.1 ± 2.5 | | [| al. | 22 | | | | | 1 | | | PLA: n= 28 | | PLA: 20.9 ± 3.1 | | 9 | | | | | | | | | | | resistance-trained | | | |] | | | | individuals | | | +---+-----------+----+------------------------+---+------------------+ | | Maym | 20 | CON: n= 10 | M | 23.20 ± 3.64 | | [| andinejad | 25 | | | | | 2 | et al. | | USRPT: n= 10 | | | | 0 | | | | | | | | | | | PLA +

USRPT: n= 10 | | | |] | | | | | | | | | | | PRO + USRPT: n= 10 | | | | | | | | | | | | | | OMEGA + USRPT: n= 10 | | | | | | | | | | | | | | PRO + OMEGA + USRPT: n= | | | | | | | 10 | | | | | | | | | | | | | | sprint swimmers | | | +---+-----------+----+-------------------------+---+------------------+ | | Imanian | 20 | CON: n= 10 | M | 19.20 ± 3.64 | | [| et al. | 25 | | | | | 2 | | | USRPT: n= 10 | | | | 1 | | | | | | | | | | PLA + USRPT: n= 10 | | | |] | | | | | | | | | | | PRO + USRPT: n= 10 | | | | | | | | | | | | | | OMEGA + USRPT: n= 10 | | | | | | | | | | | | | | PRO + OMEGA + USRPT: n= | | | | | | | 10 | | | | | | | | | | | | | | sprint swimmers | | | +---+-----------+----+-------------------------+---+------------------+ | | Hudson et | 20 | PRO: n= 7 | 1 | PRO: 25 ± 5 | | [| al. | 25 | | 2 | | | 2 | | | PLA: n= 8 | M | PLA: 26 ± 5 | | 2 | | | | 3 | | | | | | recreationally active | F | | |] | | | | individuals | | | +---+-----------+----+-------------------------+---+------------------+ | | Sadeghi | 20 | PRO: n= 11 | M | 22.81 ± 2.76 | | [| et al. | 25 | | | | | 2 | | | PLA: n= 11 | | | | 3 | | | | | | | | | | PRO+CAS: n= 11 | | | |] | | | | | | | | | | | CAS: n= 11 | | | | | | | | | | | | | | soccer players | | | +---+-----------+----+-------------------------+---+------------------+ | | Lee et | 20 | PRO L-PS23: n= 35 | 7 | PLA: 21.6 ± 2.0 | | [| al. | 22 | | 5 | | | 2 | | | PRO HK-PS23: n= 35 | M | PRO (L-PS23): | | 4 | | | | 3 | 21.4 ± 1.3 | | | | | PLA: n= 35 | 0 | | |] | | | | F | PRO (HK-PS23): | | | | | healthy individuals | | 21.8 ± 2.5 | +---+-----------+----+-------------------------+---+------------------+ | | Pour et | 20 | PRO: n= 10 | M | 19 ±2 | | [| al. | 26 | | | | | 2 | | | PLA: n=10 | | | | 5 | | | | | | | | | | PRO+SPI: n=10 | | | |] | | | | | | | | | | | SPI: n= 10 | | | | | | | | | | | | | | soccer players | | | +---+-----------+----+-------------------------+---+------------------+ | | Li et al. | 20 | PRO: n= 7 | M | PRO: 19.6 ± 1.1 | | [| | 23 | | | | | 2 | | | PLA: n= 8 | | PLA: 19.3 ± 0.7 | | 6 | | | | | | | | | | cross-country skiers | | | |] | | | | | | | +---+-----------+----+-------------------------+---+------------------+ | | Lee et | 20 | PRO LY-66: n= 22 | 4 | PRO LY-66: 21.1 | | [| al. | 24 | | 4 | ± 2.1 | | 2 | | | PRO PL-02: n= 22 | M | | | 7 | | | | 4 | PRO PL-02: 21.3 | | | | | PRO PL-02+LY-66: n= 22 | 4 | ± 1.5 | |] | | | | F | | | | | | PLA: n= 22 | | PRO PL-02+LY-66: | | | | | | | 20.9 ± 2.0 | | | | | healthy individuals | | | | | | | | | PLA: 21.9 ± 1.4 | +---+-----------+----+-------------------------+---+------------------+ | | Salleh et | 20 | PRO: n= 15 | N | PRO: 19.5 ± 1.0 | | [| al. | 21 | | R | | | 2 | | | PLA: n= 15 | | PLA: 19.9 ± 1.3 | | 8 | | | | | | | | | | badminton players | | | |] | | | | | | | +---+-----------+----+-------------------------+---+------------------+ | | P | 20 | PRO: n= 11 | M | PRO: | | [| rzewłócka | 23 | | | 24.67 ± 6.46 | | 2 | et al. | | PLA: n= 12 | | | | 9 | | | | | PLA: | | | | | mixed martial arts | | 26.18 ± 4.05 | |] | | | athletes | | | +---+-----------+----+-------------------------+---+------------------+ | | Cheng et | 20 | PRO: n= 15 | M | PRO: 20.9 ± 2.4 | | [| al. | 23 | | | | | 3 | | | PLA: n= 15 | | PLA: 20.5 ± 1.5 | | 0 | | | | | | | | | | healthy individuals | | | |] | | | | | | | +---+-----------+----+-------------------------+---+------------------+ | | Fu et al. | 20 | n= 8 | 4 | M: 27.0 ± 2.3 | | [| | 21 | | M | | | 3 | | | PRO: n= 8 | | F: 24.0 ± 0.8 | | 1 | | | | 4 | | | | | | PLA: n= 8 | F | | |] | | | | | | | | | | | recreational runners | | | +---+-----------+----+-------------------------+---+------------------+ | | Maz | 20 | PRO: n= 13 | M | PRO: 23.25 ± NR | | [| ur-Kurach

| 22 | | | | | 3 | et al. | | PLA: n= 13 | | PLA: 21.28 ± NR | | 2 | | | | | | | | | | competitive road | | | |] | | | cyclists | | | +---+-----------+----+------------------------+---+------------------+ | | Lundberg | 20 | PRO: n= 29 | 2 | PRO: 21 (18--30) | | [| et al. | 25 | | 9 | | | 3 | | | PLA: n= 29 | M | PLA: 20 (17--26) | | 3 | | | | | | | | | | biathlon skiers | 2 | | |] | | | | 9 | | | | | | | F | | +---+-----------+----+------------------------+---+------------------+

Table 1. Characteristics of the participants.

Table 2. Intervention details.

+---+-----------+----+----------------------+---------------+-------+ | N | Author | Ye | Probiotic Strain | Treatment | Dur | | o | | ar | | | ation | | . | | | | | | | +===+===========+====+======================+===============+=======+ | | Cao et | 20 | *Weizmannia* | *PRO: 4.8* × | *12* | | *[* | *al.* | *24* | *coagulans* BC 99 | 10 CFU | weeks | | 1 | | | | BC99 + 24 g | | | 6 | | | | milk protein | | | | | | | concentrate | | |] | | | | daily | | | | | | | | | | | | | PLA: 24 g milk | | | | | | | protein | | | | | | | concentrate | | | | | | | daily | | +---+-----------+----+----------------------+---------------+-------+ | | Imanian | 20 | Multi-strain | PRO: | 4 | | [| et al. | 24 | probiotic (8 strains: | 4.5 × 10 | weeks | | 1 | | | *Lactiplantibacillus* | *CFU* | | | *7* | | | *plantarum* BP06, | | | | | | | *Lacticaseibacillus* | *PLA: Starch (5* | | | *]* | | | *casei* BP07, | *g)* | | | | | | *Lactobacillus* | | | | | | | *acidophilus* BA05, | *PRO+CAS:* | | | | | | *Lactobacillus* | *Probiotic* | | | | | | *delbrueckii* BD08 | (4.5 × 10 | | | | | *bulgaricus,* | *CFU) + Casein* | | | | | | *Bifidobacterium* | *powder (20 g)* | | | | | | *infantis* BI04, | | | | | | | *Bifidobacterium* | *CAS: Casein* | | | | | | *longum* BL03, | *powder (20 g)* | | | | | | *Bifidobacterium* | | | | | | | *breve* BB02 and | All | | | | | | *Streptococcus* | *supplements* | | | | | *salivarius* | *taken 3* | | | | | | *thermophilus* BT01) | times/week (on | | | | | | | training days | | | | | | | only) | | +---+-----------+----+----------------------+---------------+-------+ | | Schreiber | 20 | Multi-strain | PRO: 1.5 × | 90 | | [| et al. | 21 | probiotic (5 strains: | 10 CFU | days | | 1 | | | *Lactobacillus* | *daily* | | | *8* | | | *helveticus Lafti* L10 | | | | | | | (28.6 %), | PLA: 1 capsule | | |] | | | *Bifidobacterium* | *(potato* | | | | | | *animalis ssp. lactis* | *starch) daily* | | | | | | *Lafti* B94 (28.6 %), | | | | | | | *Enterococcus* | | | | | | | *faecium* R0026 | | | | | | | (25.7 %), | | | | | | *Bifidobacterium* | | | | | | | *longum* R0175 | | | | | | | *(14.3 %)* and | | | | | | | *Bacillus subtilis* | | | | | | | R0179 (2.8 %)) | | | +---+-----------+----+----------------------+---------------+-------+ | | Tarik et | 20 | *Bacillus coagulans* | PRO: 2 × 10 | 60 | | [| al. | 22 | Unique IS-2 | CFU + 20 g of | days | | 1 | | | | whey protein | | | 9 | | | | powder daily | | | | | | | | | | |] | | | | PLA: lactose + | | | | | | | 20 g of whey | | | | | | | protein powder | | | | | | | daily | | +---+-----------+----+----------------------+---------------+-------+ | | Maym | 20 | Multi-strain | PRO: 4.5 × | 8 | | [| andinejad | 25 | probiotic (8 strains: | 10 CFU + 1 | weeks | | 2 | et al. | | *Lactiplantibacillus* | *starch capsule* | | | *0* | | | *plantarum* BP06, | *daily* | | | | | | *Lacticaseibacillus* | | | | *]* | | | *casei* BP07, | *OMEGA: 1000 mg*

| | | | | | *Lactobacillus* | *of fish oil +* | | | | | | *acidophilus* BA05, | *1 starch* | | | | | | *Lactobacillus* | *capsule daily* | | | | | | *bulgaricus* BD08, | | | | | | | *Bifidobacterium* | *PRO + OMEGA:* | | | | | | *infantis* BI04, | *4.5 × 10* | | | | | | *Bifidobacterium* | *CFU + 1000 mg* | | | | | | *longum* BL03, | *of fish oil* | | | | | | *Bifidobacterium* | | | | | | | *breve* BB02 and | PLA: 2 starch | | | | | | *Streptococcus* | *capsules daily* | | | | | | *thermophilus* BT01) | | | +---+-----------+----+-----------------------+----------------+-------+ | | Imanian | 20 | Multi-strain | PRO: 4.5 × | 8 | | [| et al. | 25 | probiotic (8 strains: | 10 CFU + 1 | weeks | | 2 | | | *Lactiplantibacillus* | *starch capsule* | | | *1* | | | *plantarum* BP06, | *daily* | | | | | | *Lacticaseibacillus* | | | | *]* | | | *casei* BP07, | *OMEGA: 1000 mg* | | | | | | *Lactobacillus* | *of fish oil +* | | | | | | *acidophilus* BA05, | *1 starch* | | | | | | *Lactobacillus* | *capsule daily* | | | | | | *bulgaricus* BD08, | | | | | | | *Bifidobacterium* | *PRO + OMEGA:* | | | | | | *infantis* BI04, | *4.5 × 10* | | | | | | *Bifidobacterium* | *CFU + 1000 mg* | | | | | | *longum* BL03, | *of fish oil* | | | | | | *Bifidobacterium* | | | | | | | *breve* BB02 and | PLA: 2 starch | | | | | | *Streptococcus* | *capsules daily* | | | | | | *thermophilus* BT01) | | | +---+-----------+----+-----------------------+----------------+-------+ | | Hudson et | 20 | *Saccharomyces* | *PRO: 1×10* | *2* | | *[* | *al.* | *25* | *boulardii* | Sb cells daily | weeks | | 2 | | | | | | | 2 | | | | PLA: 100 mg of | | | | | | | magnesium | | |] | | | | stearate and | | | | | | | 100 mg of | | | | | | | lactose daily | | +---+-----------+----+-----------------------+----------------+-------+ | | Sadeghi | 20 | Multi-strain | PRO: | 4 | | [| et al. | 25 | probiotic (8 strains: | 4.5 × 10 | weeks | | 2 | | | *Lactiplantibacillus* | *CFU* | | | *3* | | | *plantarum* BP06, | | | | | | | *Lacticaseibacillus* | *PLA: Starch (5* | | | *]* | | | *casei* BP07, | *g)* | | | | | | *Lactobacillus* | | | | | | | *acidophilus* BA05, | *PRO+CAS:* | | | | | | *Lactobacillus* | *Probiotic* | | | | | | *bulgaricus* BD08, | *(4.5 × 10* | | | | | | *Bifidobacterium* | *CFU) + Casein* | | | | | | *infantis* BI04, | *powder (20 g)* | | | | | | *Bifidobacterium* | | | | | | | *longum* BL03, | *CAS: Casein* | | | | | | *Bifidobacterium* | *powder (20 g)* | | | | | | *breve* BB02 and | | | | | | | *Streptococcus* | *All* | | | | | | *thermophilus* BT01) | supplements | | | | | | | taken 3 | | | | | | | times/week (on | | | | | | | training days | | | | | | | only) | | +---+-----------+----+-----------------------+----------------+-------+ | | Lee et | 20 | Live *Lactobacillus* | *PRO (L-PS23):* | *6* | | *[* | *al.* | *22* | *paracasei* group | 2 × 10 CFU | weeks | | 2 | | | (L-PS23) | daily | | | 4 | | | | | | | | | | Heat-killed *L.* | *PRO (HK-PS23):* | | | *]* | | | *paracasei* group | 2 × 10 | | | | | | (HK-PS23) | cells daily | | | | | | | | | | | | | | | PLA: MCC 2 | | | | | | | capsules daily | | +---+-----------+----+-----------------------+----------------+-------+ | | Pour et | 20 | Multi-strain | PRO: 4.5 × | 8 | | [| al. | 26 | probiotic (8 strains: | 10 CFU | weeks | | 2 | | | *Lactiplantibacillus* | *daily* | | | *5* | | | *plantarum* BP06, | | | | | | | *Lacticaseibacillus* | *PLA: Starch 5g* | | | *]* | | | *casei* BP07, | *daily* | | | | | | *Lactobacillus* | | | | | | | *acidophilus* BA05, | *PRO+SPI 4.5 ×* | | | | | | *Lactobacillus* | *10 CFU +* | | | | | | *bulgaricus* BD08, | *Spirulina 2g* | | | | | | *Bifidobacterium* | *daily* | | | | | | *infantis* BI04, | | | | | | | *Bifidobacterium* | *SPI: Spirulina* | | | | | | *longum* BL03, | *2g daily* | | | | | |

Bifidobacterium | | | | | | | *breve* BB02 and | | | | | | | *Streptococcus* | | | | | | | *thermophilus* BT01) | | | | +---+-----------+----+----------------------+----------------+-------+ | | Li et al. | 20 | *Bifidobacterium* | *PRO: yogurt* | *8* | | *[* | | *23* | *animalis subsp.* | *with the* | *weeks* | | *2* | | | *Lactis* BL-99 | addition of 4 | | | 6 | | | | × 10 CFU | | | | | | | daily | | |] | | | | | | | | | | | PLA: ordinary | | | | | | | yogurt | | +---+-----------+----+----------------------+----------------+-------+ | | Lee et | 20 | *Lactococcus lactis* | *PRO LY-66: 1,5* | *6* | | *[* | *al.* | *24* | *subsp. lactis* | × 10 CFU | weeks | | 2 | | | (LY-66) | daily | | | 7 | | | | | | | | | | *Lactobacillus* | *PRO PL-02: 1,5* | | | *]* | | | *plantarum* (PL-02) | × 10 CFU | | | | | | | daily | | | | | | | | | | | | | | PRO | | | | | | | PL-02+LY-66: | | | | | | | 1,5 × 10 | | | | | | | CFU (1:1) | | | | | | | daily | | | | | | | | | | | | | | PLA: anhydrous | | | | | | | glucose, | | | | | | | sodium | | | | | | | citrate, lemon | | | | | | | flavor, citric | | | | | | | acid, sodium | | | | | | | chloride, | | | | | | | potassium | | | | | | | citrate, | | | | | | | sodium | | | | | | | ascorbate, | | | | | | | acesulfame | | | | | | | potassium, | | | | | | | vitamin B | | | | | | | complex (2 | | | | | | | sachets in 250 | | | | | | | ml of water | | | | | | | daily) | | +---+-----------+----+----------------------+----------------+-------+ | | Salleh et | 20 | *Lactobacillus casei* | PRO: orange | 6 | | [| al. | 21 | | juice with the | weeks | | 2 | | | | addition of 3 | | | 8 | | | | × 10 CFU | | | | | | | (200 mL) daily | | |] | | | | | | | | | | | PLA: orange | | | | | | | juice (200 mL) | | | | | | | daily | | +---+-----------+----+----------------------+----------------+-------+ | | P | 20 | Multi-strain | PRO: 2 × 10 | 4 | | [| rzewłócka | 23 | probiotic (5 strains: | CFU + | weeks | | 2 | et al. | | *Bifidobacterium* | *3000--4000 IU* | | | *9* | | | *lactis* W51, | *of vitamin D3* | | | | | | *Levilactobacillus* | *daily* | | | *]* | | | *brevis* W63, | | | | | | | *Lactobacillus* | *PLA: 40 mg of* | | | | | | *acidophilus* W22, | *maltodextrin +* | | | | | | *Bifidobacterium* | *3000--4000 IU* | | | | | | *bifidum* W23 *and* | *of vitamin D3* | | | | | | *Lactococcus lactis* | daily | | | | | | W58) | | | +---+-----------+----+----------------------+----------------+-------+ | | Cheng et | 20 | Heat-Killed | PRO: | 6 | | [| al. | 23 | *Lactiplantibacillus* | *3 × 10 CFU* | *weeks* | | *3* | | | *plantarum* TWK10 | daily | | | 0 | | | | | | | | | | PLA: capsule | | |] | | | | with cellulose | | | | | | | and | | | | | | | maltodextrin | | +---+-----------+----+----------------------+----------------+-------+ | | Fu et al. | 20 | *Lactobacillus* | *PRO: 1.2 ×* | *4* | | *[* | | *21* | *plantarum* PS128 | 10 CFU | weeks | | 3 | | | | daily | | | 1 | | | | | | | | | | PLA: NR | | |] | | | | | | | +---+-----------+----+----------------------+----------------+-------+ | | Maz | 20 | Multi-strain | PRO: 1 × | 16 | | [| ur-Kurach | 22 | probiotic (13 strains | 10 CFU | weeks | | 3 | et al. | | *Lactobacillus* | *daily* | | | *2* | | | *plantarum,* | | | | | | | *Lactobacillus casei,* | *PLA: potato* | | | *]* | | | *Lactobacillus* | *starch* | | | | | | *rhamnosus,* | | | | | | | *Bifidobacterium* | | | | | | | *breve, Lactobacillus* | | | | | | | *acidophilus,* | | | | | | | *Bifidobacterium* | | | | | | | *longum,* | | | | | | | *Bifidobacterium* | | | | | | | *bifidum,* | | | | | | | *Bifidobacterium* | | | | | | | *infantis,* | | | | | | | *Lactobacillus* | | | | | | | *helveticus,* | | | | | | | *Lactobacillus* | | | | | | | *fermentum,* | | | | | | | *Lactobacillus* | | | | | | | *bulgaricus,* | | | | | | | *Lactococcus lactis,* | | | | | | | *and Streptococcus* | | | | | | | *thermophilus*) | | | +---+-----------+----

+----------------------+---------------+-------+ | | Lundberg | 20 | *Propionibacterium* | *PRO: 75g (F) /* | *24* | | *[* | *et al.* | *25* | *freudenreichii subsp.* | *90g (M) of* | *weeks* | | *3* | | | *shermanii* LMGT 2951 | Jarlsberg | | | 3 | | | | cheese (with | | | | | | | 7,5x10 / | | |] | | | | 9x10 CFU) | | | | | | | daily | | | | | | | | | | | | | | PLA: 75g (F) / | | | | | | | 90g (M) of | | | | | | | Norvegia | | | | | | | cheese daily | | +---+-----------+----+----------------------+---------------+-------+

4. Quality Assessment

The methodological quality of the included RCTs was evaluated using the Cochrane Risk of Bias 2 (RoB 2) tool. The assessment focused on five critical domains: the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result.

RESULTS

1. Study Selection (PRISMA Flow)

Figure 1 illustrates the PRISMA flow chart detailing the study selection process. Initially, a total of 1,857 records were identified through electronic database searches. After applying preliminary filters- restricting results to randomized controlled trials published in English within the last five years and involving human subjects- 132 records remained.

After removing duplicates, 84 unique records underwent title and abstract screening. Of these, 65 records were excluded for the following reasons:

Inappropriate population (n= 16): Studies involving subjects with clinical conditions or individuals outside the age criteria.

Wrong intervention (n= 27): Studies applying fermented foods (e.g., kefir), non-probiotic supplements, or dietary modifications.

Lack of objective outcomes (n= 15): Records without validated physical performance testing.

Incorrect study design (n= 7): Studies that were not primary RCTs.

Consequently, 19 full-text articles were retrieved and assessed for eligibility. Upon closer examination, one additional record was excluded due to significant differences in exercise habits between the intervention and control groups, as reported by the authors 34. This process resulted in a final inclusion of 18 studies for the qualitative synthesis.

Identification of studies via databases and registers

Identification

Records identified from:

> PubMed (n = 713) > > Scopus (n = 1144) > > Registers (n = 0)

Records removed *before screening*:

> Records marked as ineligible by automation tools (n = 1725) > > Duplicate records removed (n = 48) > > Records removed for other reasons (n = 0)

Screening

Records screened

(n = 84)

Records excluded

(n = 65)

Reports sought for retrieval

(n = 19)

Reports not retrieved

(n = 0)

Reports assessed for eligibility

(n = 19)

Reports excluded:

> Significant differences in training intensity between groups (n = 1)

Included

Studies included in review

(n = 18)

Figure 1. PRISMA flow chart for the identification of the included studies.

2. Characteristics of Included Studies

A total of 18 randomized controlled trials were included in this review, with a combined sample size of approximately 817 participants (ranging from n=15 to n=105 per study). Male participants predominated across the sample (approximately 86%), although five trials included women within mixed-gender cohorts (Hudson et al. 2025; Lee et al. 2022; Lee et al. 2024; Fu et al. 2021; Lundberg et al. 2025). Most studies recruited young adults with a mean age of 19-27 years.

The participants represented a broad athletic spectrum, ranging from elite and well-trained athletes (e.g., cyclists, swimmers, soccer players, Mixed Martial Arts Athletes, and biathlon skiers) to recreationally active individuals and healthy college students.

Regarding intervention characteristics, the probiotic supplementation involved a broad taxonomic variety, primarily encompassing the genera *Lactobacillus* (including *L. plantarum, L. casei, L. acidophilus, L. bulgaricus, L. paracasei, L. helveticus, L. rhamnosus,* and *L. lactis*) and *Bifidobacterium* (notably *B. breve, B. longum, B. animalis,* and *B. infantis*), with one study investigating the yeast strain *Saccharomyces boulardii* (Hudson et al. 2025). Furthermore, several trials utilized multi-strain formulations s containing between 5 and 13 species, demonstrating an emerging research focus on synergistic microbial blends.

The duration of supplementation ranged from 2 to 24 weeks, with the majority lasting 4 to 8 weeks.

The daily probiotic dosage across the included studies showed significant heterogeneity, ranging from 1 × 10 to 4.5 × 10 Colony Forming Units (CFU). The majority of interventions used high-dose protocols exceeding 1 × 10 CFU per day to ensure sufficient intestinal colonization. While most studies followed a daily administration schedule, two studies (Imanian et al. 2024; Sadeghi et al. 2025) used a thrice-weekly protocol synchronized with training days.

Eight studies examined co-supplementation with other nutrients or functional compounds, including vitamin D (Przewłocka et al. 2023), omega-3 fatty acids (Maymandinejad et al. 2025; Imanian et al. 2025), casein powder (Imanian et al. 2024; Sadeghi et al. 2025), protein powder (Cao et al. 2024; Tarik et al. 2022), and spirulina (Pour et al. 2026). These trials explored whether the probiotic acted synergistically within a combined nutritional intervention. Additionally, in three of the studies, probiotics were delivered via food matrices such as cheese, yogurt, and orange juice (Lundberg et al. 2025; Li et al. 2023; Salleh et al. 2021).

Notably, when delivered via food products, dosages remained consistent with supplement standards. Placebo groups typically received inert substances, most commonly starch (potato or corn), maltodextrin, or cellulose, ensuring an identical appearance and taste to the active intervention.

3. Synthesis of Results

3.1 Muscle Strength

Across the included studies, muscle strength outcomes were assessed through one-repetition maximum (1RM), isokinetic dynamometry, Isometric Mid-Thigh Pull (IMTP), and handgrip strength tests. Overall, 12 trials evaluated this domain, of which the majority reported meaningful benefits of probiotic supplementation, especially with multi-strain formulations and when combined with other supportive nutrients.

Administered with milk protein, *Weizmannia coagulans* BC99 (Cao et al. 2024) improved muscular endurance, although it did not further enhance maximal strength over protein alone. Conversely, *Bacillus coagulans* Unique IS-2 taken with whey protein (Tarik et al. 2022) significantly increased lower-body strength (1RM leg press), though effects on upper-body lifts were non-significant. Two studies identified synergistic interactions between probiotics and complementary nutritional components: Imanian et al. (2025) found that combining multi-strain probiotics with omega-3 fatty acids under ultra-short race-pace training (USRPT) elicited superior improvements in upper-body muscular strength compared with either supplement alone or training without supplementation. Sadeghi et al. (2025) reported that probiotic + casein co-supplementation (4.5×10^{11} CFU + 20 g CAS) enhanced knee extensor strength and power at 180°/s more than either nutrient alone, emphasizing their joint relevance for high-speed torque production in soccer players. Similarly, Pour et al. (2026) observed that a multi-strain probiotic improved posterior-chain (flexor) strength, with spirulina co-administration providing additional, though non-essential, gains.

Several single-strain studies also recorded positive outcomes. Li et al. (2023) presented enhanced isokinetic knee extensor strength (RPT 60°/s) following eight weeks of *Bifidobacterium animalis* BL-99. While Lundberg et al. (2025) observed strength increases in both the placebo and probiotics group, long-term consumption of Jarlsberg cheese containing *Propionibacterium freudenreichii* showed a more pronounced strength increase among females.

In contrast, Salleh et al. (2021) reported no differences in handgrip performance after six weeks of supplementing *Lactobacillus casei*, highlighting potential strain-specific limitations.

Three trials examined muscle strength after exercise-induced muscle damage (EIMD). Lee et al. (2022) showed that both live and heat-killed *Lactobacillus paracasei* PS23 mitigated strength loss in the IMTP test and accelerated recovery within 48 h, with the heat-killed form showing superior restoration of peak force. Lee et al. (2024) similarly found that *L. plantarum* PL-02 and *L. lactis* LY-66 attenuated post-EIMD reductions in relative peak force and rate of force development, confirming probiotic-mediated protection of neuromuscular function. Fu et al. (2021) further demonstrated that *L. plantarum* PS128 limited declines in knee extensor and flexor peak torque following a half-marathon, supporting faster return-to-play recovery. Supplementing these, Cheng et al. (2023) found significant bilateral gains in handgrip strength after six weeks of heat-killed *L. plantarum* TWK10, suggesting postbiotic potency in enhancing contractile force even without a live microbial component.

3.2 Muscle Power and Endurance

Muscle power outcomes were assessed in eight studies using countermovement jump (CMJ), vertical jump height, medicine ball throw, and rate of force development (RFD) measures, with five trials displaying significant improvements. Single-strain *Bacillus coagulans* Unique IS-2 combined with whey protein enhanced vertical jump performance in comparison to whey protein alone (Tarik et al. 2022), while multi-strain probiotic formulations showed superior effects when combined with complementary nutrients. Notably, probiotic + omega-3 synbiotic interventions during ultra-short race-pace training (USRPT) yielded pronounced improvements in both aquatic and dry-land power metrics, including start distance, push-off distance, in-water vertical jump, and medicine ball throw performance, with the combined approach outperforming individual supplementation (Maymandinejad et al. 2025; Imanian et al. 2025). Studies examining muscle power post-EIMD consistently showed protective effects: both live and heat-killed *Lactobacillus paracasei* PS23 mitigated declines in CMJ height within 24 h post-EIMD, with heat-killed forms revealing superior restoration at 48 h (Lee et al. 2022), while *L. plantarum* PL-02 and *L. lactis* LY-66 effectively attenuated losses in peak rate of force development 48 h post-EIMD (Lee et al. 2024). Conversely, three trials reported no significant changes in vertical jump height with single-strain interventions or multi-strain + spirulina combinations (Pour et al. 2026; Salleh et al. 202; Fu et al. 2021).

Muscular endurance was evaluated using wall-squat, repeated jump, time-to-task failure, barbell bench press, and squat tests in four studies, all of which demonstrated positive outcomes. *Weizmannia coagulans* BC99, combined with milk protein concentrate, significantly improved muscular endurance, rated by Repetitions at 80% of One-Repetition Maximum (Cao et al. 2024). The probiotic + omega-3 synbiotic approach again proved most effective, with significant improvements in repeated vertical jump tests both in water and on land (Maymandinejad et al. 2025) and enhanced time-to-task failure in the combined intervention group (Imanian et al. 2025). Similarly, the multi-strain probiotic + casein combination dominated muscle endurance outcomes, particularly in wall-squat performance, suggesting that protein co-supplementation improves the ergogenic effects on sustained muscular contractions (Sadeghi et al. 2025).

3.3 Aerobic Performance

Aerobic capacity, assessed primarily through VO_2max, time to exhaustion (TTE), and total time to fatigue, was examined in ten intervention studies investigating the effects of probiotic supplementation. Among these, several showed significant improvements in aerobic performance parameters, particularly when multi-strain probiotics or synbiotic combinations were used. Imanian et al. (2024) reported that four weeks of supplementation with a multi-strain probiotic blend combined with casein (4.5×10^{11} CFU + 20 g CAS, three times weekly) significantly increased aerobic endurance, VO_2max, and the respiratory compensation point in soccer players, with the synbiotic group showing superior improvements compared with placebo. Similarly, Mazur-Kurach et al. (2022) observed that a 16-week multi-strain probiotic (13 strains, 1×10^{11} CFU daily) significantly increased VO_2max and exercise duration in competitive cyclists. In contrast, Schreiber et al. (2021) found no improvement in VO_2max or time to fatigue after 90 days of multi-strain supplementation (5 strains, 1.5×10 CFU daily). Still, they reported reduced perceived exertion, showing potential psychophysiological benefits.

Beyond multi-strain formulations, several single-strain interventions also presented notable outcomes. Li et al. (2023) demonstrated that eight weeks of *Bifidobacterium animalis subsp. Lactis* BL-99 supplementation markedly increased VO_2max in cross-country skiers, while Cheng et al. (2023) showed that six weeks of heat-killed *Lactiplantibacillus plantarum* TWK10 significantly improved TTE compared with placebo. Salleh et al. (2021) found that administering Lactobacillus casei for 6 weeks improved aerobic performance (VO_2max) in badminton players. Supporting these conclusions, Lee et al. (2024) noted significant gains in VO_2max after six weeks of combined *Lactococcus lactis* and *Lactobacillus plantarum* supplementation. In contrast, Tarik et al. (2022) reported no change in VO_2max following supplementation with *Bacillus coagulans* Unique IS-2, and Fu et al. (2021) observed that *Lactobacillus plantarum* PS128 did not enhance VO_2max despite benefits for recovery after prolonged endurance exercise. Lastly, Lundberg et al. (2025) reported that a 24-week intervention with Jarlsberg cheese (PRO) and Norvegia cheese (PLA) resulted in a significant increase in aerobic capacity (VO2max) in both groups, without significant differences between them.

3.4 Anaerobic Performance

Across nine studies, anaerobic performance was primarily assessed using Wingate Anaerobic Tests (WAnT), Running-Based Anaerobic Sprint Tests (RAST), or Sprint Interval Training (SIT) protocols, and parameters such as peak and mean power output, fatigue index, and total work were evaluated. The findings collectively indicate that probiotic supplementation may provide ergogenic benefits under specific conditions, especially when combined with additional nutritional components or following exercise-induced muscle damage. Maymandinejad et al. (2025) demonstrated that concurrent supplementation with a multi-strain probiotic (eight strains) and omega-3 fatty acids substantially improved anaerobic power metrics (Sprint Index and velocity) in competitive swimmers, with the synbiotic combination (PRO+OMEGA) producing greater gains than either supplement alone. Similarly, Sadeghi et al. (2025) observed that the combination of a multi-strain probiotic and casein (PRO+CAS) led to considerable improvements in RAST maximal and mean power output, outperforming both probiotic-only and casein-only groups, highlighting a potent synergistic effect. In contrast, Pour et al. (2026) found no significant changes in anaerobic indices (RAST power and fatigue index) following multi-strain probiotic and spirulina co-supplementation in soccer players, though other aspects of performance improved. Mazur-Kurach et al. (2022) also observed no measurable effects on WAnT outcomes (global workload, MAP, or average power) following long-term multi-strain probiotic use. However, improvements were noted in aerobic metrics. Moreover, Przewłocka et al. (2023) revealed that combining multi-strain probiotics with vitamin D_3 significantly enhanced total work output and mean power in mixed martial arts athletes, emphasizing the potential of probiotic-micronutrient synergy for anaerobic endurance.

Among studies using single-strain or non-synbiotic formulations, results were more varied. Hudson et al. (2025) reported that short-term supplementation with *Saccharomyces boulardii* (1×10^9 CFU, 14 days) did not enhance SIT-induced anaerobic gains, despite both groups improving peak power output through training. Similarly, Fu et al. (2021) found that supplementation with *Lactobacillus plantarum* PS128 did not significantly affect anaerobic parameters (peak power, mean power, or fatigue index) in recreational runners. Conversely, studies involving EIMD contexts showed consistent benefits. Lee et al. (2022) demonstrated that both live and heat-killed *Lactobacillus paracasei* PS23 markedly attenuated declines in anaerobic performance (WAnT) and reduced fatigue index values following EIMD, accelerating recovery within 24-48 hours. Extending this evidence, Lee et al. (2024) found that *Lactobacillus plantarum* (PL-02) and *Lactococcus lactis* (LY-66) supplementation significantly increased relative mean and peak power during WAnT tests, while also improving muscle strength and recovery markers post-EIMD.

3.5 Speed, Agility, and Reaction Time

Speed, agility, and reaction time outcomes were evaluated in three studies applying standardized field tests, including the Illinois Agility Test (IA), T-Test, and reaction time assessments. The evidence suggests that performance benefits were most pronounced when multi-strain probiotics were combined with additional ergogenic compounds, forming synbiotic or multi-nutrient interventions. Maymandinejad et al. (2025) demonstrated that eight weeks of multi-strain probiotic supplementation (eight bacterial strains) combined with omega-3 fatty acids significantly improved agility (T-Test time), reaction speed, and sprint performance in competitive swimmers. The greatest gains were observed in the synbiotic condition (PRO+OMEGA), confirming a synergistic effect between probiotics and omega-3 fatty acids. Similarly, Pour et al. (2026) reported that both multi-strain probiotics and spirulina, either individually or in combination, enhanced agility performance as measured by the Illinois Agility Test, with the PRO+SPI synbiotic producing the strongest results; however, no significant changes were observed in sprint or reaction time tests. In contrast, Salleh et al. (2021) observed no significant improvements in speed or agility following six weeks of *Lactobacillus casei* supplementation in badminton players, suggesting that single-strain interventions may yield limited efficacy for these performance domains.

3.6 Exercise-Induced Muscle Damage (EIMD)

Three studies investigated the effects of probiotic supplementation on recovery and performance following exercise-induced muscle damage, primarily assessing variables such as muscle strength, power output, and fatigue resistance post-exercise. Fu et al. (2021) reported that *Lactobacillus plantarum* PS128 supplementation effectively minimized muscle strength decline and maintained performance during prolonged endurance events, consequently accelerating post-race recovery and return to training. Similarly, Lee et al. (2022) found that both live (L-PS23) and heat-killed (HK-PS23) *Lactobacillus paracasei* PS23 substantially reduced the loss in muscle strength (IMTP), explosive power (CMJ), and anaerobic performance (WAnT) following EIMD. Probiotic intake accelerated functional recovery within 24-48 hours, with HK-PS23 showing superior effects on restoring jump height and peak force compared with placebo, suggesting a potent postbiotic-like mechanism. Extending these outcomes, Lee et al. (2024) showed that six weeks of supplementation with *Lactococcus lactis subsp. Lactis* (LY-66), *Lactobacillus plantarum* (PL-02), and their combination (PL-02+LY-66) effectively attenuated the reductions in relative peak force and peak rate of force development observed at 24 and 48 hours post-EIMD. These interventions demonstrated superior muscle recovery compared with placebo, underscoring the protective and restorative roles of both live and heat-killed probiotics.

4. Quality Assessment (Risk of Bias)

The methodological quality of the 18 included randomized controlled trials was thoroughly assessed using the Cochrane Risk of Bias 2 (RoB 2) tool. The assessment covered five specific domains of potential bias, and the results are summarized in Figure 2.!\[\](media/image1.png){width="4.188222878390201in" height="5.314710192475941in"}

Figure 2. Risk of bias summary

4.1 Overall Risk of Bias

The overall assessment showed that 7 out of 18 studies were judged to be at low risk of bias, demonstrating high methodological quality across all domains. 10 studies were categorized as having "some concerns", primarily due to issues identified in Domain 5 regarding the absence of a pre-registered clinical trial protocol or a publicly available statistical analysis plan. Only one study (Lundberg et al. 2025) was rated as having a high risk of bias due to concerns about the inability to blind participants, stemming from distinct differences in the appearance and taste of the cheeses.

In conclusion, although the randomization and outcome measurement processes across the studies were mostly robust, the overall "some concerns" rating in most trials indicates that issues such as incomplete pre-registration and inconsistent protocol implementation may undermine the credibility and reproducibility of the findings. Therefore, addressing these limitations should be prioritized in future research to strengthen the reliability and impact of subsequent findings.

DISCUSSION

1. Summary of Key Findings

The analysis of eighteen randomized controlled trials confirms that probiotic supplementation can positively influence specific domains of physical performance, with the most robust evidence emerging for muscular strength, aerobic capacity, and accelerated recovery following exercise-induced muscle damage. These findings correspond closely with the theoretical model of the "gut-muscle axis", which suggests that interactions between the intestinal microbiota and skeletal muscle mediate systemic adaptations in response to exercise and nutritional interventions. A central finding of this review is that the ergogenic potential of probiotics is significantly amplified when administered as synbiotics or in combination with complementary nutrients, supporting the mechanistic framework in which gut microbiota modulate nutrient metabolism and immune function. Notably, formulations paired with omega-3 fatty acids, casein, or whey protein consistently outperformed single-strain or isolated probiotic interventions. Synergistic protocols-such as those investigated by Imanian (2024, 2025), Maymandinejad (2025), and Sadeghi (2025)- demonstrated superior gains in power, explosive strength, and speed. Furthermore, the consistent ability of strains such as *L. paracasei* PS23 and *L. plantarum* PL-02 to attenuate strength loss post-EIMD underscores their role as potent recovery agents within this gut-muscle axis framework. These collective results support the hypothesis that modulating the gut-muscle axis through targeted supplementation is an effective ergogenic strategy.

2. Interpretation of Results and Physiological Mechanisms

In light of the gut-muscle axis concept, the performance enhancements observed following probiotic supplementation likely arise from several overlapping physiological mechanisms. Primarily, probiotics can increase the availability of SCFAs, such as acetate and propionate, which can modulate skeletal muscle homeostasis and exercise performance through metabolic, inflammatory, autophagic, and oxidative stress pathways 35, 36. Additionally, SCFAs have been shown to activate AMPK and the PGC-1α pathway, thereby enhancing fatty acid oxidation and increasing mitochondrial function, which may increase the anti-fatigue capacity of slow fibers 37.

Mitigating exercise-induced muscle damage represents another critical pathway. Strains such as *Lactobacillus paracasei* PS23 and *L. plantarum* PL-02 were found to reduce strength loss following eccentric exercise, likely by significantly reducing markers of muscle inflammation (Lee et al. 2022). By limiting oxidative damage, these probiotics facilitate a more rapid recovery of peak power and strength. Additionally, evidence indicates that probiotics significantly modulate biochemical parameters associated with inflammation 38. Specifically, supplementation has been shown to reduce pro-inflammatory markers, including C-reactive protein (CRP), tumor necrosis factor-alpha (TNF-α), and interleukin-6 (IL-6), as well as IL-12 and IL-4 39, 40. By attenuating excessive exercise-induced cytokine storms and mitigating systemic oxidative stress, these microbial interventions may alleviate the physiological burden of high-intensity training. This reduction in the inflammatory response may not only protect neuromuscular function but also improve endurance capacity and accelerate the restoration of performance readiness.

The efficacy of probiotics is notably amplified through synergy with other nutrients, such as casein, omega-3 fatty acids or vitamin D. Omega-3 lipids impact the immune system by influencing cell membrane fluidity, signaling processes, and gene expression related to immune responses 41. Casein provides a sustained source of amino acids. Adequate serum levels of 25(OH)D increase muscle strength and physical performance 42.

Probiotics likely enhance the absorption and utilization of these compounds, explaining the greater performance gains observed in synbiotic groups across multiple parameters. Furthermore, supplementation with *Weizmannia coagulans* BC99 has been shown to increase the bioavailability of key amino acids- including leucine, isoleucine, and glutamine- consequently promoting muscle protein synthesis and systemic recovery (Cao et al. 2024). Additionally, probiotic treatment has been shown to improve bone formation, increase bone density, and prevent bone loss, which can accelerate fracture healing and have a positive effect on the bone metabolism of athletes 43.

Finally, the positive results observed with heat-inactivated strains (e.g., heat-killed *L. plantarum* TWK10 and HK-PS23) are particularly revealing. These postbiotics showed comparable, and in some cases superior, effects on muscle recovery relative to live cultures. This suggests that bacterial metabolites and structural components, rather than active intestinal colonization alone, may play the primary role in modulating the gut-muscle axis for athletic performance.

3. Differences in studies

Despite positive trends, considerable discrepancies exist between the included studies. For instance, the lack of a significant improvement in VO2max in the Tarik et al. (2022) trial contrasts with the positive outcomes reported by Imanian (2024) and Salleh et al. (2021). Such variations can largely be attributed to differences in dosage and intervention duration. Interventions lasting only 4-6 weeks or using low doses (< 10 CFU) often appear insufficient to achieve meaningful gut colonization or stable microbiome modulation. In contrast, protocols employing higher dosages (>10 CFU/day) and extended durations (>8 weeks) consistently yielded more robust performance benefits.

Additionally, participants' baseline training status significantly influenced the magnitude of the observed effects. Highly trained or elite athletes (e.g., the cyclists in the study by Schreiber et al. 2021) often exhibit a "ceiling effect," in which the potential for further physiological adaptation is limited compared to that of recreational athletes or healthy, untrained individuals. This suggests that while probiotics are beneficial across the athletic spectrum, their ergogenic impact may be more readily detectable in populations with greater physiological headroom for improvement.

4. Limitations

Despite the significant findings, several limitations of this analysis must be acknowledged to maintain a balanced perspective. First, many of the included trials featured small sample sizes (often $n < 30$), which may limit the statistical power and the ability to detect subtle differences. Second, there is a clear gender imbalance in the research, with approximately 86% of participants being male, limiting the generalizability of these results to female athletes.

Furthermore, the high heterogeneity of the interventions- including a wide array of probiotic strains, varying dosages, different supplementation durations, and diverse delivery matrices (e.g., capsules vs. food products)- makes it challenging to identify a single, universal "gold standard" protocol. Additionally, the lack of rigorous training and dietary standardization in some studies may have introduced confounding variables. Finally, only a subset of the trials provided comprehensive gut microbiome profiling before and after the intervention, which limits our ability to definitively link performance gains to specific changes in microbial composition.

5. Future Research Directions

To advance our understanding of the gut-muscle axis, future research should prioritize large-scale, multicenter clinical trials with a specific focus on female cohorts and athletes across diverse sports disciplines. There is also a significant need to explore the efficacy of postbiotics and their specific metabolites (such as SCFAs and bioactive peptides) as stable, standardized alternatives to live cultures. Longer-term longitudinal studies (exceeding 24 weeks) are required to evaluate the impact of chronic probiotic use on mitochondrial adaptations, body composition, and systemic immune function.

CONCLUSIONS

Evidence from this systematic review indicates that probiotic supplementation, particularly in multi-strain and synbiotic formulations, serves as an effective strategy to support physical performance by enhancing muscular strength, explosive power, aerobic capacity, and functional recovery. A central conclusion is that the ergogenic potential of probiotics is significantly amplified when paired with synergistic nutrients such as omega-3 fatty acids, casein, or whey protein. These combinations appear to optimize muscle metabolism and immune responsiveness more effectively than individual supplementation. However, these findings should be interpreted with caution, given limitations across the included research, such as small sample sizes, gender imbalance, and heterogeneity in probiotic strains, dosages, and study protocols.

The underlying ergogenic mechanisms are multifaceted, involving increased production of short-chain fatty acids, mitigation of systemic oxidative stress, preservation of gut barrier integrity, and modulation of exercise-induced inflammatory processes. Furthermore, emerging evidence regarding postbiotics (heat-inactivated strains) suggests that bacterial metabolites and structural components can be just as effective as live cultures in accelerating recovery and restoring neuromuscular function after exercise-induced muscle damage.

However, the efficacy of these interventions is highly contingent upon the specific strain, dosage (optimally > 10 CFU/day), and duration of supplementation (> 8 weeks). Moreover, the magnitude of adaptation is influenced by the athlete's baseline training status, with recreational individuals often exhibiting a greater response than elite athletes due to the "ceiling effect".

In light of these findings, while probiotics offer a promising tool for training support, further rigorous and standardized research is essential to establish definitive, evidence-based clinical guidelines. In the interim, practitioners should consider incorporating multi-strain or synbiotic probiotic supplementation alongside synergistic nutrients, such as omega-3 fatty acids and protein, when designing nutrition protocols for athletes seeking to enhance performance and recovery. Future studies should prioritize longitudinal observations, include more diverse female cohorts, and use precise microbiome profiling to develop individualized probiotic protocols that maximize both long-term training adaptations and the overall health of the athlete.

Disclosure

Authors' Contribution

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Conflict of Interest Statement

The authors declare no conflicts of interest.

Declaration of the Use of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used Gemini AI for language enhancement purposes, such as grammar correction and stylistic refinement. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the substantive content of the publication.

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