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Lactobacillus Plantarum TWK-10 Single Strain Supplementation: Examining its Effects on Physical Performance, Physiological Metrics, and Fatigue-Related Parameters through a Systematic Review

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ABSTRACT

Introduction: Physical activity has been observed to impact the diversity and composition of the microbiome. While existing research primarily concentrated on the influence of exercise on gut microorganisms and diversity, this systematic review seeks to explore the potential of TWK 10 probiotic supplementation on enhancing fatigue-related indicators among untrained individuals.

Method: we conducted a comprehensive systematic review spanning the last decade (2013–2023), searching PubMed, Scopus, and Web of Science for both human and animal trials, with all searches completed by August 2023.

Results: Eight clinical intervention studies that evaluated the impact of TWK-10 supplementation on diverse performance measurements and physiological parameters in both human and animals (totally consisting of 208 amateur athletes and 63 mice) were chosen. Intervention durations ranged from 6 to 18 weeks. Results from animal trials indicated that TWK-10 supplementation enhanced grip strength and endurance swimming time. Conversely, human trials did not reveal significant effects of TWK-10 on grip strength, glucose levels, muscle strength, body weight, or body composition. Inconsistencies were observed across studies regarding the impact of TWK-10 on serum levels of lactate, ammonia, glucose, creatine kinase (CK), and blood urea nitrogen (BUN). Some studies reported increased muscle mass and decreased fat mass following TWK-10 supplementation. Furthermore, TWK-10 administration evoked alterations in gut microbiota and concentrations of short-chain fatty acids.

Conclusions: Further meticulously designed research is imperative to comprehensively ascertain the influence of TWK-10 supplementation on performance assessments and physiological parameters. Discrepancies in study outcomes may be attributed to disparities in fiber intake,gut microbiota composition and duration of the trials.

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Introduction

Achieving peak athletic performance necessitates a multifaceted approach, integrating foundational physical conditioning, sport-specific training, and meticulously tailored nutritional strategies. As athletes approach elite levels, marginal gains become critical, prompting the judicious use of evidence-based performance supplements. However, certain supplements may induce gastrointestinal (GI) distress or pose health risks, necessitating careful selection (1).

A notable trade-off exists between performance-driven dietary practices and gut microbiota health. For instance, some athletes adopt low-fibre diets to minimize GI discomfort during competition, yet this practice may compromise microbial diversity and functionality (2, 3). Emerging research explores probiotic supplementation as a potential countermeasure

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to mitigate these adverse effects while maintaining performance efficacy (4).

The human microbiota comprises diverse microorganisms (bacteria, viruses, archaea) (5, 6) inhabiting the skin, gut, and other mucosal surfaces (6, 7). Over 70% reside in the intestines, where they maintain mucosal integrity, regulate metabolism, and modulate immunity (8). Gut microbiota diversity and balance are critical for intestinal health, gut-brain axis signaling, and overall physiological function (9). Probiotics are utilized as possible performance-enhancing aids to improve exercise capacity (10). Research indicates that these microorganisms can enhance athletic performance by fostering nutrient assimilation, elevating basal growth hormone levels, and enhancing muscle adaptation during resistance training (11, 12).

Over the past decade, Lactobacillus plantarum has emerged as a prominent probiotic strain, with growing interest in its potential health benefits. *Lactobacillus plantarum* has been found to increase the production of SCFAs, with butyrate serving as the primary energy source for enterocytes (13). Propionate has been linked to increased glucose production in the liver through gluconeogenesis, potentially accelerating mutual communication between the gut and the brain and leading to enhanced adrenaline secretion and improved exercise performance (14).

Feeling fatigued after exercise can be detrimental to sports performance (15) and can decrease athletes' function. Research suggests that the consumption of *L. Plantarum* TWK-10 (LP10), a specific strain of *Lactobacillus plantarum*, may mitigate lactate production (16). Furthermore, studies have indicated that *L. Plantarum* possesses antioxidant properties, both in vivo and in vitro, which can contribute to prolonged sports performance by reducing the production of metabolites and exerting an anti-fatigue effect (17-20). Thus, existing evidence suggests that Lactobacillus plantarum may confer ergogenic benefits by improving physical performance while simultaneously alleviating fatigue and modulating post-exercise inflammation (16, 21). TWK10 may also have a role in preventing and improving sarcopenia and muscle atrophy, as in previous studies it has been associated with increased muscle mass and reduced fat mass (16, 22-24).

Existing studies have predominantly examined exercise-induced microbiota modulation, with insufficient exploration of microbiota-performance relationships as potential ergogenic strategies. Although *Lactobacillus plantarum TWK10* has been proposed as a performance-enhancing probiotic, rigorous evidence—including systematic reviews or meta-analyses—remains scarce. This review critically synthesizes current findings on TWK10's efficacy in enhancing exercise performance and mitigating fatigue.

Materials and Methods

This systematic review aims to assess the impact of *Lactobacillus plantarum* TWK10 single-strain supplementation on the performance of untrained athletes. Additionally, relevant animal studies were reviewed to enhance the understanding of this topic. To define the research question, the PICOS criteria (Table 1) were used.

Table 1. PICOS criteria for inclusion and exclusion of studies

Parameter	Criteria
Participant	Untrained healthy athletes aged 20-85/ healthy animal
Intervention	supplementation with TWK10
Comparator	Placebo/ No supplementation
Outcomes	Physical Performance, Physiological Metrics, and Fatigue-Related Parameters
Study design	Placebo-controlled trial

Search strategy

The PubMed database was searched using the following Boolean equation, with all searches finalized by August 2023:

("*Lactobacillus plantarum* TWK10" [Title/Abstract] OR "TWK10" [Title/Abstract] OR "LP10" [Title/Abstract]) AND (("exercise" [MeSH Terms] OR "exercise" [Title/Abstract]) OR ("sports" [MeSH Terms] OR "sports" [Title/Abstract] OR "sport" [Title/Abstract]) OR ("performance" [Title/Abstract]) OR "strength" [Title/Abstract] OR "anaerobic" [Title/Abstract] OR ("power" [MeSH Terms] OR "power" [Title/Abstract]) OR ("athletes" [MeSH Terms] OR "athletes" [Title/Abstract] OR "athlete" [Title/Abstract] OR "animal" [Title/Abstract] OR "mouse" [Title/Abstract] OR "mice" [Title/Abstract] OR "rabbit" [Title/Abstract] OR "pig" [Title/Abstract] OR "rat" [Title/Abstract] OR "mammals" [Title/Abstract] OR "mammal" [Title/Abstract] OR "cat" [Title/Abstract])). For the Scopus and Web of Science (WOS) databases, the following Boolean search equation was applied: ((TWK10 OR LP10) AND (exercise OR sport OR performance OR strength OR anaerobic OR power OR athlete)), with all search procedures finalized by the end of August 2023.

Text Screening and Data Extraction

The titles and abstracts of the initial search were screened by the investigator (M.N and M. AKH) based on the predetermined inclusion and exclusion criteria under the judgement of R.R. Subsequently, studies were chosen for evaluation if they met the following criteria: (1) *Lactobacillus plantarum* TWK10 supplementation, (2) an untrained population, (3) human or animal trials, (4) controlled with a placebo or control group, (5) access to the full text and (6) peer-reviewed and original articles written in English. Conversely, articles were excluded if they (1) combined probiotics with other supplements, (2) did not involve an untrained population, (3) lacked a placebo or control condition for comparison, (4) did not report pre and post-exercise information, or (5) were the review articles, unpublished abstracts, thesis, or dissertations.

The level of agreement between authors during the data screening and selection process was evaluated using Cohen's Kappa statistic to assess consistency and reduce bias in selecting relevant studies.

Risk of Bias Assessment

The revised Cochrane Risk of Bias tool for randomized trials (RoB2) was used to assess the risk of bias in the human-selected studies, while the SYRCLE risk of bias tool, modified from the Cochrane risk of bias framework, was used to evaluate the methodological quality of the animal-included studies. The evaluation was conducted by two reviewers, M.A.K. and M.N. Any conflicts were resolved by a third researcher, R.R.

Results

Article Selection and Characteristics

Based on the predetermined inclusion criteria, a systematic search yielded a total of 8 studies that met the criteria for inclusion in this review. It is worth noting that the chosen articles all underwent rigorous double-blind randomized clinical trials (RCTs) (Figure 1).

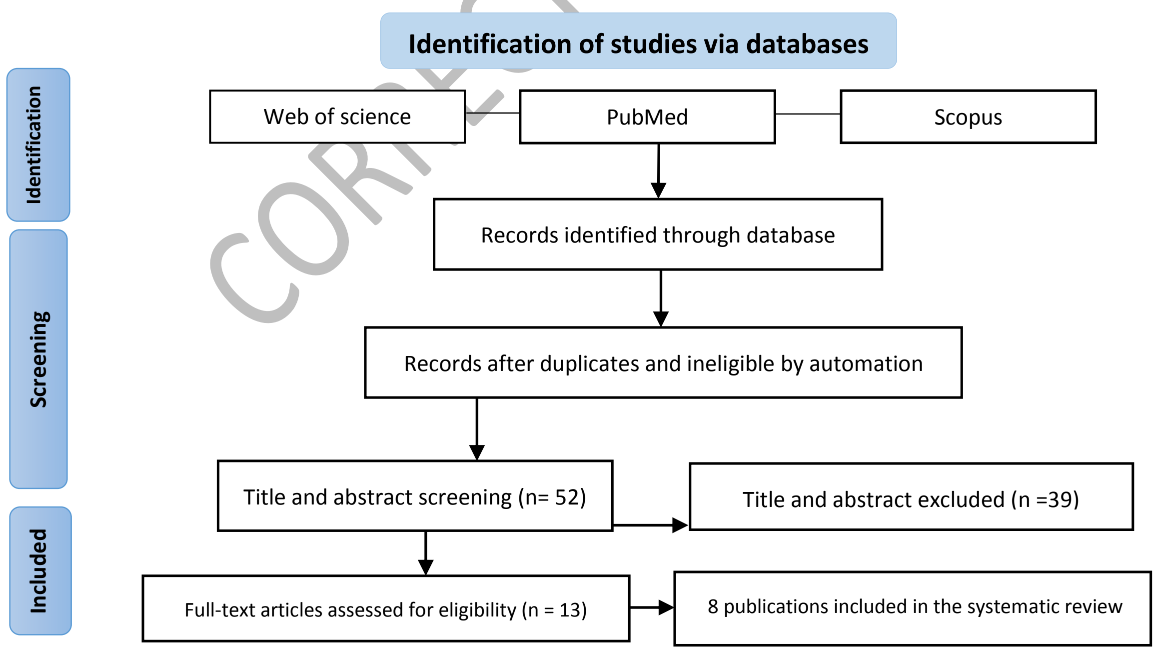

Figure 1. PRISMA flow diagram of the article selection.

Upon careful review of the 8 chosen studies, it was found that 5 of them concentrated on human samples (16, 21, 23, 25, 26), with the remaining 3 studies focusing on animal samples (24, 27). The human studies enrolled a total of 208 participants with an average sample size of 30 people, whereas the animal studies utilized 63 with an average sample size of 20 mice as experimental subjects. Out of all the publications with human samples, only three (16, 25, 28) chose samples from both sexes, while the remaining two (21, 24, 26, 27) exclusively selected samples from men. In all cases, the participants were characterized as amateur athletes without any formal professional sports training background.

Especially relevant to this review, the study population generally consisted of healthy individuals without any underlying medical conditions. However, it is important to note that only one study included participants between the ages of 55 and 85, who had bone fractures ranging from 1 to 4 degrees as an additional characteristic. The duration of the interventions examined in the selected studies varied based on the study protocols. The interventions lasted from a minimum of 6 weeks to a maximum of 18 weeks. The full characteristic data of included articles in this systematic review can be found in Table 2 and Table 3.

Table 2. Summary of human randomized clinical trials of *L.plantarum* TWK10 supplementation for sport performance in comparison of placebo control.

	Authors	Year	Type of Study	Participants (n, age & sex)	Health status	Type of *L.plantarum* TWK10	Intervention (duration and dosage)	Control group	Outcome measures
1	Wen-Ching Huang et al (26).	2018	RCT	16 male adults between 20–40 years old	Healthy people without professional athletic training	Capsule form made from Taiwanese pickled vegetables	6 weeks Two groups: 1×10^{11} CFU L.plantarum TWK10	–	↑Time to exhaustion, glucose, ↔RPE, lactate, ammonia, CK, ffa, VO2max.
2	Wen-Ching Huang et al (28).	2019	RCT	54 participants (27 men and 27 women) aged 20–30 years old	Healthy people without professional athletic training	Capsule form	6 weeks 3 groups based on V02max (18 people/group): placebo, 3×10^{10} CFU/daily, and 9×10^{10} CFU/daily	Placebo	Dose-dependently: ↑Time to exhaustion, serum glucose during exercise, muscle mass by high dose, ↔weight, BMI, CK In the exercise or recovery phase: ↓Serum lactate, serum ammonia.
3	1.3.1. Mon-Chien Lee et al (25).	2021	RCT	55 people 55–85 years old	Healthy people	Capsule format	18 weeks 3 groups: 2×10^{10} CFU/daily(n=12), And 6×10^{10} CFU/daily (n=13)	Placebo	↔Hand grip strength, 10-meter walk test, 30-second chair stand test, muscle mass fat mass, Bone mineral density

	Authors	Year	Type of Study	Participants (n, age & sex)	Health status	Type of *L.plantarum* TWK10	Intervention (duration and dosage)	Control group	Outcome measures
4	1.3.2. Chia-Chia Lee et al (16).	2022	RCT	53 adults (26 men and 27women) aged 20–30 years old	Healthy people without professional athletic training	-	6 weeks 3 groups: viable TWK10 3 × 10^{11} CFU /daily, And heat-killed TWK10, 3 × 10^{11} CFU/daily And Placebo	Placebo	In both TWK10-hk and viable TWK10: ↔Creatine kinase, lactate, ammonia, glucose ↑time to exhaustion, SCFA, BMI In the viable TWK10: ↓ fat mass,↑muscle weight In the TWK10-hk: ↓NLR and PLR
5	Yi-Chen Cheng et al (21).	2023	RCT	Thirty healthy males aged 20–40 years	Healthy males without professional athletic training	isolated from Taiwanese pickled cabbage, in capsule form	6-weeks Two groups based on V02max levels: Heat-killed TWK10, 1.5×10^{10} CFU/ daily	Control	↑exercise endurance time in the TWK10-HK, The grip strength on the right and left hands, muscle weight ↓serum lactate, and ammonia ↔BW, BMI, body fat mass, NLR and PLR

Abbreviations: RCT, Randomized Controlled Trial; CFU, Colony Forming Units;↑, incresed;↓,decreased;↔ not changed; CK, Creatine Kinase; BUN, Blood Urea Nitrogen; TG, triglycerides; RPE, Rate of Perceived Exertion; number; BMI, Body Mass Index; BAT, Brown Adipose Tissues; BW, Body Weight; SCFA, Short-chain fatty acids; ICR, Institute of Cancer Research; TP, Total Protein; UA, Uric Acid; TC, Total Cholesterol; FFA, Free Fatty Acid; BV/TV, Bone Volume Fraction; Tb. N, Trabecular Number; EFP, Epididymal Fat Pad; Tb.Sp, Trabecular Spacing; NLR, Neutrophil to Lymphocyte Ratio; PLR, Platelet to Lymphocyte Ratio; LP10, *L. plantarum* TWK10;

Table 3. Summary of animal randomized clinical trials of *L.plantarum* TWK10 supplementation for sport performance in comparison of placebo control.

	Authors	Year	Type of Study	Participants (n, age & sex)	Health status	Type of *L.plantarum* TWK10	Intervention (duration and dosage)	Control group	Outcome measures
1	**Yi-Ming Chen et al** (22).	2016	RCT	24 male (ICR) strain mice	Healthy mice	liquid bacterial suspension, Isolated from Taiwanese fermented cabbage	6 weeks assigned to 3 groups (8 mice/group): Vehicle And 2.05 × 10^8 CFU/kg/daily And 1.03 × 10^9 CFU/kg/daily	Placebo	**Dose-dependently:** ↑exercise performance, swimming performance, forelimb grip strength, ↓physical fatigue, **During the exercise**: ↓serum lactate, ammonia, ck level, ↔glucose, serum BUN **End of the exercise:** ↓serum BUN, albumin, TG,↔CK, TP, creatinine, UA, TC, glucose

	Authors	Year	Type of Study	Participants (n, age & sex)	Health status	Type of *L.plantarum* TWK10	Intervention (duration and dosage)	Control group	Outcome measures
2	**Wen-Ching Huang et al** (52).	2019	RCT	6-8 Male C57BL/6JNarl mice (6 weeks old	Healthy mice	Gavage	6weeks 2groups 10×10^9 CFU /0.5 mL every weeks	Control	↔ to Time exhaustion, CK, glucose, muscle glycogen level ↑BMR, physical activities ↓ lactate, ammonia
3	**Chia-Chia Lee et al** (25).	2021	RCT	33 male ICR mice were grouped by age into the young (age 4 months; n = 17) and the aged groups (age 19–22 months; n = 16) and each group was assigned to TWK10 or placebo	Healthy mice	liquid bacterial suspension, isolated from Taiwanese pickled cabbage	8 weeks 2 groups: 1×10^9 CFU/daily And vehicle	Placebo	↔BW, BAT, muscle weight, ↑glycogen, grip strength, BV/TV, Tb. N, BAT, SCFA, ↓EFP, abdominal fat, Tb. Sp

Abbreviations: RCT, Randomized controlled trial; CFU, Colony Forming Units;↑, incresed;↓,decreased;↔ not changed; CK, Creatine Kinase; BUN, Blood Urea Nitrogen; TG, Triglycerides ;RPE, Rate of Perceived Exertion number; BMI, Body Mass Index; BAT, Brown Adipose Tissues; BW, Body Weight; SCFA, Short-Chain Fatty Acids; ICR, Institute of Cancer Research; TP, Total Protein; UA, Uric Acid; TC, Total Cholesterol; FFA, Free Fatty Acid; BV/TV, Bone Volume fraction; Tb. N, Trabecular Number; EFP, Epididymal Fat Pad; Tb.Sp, Trabecular Spacing; NLR, Neutrophil to Lymphocyte Ratio; PLR, Platelet to Lymphocyte Ratio; LP10, *L. plantarum* TWK10; BMR, Basal Metabolic Rate;

Assessment the Risk of Bias

Regarding the risk of bias assessment, out of the five human studies included in this systematic review, one study exhibited a high risk of bias, two studies demonstrated a low risk of bias, and two studies were categorized as having a moderate risk of bias. This variability in risk levels highlights the potential impact of study design and methodology on the overall validity of the findings (Table 4).

Table 4. Quality assessment of clinical trials (according to the Cochrane guideline) included in the current study

Study	Sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective outcome reporting	Other potential threats to validity	General risk of bias
Mon-Chien Lee et al.2021	U	H	L	U	L	L	L	Low
Wen-Ching Huang et al.2019	U	U	L	H	L	L	L	Low
Wen-Ching Huang et al.2018	U	H	L	H	L	L	H	High
Wen-Ching Huang et al.2021	U	U	U	H	L	L	H	Moderate
Yi-Chen Cheng et al.2023	U	U	L	H	L	H	L	Moderate

Abbreviations: L, low risk; U, unclear risk; H, high risk based on the Cochrane Collaboration's tool for assessing risk of bias qualitatively

The SYRCLE risk of bias tool was used to assess the methodological quality of the included animal studies. This tool evaluates key areas of potential bias, such as reporting bias, detection bias, performance bias, selection bias, and other relevant factors. The highest possible score for each study was 10. Out of the three animal studies included in this review, two studies received a score of 3, indicating a moderate risk of bias, while one study received a score of 2, indicating a higher risk of bias (Table 5).

Table 5. Quality assessment of animal trials (according to the SYRCLE guideline) included in the current study

Study	Sequence generation	Baseline characteristics	Allocation concealment	Random housing	Blinding researchers	Random assessment	Blinding outcome assessors	Incomplete outcome data	Selective outcome reporting	Others	Total
Yi-Ming Chen et al.2016	H	U	U	H	H	U	H	L	L	L	3
Chia-Chia Lee et al.2022	U	U	H	H	H	U	H	L	L	L	3
Wen-Ching Huang et al.2019	H	L	H	H	H	H	H	L	U	U	2

Abbreviations: L, low risk; U, unclear risk; H, high risk based on the SYRCLE Collaboration's tool for assessing risk of bias qualitatively

Outcome

Effect of TWK 10 supplementation on performance

Animal research has revealed that TWK 10 supplementation can bolster grip strength in both young and elderly rats, (24, 29) even without additional training (22). However, when it comes to human studies, the results are conflicting (25). On the topic of gait balance, a study on individuals consuming high doses of the 10 displayed promising results, showing significant improvements in the 3 m timed up-and-go test. However, the 10 m walk test and the 30 s chair stand test, which assesses walking ability, lower-limb muscle strength, and endurance, did not show any significant positive effects from supplement consumption when compared to a placebo. (25). In conclusion, while animal studies suggest potential benefits of TWK 10 supplementation on grip strength, human studies have been inconsistent. Furthermore, although TWK 10 consumption has shown positive effects on gait balance in the elderly, it does not appear to significantly improve walking ability and lower-limb muscle strength and endurance. Further research is required to gain a deeper understanding of the specific mechanisms involved in TWK 10's impact on muscle strength improvement.

Another investigation on mean exhaustion times found that both TWK 10 and heat-killed TWK 10 groups demonstrated significantly higher mean exhaustion times compared to a control group (16, 21). Nevertheless, the overall understanding of how TWK 10 supplementation affects muscle strength and its underlying mechanism remains limited due to extensive research.

The Effect of Supplementation with TWK 10 on Exercise Performance in Weighted Swimming Test

In an animal study investigating fatigue indicators, it was noted that endurance swimming time exhibited a dose-dependent rise (22). This observation indicates the importance of assessing endurance during exercise as a key indicator of fatigue levels. Additional investigation is warranted to delve into the underlying mechanisms and the potential implications of these findings in human subjects.

Effect of Supplementation with TWK 10 on Serum Levels of Serum Lactate, Ammonia, Glucose, CK and BUN Levels after an Acute Exercise Test

The assessment of muscle fatigue resulting from exercise can be performed through the analysis of serum levels of lactate, ammonia, glucose, CK, and BUN factors (30, 31). An animal study revealed that serum levels of lactate, ammonia, and creatine kinase decreased in a dose-dependent manner following six weeks of supplementation in an acute exercise test.

However, urea and glucose levels did not exhibit significant changes (22).

In human studies, conflicting findings were reported regarding the impact of TWK 10 on lactate levels, with some indicating no significant effect (16, 26). In contrast, others showed improved lactate accumulation during exercise and recovery compared to a placebo group (21, 23). The effect of TWK 10 on ammonia levels also yielded contradictory results, with some studies reporting no significant effect (16, 26), and others showing reduced ammonia accumulation during exercise and recovery compared to a placebo group (21, 23).

Among human studies, supplementation with TWK 10 did not result in significant changes in levels of CK, FFA, AST, ALT, BUN, CREA, UA, glycerol, and vo2max compared to the placebo group (16, 23, 26). However, there were some discrepancies in the effect on glucose levels, as some studies showed a significant increase during exercise stimulation between groups (23, 26) while others found no significant differences (16). In an animal study, no significant changes were observed in BUN, albumin, TG, CK, TP, creatinine, UA, TC, and glucose levels after an acute exercise test (22). In terms of bone quality restoration indicators, the administration of TWK10 resulted in a notable increase in Tb. N in both young and old mice compared to control mice (24).

In summary, the effects of TWK 10 supplementation on various indicators of muscle fatigue have shown mixed results, with some positive impacts such as decreased lactate and ammonia accumulation and increased time to exhaustion. However, the effects on glucose concentrations remain inconclusive. Additionally, TWK 10 has demonstrated potential benefits in improving bone quality. Further research is necessary to comprehensively understand the mechanisms and overall efficacy of TWK 10 supplementation concerning muscle fatigue and bone health.

Other General Features after Supplementation with TWK 10

Studies have shown that the administration of viable or heat-killed TWK10 leads to an increase in the abundance of SCFA-producing bacteria and a significant increase in the concentration of short-chain fatty acids in both young mice and humans (16, 24). In young mice, supplementation with TWK10 resulted in a dose-dependent decrease in the weight of the epididymal fat pad and the mean abdominal fat mass, as well as an increase in the relative weight of muscles such as the gastrocnemius and soles (24, 29) Additionally, TWK10 supplementation was found to increase the amount of type 1 muscle fibers in the gastrocnemius muscle in a dose-dependent manner (22). Furthermore, some studies showed that supplementation with TWK 10 does not have a significant effect on the weight of the gastrocnemius muscle in either young or old rats. Still, the level of glycogen in young and old rats increased after taking the supplement, which can be related to the increase in the strength of the front limb. However, the total body weight did not change significantly (24).

Human studies have also indicated that TWK10 supplementation can increase muscle mass and decrease fat mass (16, 23) However, there were no significant differences in body weight and BMI among the groups (16, 21, 23). In elderly individuals, supplementation with TWK10 did not yield any significant changes in body composition or bone mineral density compared to placebo (25). Studies have shown that supplementation with TWK 10 has no significant effect on the RPE index, although the TWK 10 group had lower RPE than the placebo group (26).

Regarding the effects of TWK10 on exercise-induced inflammatory responses (32), studies demonstrated that there was no significant decrease in NLR and PLR indices in TWK10 receiving groups compared to placebo (23). However, the findings for heat-killed TWK10 yielded conflicting results (16, 21).

It should be noted that the impact of diet on the microbiome and gut health of endurance athletes should be considered in the interpretation and comparison of study results (33). The amount of fibre consumed plays a crucial role in gut health, as it affects transit time, stool frequency, and the production of SCFAs by microbiota (34, 35).

In conclusion, the administration of TWK10 has demonstrated beneficial effects on gastrointestinal well-being and body structure in both young mice and humans. Nonetheless, its impact on total body weight and inflammatory reactions may exhibit variations. Additional research is required to completely comprehend the potential advantages of TWK10 supplementation in diverse demographics and exercise scenarios.

Discussion

This analysis reviewed interventions carried out between 2013 and 2023, illustrating the growing interest in using *Lactobacillus plantarum* TWK10 probiotic supplementation for exercise and physical activity. These interventions focused on investigating the impact of probiotics on various functional traits in untrained individuals and animal models. Collectively, the studies revealed positive effects of TWK10 probiotic supplementation on athletic performance, although not always statistically significant.

Notably, single-strain TWK 10 probiotic products demonstrated favourable effects on endurance, body composition, and fatigue recovery. Furthermore, research indicates that the effects of this strain may depend on the dosage (22, 23, 25).

Until recently, the influence of probiotic supplementation on exercise performance and muscle strength had been largely unexplored. However, recent studies have shown that LP10 supplementation increased muscle mass, forelimb grip strength, and muscle explosive power in the absence of a structured training protocol. LP-10 supplements increased intestinal SCFA content (16, 24). These SCFAs affect lipid, glucose, and cholesterol metabolism in various tissues and maintain intestinal integrity. Activating peroxisome proliferator-activated receptor γ coactivator 1α (PGC-1α) initiates the process of adenosine triphosphate (ATP) production, consequently providing the necessary energy for physical exercise and augmenting the overall performance in endurance-based physical activities (36). These may justify the possible mechanisms in the field of increasing muscle mass and strength (35). Additionally, in earlier studies, the administration of Lactobacillus was found to decrease the presence of atrophy markers (37); therefore, it has been suggested that the gut microbiota could impact muscle metabolism (38) and might represent a potential therapeutic focus in addressing muscle wasting. Systemic inflammatory cytokines and the restoration of Lactobacilli levels were observed to decrease the indicators of the autophagy-lysosomal pathway, a significant protein breakdown system in the gastrocnemius and tibialis muscles (39). Consequently, based on our current findings, the supplementation of LP10 resulted in amplified muscle mass, leading to improved forelimb grip strength. These findings suggest promising potential for the use of probiotics to enhance athletic performance, particularly in the areas of endurance, body composition, and muscle strength (22, 24).

Physical activity, being a stressor for the body, triggers inflammatory reactions by stimulating the release of pro-inflammatory cytokines and reactive oxygen species from activated white blood cells, ultimately leading to muscle and tissue damage (40-43). Previous research has demonstrated a notable decrease in NLR and PLR values (16), which serve as indicators of exercise-induced systemic inflammatory responses (32), in individuals administered a high dose of heat-killed TWK10 compared to those given a low dose (21). This finding supports earlier studies suggesting that the anti-inflammatory effects of probiotics are contingent on the dosage administered (44-46). However, more research on energy metabolism and gut microbiota is needed to better understand the underlying mechanisms involved in the regulation of body composition by live and heat-killed TWK10.

LP10 supplementation may have the ability to remove and use blood lactate after exercise (22, 23). Lactic acid, a fatigue-associated factor in exercise, is generated through the glycolytic pathway (47). Through the studies, it is understood that TWK10 primarily supports the energy demands of exercise by enhancing the oxidation of fatty acids instead of the degradation of glucose, consequently leading to a decrease in lactic acid production (21). During intense physical activity, ammonia, a byproduct of the metabolism of nitrogen-containing compounds, is regarded as a contributing factor to the initiation of fatigue induced by exercise (48). These cellular byproducts are capable of inducing muscular fatigue via intracellular acidification within the organism (49). Hence, to recuperate from exercise-induced fatigue, it is imperative to facilitate the repair of bodily damage and expel the accumulated exercise-related metabolites. In the current research, the application of heat-killed and viable TWK10 diminishes post-exercise ammonia formation (21, 27, 28) and expedites muscle recuperation. Therefore, the use of heat-killed TWK10 is linked to potential anti-fatigue advantages by curbing lactate and ammonia generation during physical activity.

Given the predominantly favorable findings thus far, additional research could be valuable in assessing the potential enhancement of physical performance through probiotic use while considering the potential performance-enhancing effects of probiotics (50, 51).

Strengths

This systematic review investigate a relatively new field of research and provides robust evidence, derived from randomized studies. The inclusion of various functional tests and different performance measures strengthens the validity of the findings, offering insights into the potential benefits of *Lactobacillus plantarum* TWK10 supplementation for athletic performance.

Limitations

A significant limitation of the studies reviewed is the lack of control over participants' physical activity levels, making it difficult to compare results across studies. Additionally, most of the research focused primarily on the effects of probiotics on intestinal health, with limited exploration of their impact on broader performance aspects.

Conclusion

In summary, findings from the examined studies indicate that supplementation with the single-strain LP10 probiotic is likely to result in enhancements in specific aspects of performance, such as endurance, strength, conditions, and performance-related physical features, including muscle soreness and body composition. Nevertheless, the diversity among the existing studies precludes us from making conclusive determinations on this matter. While interest in this area of research is growing, it remains challenging to make direct comparisons between the available studies to establish robust evidence. Further controlled and comparative studies are necessary to substantiate the impact of LP10 supplementation on athletic performance.

Clinical Implications

The positive effects of *Lactobacillus plantarum* TWK10 supplementation on endurance, muscle strength, and body composition suggest its potential as a beneficial adjunct in sports nutrition. Probiotics may help enhance performance and recovery, particularly for athletes or individuals seeking improved physical outcomes.

Future Directions

Future research should focus on controlling for physical activity levels to ensure consistent results. Additionally, exploring the mechanisms of probiotics on muscle metabolism and recovery, and studying long-term effects in athletes, will help clarify their role in optimizing athletic performance.

Declarations

Funding

The Current study has received no funds.

Author Contribution

MN and MAK conducted the updated literature searches. MN and FD participated in screening and analyzing the retrieved references. MAK, FD, and MSF conducted independent review and scoring of all papers, with access to all data. RR and MN prepared an outline and revised subsequent paper drafts. MN, RR, and MSF further revised the outline and subsequent drafts. All authors have approved the final version of the article and its authorship list.

Conflicts of Interest

There is none to declare.

References

1. Peeling P, Binnie MJ, Goods PSR, Sim M, Burke LM. Evidence-Based Supplements for the Enhancement of Athletic Performance. Int J Sport Nutr Exerc Metab. 2018;28(2):178-87.
2. Jang L-G, Choi G, Kim S-W, Kim B-Y, Lee S, Park H. The combination of sport and sport-specific diet is associated with characteristics of gut microbiota: an observational study. Journal of the International Society of Sports Nutrition. 2019;16(1):21.
3. Clark A, Mach N. Exercise-induced stress behavior, gut-microbiota-brain axis and diet: a systematic review for athletes. Journal of the International Society of Sports Nutrition. 2016;13(1):43.
4. Maughan RJ, Burke LM, Dvorak J, Larson-Meyer DE, Peeling P, Phillips SM, et al. IOC Consensus Statement: Dietary Supplements and the High-Performance Athlete. Int J Sport Nutr Exerc Metab. 2018;28(2):104-25.
5. Sekirov I, Russell SL, Antunes LCM, Finlay BB. Gut microbiota in health and disease. Physiological Reviews. 2010.
6. Neish AS. Microbes in gastrointestinal health and disease. Gastroenterology. 2009;136(1):65-80.
7. Chiller K, Selkin BA, Murakawa GJ. Skin microflora and bacterial infections of the skin. The Journal of

Investigative Dermatology Symposium Proceedings. 2001;6(3):170-4.
8. Ley RE, Peterson DA, Gordon JI. Ecological and evolutionary forces shaping microbial diversity in the human intestine. Cell. 2006;124(4):837-48.
9. Monda V, Villano I, Messina A, Valenzano A, Esposito T, Moscatelli F, et al. Exercise Modifies the Gut Microbiota with Positive Health Effects. Oxidative Medicine and Cellular Longevity. 2017;2017:1-8.
10. Marttinen M, Ala-Jaakkola R, Laitila A, Lehtinen MJ. Gut microbiota, probiotics and physical performance in athletes and physically active individuals. Nutrients. 2020;12(10):2936.
11. Powers ME, Yarrow JF, McCoy SC, Borst SE. Growth hormone isoform responses to GABA ingestion at rest and after exercise. Med Sci Sports Exerc. 2008;40(1):104-10.
12. Pugh JN, Wagenmakers AJ, Doran DA, Fleming SC, Fielding BA, Morton JP, et al. Probiotic supplementation increases carbohydrate metabolism in trained male cyclists: A randomized, double-blind, placebo-controlled crossover trial. American Journal of Physiology-Endocrinology and Metabolism. 2020;318(4):E504-13.
13. Kiela PR, Ghishan FK. Physiology of Intestinal Absorption and Secretion. Best Practice & Research Clinical Gastroenterology. 2016;30(2):145-59.
14. Holscher HD. Dietary fiber and prebiotics and the gastrointestinal microbiota. Gut Microbes. 2017;8(2):172-84.
15. Gauchard GC, Gangloff P, Vouriot A, Mallie J-P, Perrin PP. Effects of exercise-induced fatigue with and without hydration on static postural control in adult human subjects. International Journal of Neuroscience. 2002;112(10):1191-206.
16. Lee CC, Liao YC, Lee MC, Cheng YC, Chiou SY, Lin JS, et al. Different Impacts of Heat-Killed and Viable Lactiplantibacillus plantarum TWK10 on Exercise Performance, Fatigue, Body Composition, and Gut Microbiota in Humans. Microorganisms. 2022;10(11).
17. Li S, Zhao Y, Zhang L, Zhang X, Huang L, Li D, et al. Antioxidant activity of Lactobacillus plantarum strains isolated from traditional Chinese fermented foods. Food Chemistry. 2012;135(3):1914-9.
18. Kaushik JK, Kumar A, Duary RK, Mohanty AK, Grover S, Batish VK. Functional and probiotic attributes of an indigenous isolate of Lactobacillus plantarum. PloS One. 2009;4(12):e8099.
19. Su K-Y, Yu CY, Chen Y-W, Huang Y-T, Chen C-T, Wu H-F, et al. Rutin, a flavonoid and principal component of Saussurea involucrata, attenuates physical fatigue in a forced swimming mouse model. International Journal of Medical Sciences. 2014;11(5):528.
20. Wu R-E, Huang W-C, Liao C-C, Chang Y-K, Kan N-W, Huang C-C. Resveratrol protects against physical fatigue and improves exercise performance in mice. Molecules. 2013;18(4):4689-702.
21. Cheng YC, Lee CC, Lee MC, Hsu HY, Lin JS, Huang CC, et al. Effects of heat-killed Lactiplantibacillus plantarum TWK10 on exercise performance, fatigue, and muscle growth in healthy male adults. Physiological Reports. 2023;11(19):e15835.
22. Chen YM, Wei L, Chiu YS, Hsu YJ, Tsai TY, Wang MF, et al. Lactobacillus plantarum TWK10 Supplementation Improves Exercise Performance and Increases Muscle Mass in Mice. Nutrients. 2016;8(4):205.
23. Huang WC, Lee MC, Lee CC, Ng KS, Hsu YJ, Tsai TY, et al. Effect of Lactobacillus plantarum TWK10 on Exercise Physiological Adaptation, Performance, and Body Composition in Healthy Humans. Nutrients. 2019;11(11).
24. Lee CC, Liao YC, Lee MC, Lin KJ, Hsu HY, Chiou SY, et al. Lactobacillus plantarum TWK10 Attenuates Aging-Associated Muscle Weakness, Bone Loss, and Cognitive Impairment by Modulating the Gut Microbiome in Mice. Frontiers in Nutrition. 2021;8.
25. Lee MC, Tu YT, Lee CC, Tsai SC, Hsu HY, Tsai TY, et al. Lactobacillus plantarum TWK10 Improves Muscle Mass and Functional Performance in Frail Older Adults: A Randomized, Double-Blind Clinical Trial. Microorganisms. 2021;9(7).
26. Huang WC, Hsu YJ, Li H, Kan NW, Chen YM, Lin JS, et al. Effect of Lactobacillus Plantarum TWK10 on Improving Endurance Performance in Humans. The Chinese journal of physiology. 2018;61(3):163-70.
27. Chen Y-M, Wei L, Chiu Y-S, Hsu Y-J, Tsai T-Y, Wang M-F, et al. Lactobacillus plantarum TWK10 supplementation improves exercise performance and increases muscle mass in mice. Nutrients. 2016;8(4):205.
28. Huang W-C, Lee M-C, Lee C-C, Ng K-S, Hsu Y-J, Tsai T-Y, et al. Effect of Lactobacillus plantarum TWK10 on exercise physiological adaptation, performance, and body composition in healthy humans. Nutrients. 2019;11(11):2836.
29. Liu TH, Chiou J, Tsai TY. Effects of Lactobacillus plantarum TWK10-fermented soymilk on deoxycorticosterone acetate-salt-induced hypertension and associated dementia in rats. Nutrients. 2016;8(5).
30. Strojnik V, Komi PV. Fatigue after submaximal intensive stretch-shortening cycle exercise. Medicine and Science in Sports and Exercise. 2000;32(7):1314-9.
31. Izquierdo M, Gonzalez-Izal M, Navarro-Amezqueta I, Calbet JA, Ibanez J, Malanda A, et al. Effects of strength training on muscle fatigue mapping from surface EMG and blood metabolites. Medicine & Science in Sports & Exercise. 2011;43(2):303-11.
32. Walzik D, Joisten N, Zacher J, Zimmer P. Transferring clinically established immune inflammation markers into exercise physiology: focus on neutrophil-to-lymphocyte ratio, platelet-to-lymphocyte ratio and systemic immune-inflammation index. European Journal of Applied Physiology. 2021;121(7):1803-14.

33. Jones JM. CODEX-aligned dietary fiber definitions help to bridge the 'fiber gap'. Nutrition Journal. 2014;13(1):1-10.
34. Tap J, Furet JP, Bensaada M, Philippe C, Roth H, Rabot S, et al. Gut microbiota richness promotes its stability upon increased dietary fibre intake in healthy adults. Environmental Microbiology. 2015;17(12):4954-64.
35. Den Besten G, Van Eunen K, Groen AK, Venema K, Reijngoud D-J, Bakker BM. The role of short-chain fatty acids in the interplay between diet, gut microbiota, and host energy metabolism. Journal of Lipid Research. 2013;54(9):2325-40.
36. Clark A, Mach N. The crosstalk between the gut microbiota and mitochondria during exercise. Frontiers in Physiology. 2017;8:319.
37. Bindels LB, Beck R, Schakman O, Martin JC, De Backer F, Sohet FM, et al. Restoring specific lactobacilli levels decreases inflammation and muscle atrophy markers in an acute leukemia mouse model. PloS One. 2012;7(6):e37971.
38. Bindels LB, Delzenne NM. Muscle wasting: the gut microbiota as a new therapeutic target? The International Journal of Biochemistry & Cell Biology. 2013;45(10):2186-90.
39. White JP, Baynes JW, Welle SL, Kostek MC, Matesic LE, Sato S, et al. The regulation of skeletal muscle protein turnover during the progression of cancer cachexia in the ApcMin/+ mouse. PloS One. 2011;6(9):e24650.
40. Cerqueira É, Marinho DA, Neiva HP, Lourenço O. Inflammatory effects of high and moderate intensity exercise—a systematic review. Frontiers in Physiology. 2020;10:1550.
41. Silveira LS, Antunes BdMM, Minari ALA, Dos Santos RVT, Neto JCR, Lira FS. Macrophage polarization: implications on metabolic diseases and the role of exercise. Critical Reviews™ in Eukaryotic Gene Expression. 2016;26(2).
42. Suzuki K. Involvement of neutrophils in exercise-induced muscle damage and its modulation. Gen Intern Med Clin Innov. 2018;3:1-8.
43. Suzuki K. Chronic inflammation as an immunological abnormality and effectiveness of exercise. Biomolecules. 2019;9(6):223.
44. Evrard B, Coudeyras S, Dosgilbert A, Charbonnel N, Alamé J, Tridon A, et al. Dose-dependent immunomodulation of human dendritic cells by the probiotic Lactobacillus rhamnosus Lcr35. PLos One. 2011;6(4):e18735.
45. Ren J, Zhao Y, Huang S, Lv D, Yang F, Lou L, et al. Immunomodulatory effect of Bifidobacterium breve on experimental allergic rhinitis in BALB/c mice. Experimental and Therapeutic Medicine. 2018;16(5):3996-4004.
46. Sun Z, Li H, Li Y, Qiao J. Lactobacillus salivarius, a potential probiotic to improve the health of LPS-challenged piglet intestine by alleviating inflammation as well as oxidative stress in a dose-dependent manner during weaning transition. Frontiers in Veterinary Science. 2020;7:547425.
47. Brooks GA. The science and translation of lactate shuttle theory. Cell Metabolism. 2018;27(4):757-85.
48. Banister E, Allen M, Mekjavic I, Singh A, Legge B, Mutch BJ. The time course of ammonia and lactate accumulation in blood during bicycle exercise. European Journal of Applied Physiology and Occupational Physiology. 1983;51(2):195-202.
49. Donati Zeppa S, Agostini D, Gervasi M, Annibalini G, Amatori S, Ferrini F, et al. Mutual interactions among exercise, sport supplements and microbiota. Nutrients. 2019;12(1):17.
50. de Sire A, Marotta N, Lippi L, Scaturro D, Farì G, Liccardi A, et al. Pharmacological treatment for acute traumatic musculoskeletal pain in athletes. Medicina. 2021;57(11):1208.
51. Pyne DB, West NP, Cox AJ, Cripps AW. Probiotics supplementation for athletes–clinical and physiological effects. European Journal of Sport Science. 2015;15(1):63-72.
52. Huang WC, Chen YH, Chuang HL, Chiu CC, Huang CC. Investigation of the Effects of Microbiota on Exercise Physiological Adaption, Performance, and Energy Utilization Using a Gnotobiotic Animal Model. Frontiers in Microbiology. 2019;10:1906.