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Effects of tart cherry juice on exercise-induced muscle soreness and recovery: A systematic review and meta-analysis

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ABSTRACT

Background: Exercise-induced muscle damage is expected to cause delayed onset muscle soreness, inflammation, and decreased muscle function. Tart cherry juice supplementation has been explored for its anti-inflammatory and antioxidant effects, which are believed to assist in recovery as well as enhance muscle function. **Objective.** Integrate the evidence from published research to ascertain the effects of tart cherry juice supplementation on muscle function, recovery, and reduction of muscle damage, with specific reference to the key outcomes such as delayed onset muscle soreness, muscle strength, range of motion, and inflammatory and oxidative stress biomarkers. **Methods.** This was a systematic review and meta-analysis of the effectiveness of tart cherry juice supplementation on muscle soreness and recovery based on studies employing varied exercise protocols. A random-effects model was used to estimate MD with 95% CI between various outcomes, such as delayed onset muscle soreness, maximal voluntary isometric contraction, range of motion, inflammation (IL-6), and creatine kinase levels. **Results.** Tart cherry juice supplementation improved range of motion significantly (MD = 0.33, 95% CI [0.02, 0.65], $p = 0.04$) and decreased IL-6 levels significantly (MD = -0.34, 95% CI [-0.56, -0.12], $p = 0.003$) without heterogeneity ($I^2 = 0\%$). The impact on delayed onset muscle soreness was non-significant (MD = -0.47, 95% CI [-1.12, 0.18], $p = 0.16$) with minimal heterogeneity ($I^2 = 0\%$). Maximal voluntary isometric contraction and creatine kinase also had no significant improvements (MD = 0.64, $p = 0.33$; MD = -33.40, $p = 0.38$, respectively). Heterogeneity of outcomes was observed in subgroup analyses based on intervention protocols and recovery measures. **Conclusion.** Tart cherry juice improvement was moderate in enhancing range of motion and decreasing IL-6 levels, but its effectiveness on delayed onset muscle soreness, maximal voluntary isometric contraction, and creatine kinase was uncertain. Standardized dosing and extended follow-up durations are required in future research to revalidate these outcomes.

KEYWORDS: tart cherry juice, exercise-induced muscle damage, muscle recovery, inflammation, delayed onset muscle soreness, meta-analysis

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Воздействие сока вишни обыкновенной на вызванную физической нагрузкой мышечную боль и ее устранение: систематический обзор и метаанализ

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АННОТАЦИЯ

Введение. Предполагается, что поражение мышц, вызванное физической нагрузкой, вызывает синдром отсроченной мышечной болезненности. Введение в рацион сока вишни обыкновенной исследовалось с точки зрения его противовоспалительных и антиоксидантных свойств, способствующих как устранению синдрома, так и улучшению функционирования мышц. **Цель.** Объединить данные исследований, рассматривающих воздействие сока вишни обыкновенной на мышечную функцию, ее восстановление и снижение уровня повреждения мышечной ткани, с данными конкретных публикаций по таким ключевым факторам, как синдром отсроченной мышечной болезненности, мышечная сила, диапазон движений и биомаркеры воспаления и оксислительного стресса. **Методы.** Систематический обзор и метаанализ, представленные здесь, затрагивают эффективность воздействия сока вишни обыкновенной на мышечную боль и ее устранение на основе исследований, посвященных разнообразным регламентам физических упражнений. Для определения разницы средних значений (MD) результатов исследований, таких как синдром отсроченной мышечной болезненности, максимальное произвольное изометрическое сокращение, диапазон движения, воспаление (интерлейкин-6, IL-6) и уровень креатинкиназы, использовалась модель случайных эффектов с 95% ДИ. **Результаты.** Использование добавок с соком вишни обыкновенной способствовало значительному улучшению диапазона движения (MD = 0,33, 95% ДИ [0,02, 0,65], p = 0,04) и снижению уровня IL-6 (MD = -0,34, 95% ДИ [-0,56, -0,12], p = 0,003) без гетерогенности (I^2 = 0%). Воздействие на синдром отсроченной мышечной болезненности было незначительным (MD = -0,47, 95% CI [-1,12, 0,18], p = 0,16) с минимальной гетерогенностью (I^2 = 0%). Для максимального произвольного изометрического сокращения и уровня креатинкиназы заметных улучшений также не наблюдалось (MD = 0,64, p = 0,33; MD = -33,40, p = 0,38 соответственно). Гетерогенность результатов присутствовала в анализах подгрупп, основанных на протоколах вмешательства и мерах восстановления. **Заключение.** Улучшения, связанные с приемом добавок с соком вишни обыкновенной, были умеренными для увеличения диапазона движения и уменьшения уровня интерлейкина-6, однако его эффективность относительно синдрома отсроченной мышечной болезненности, максимального произвольного изометрического сокращения и уровня креатинкиназы остается неясной. В будущих исследованиях потребуются стандартизация дозы и продолжительное наблюдение для переподтверждения полученных результатов.

КЛЮЧЕВЫЕ СЛОВА: сок вишни обыкновенной, повреждение мышц, связанное с физической активностью, воспаление, синдром отложенной мышечной болезненности, метаанализ

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ДЕКЛАРАЦИЯ О НАЛИЧИИ ДАННЫХ: данные, подтверждающие выводы этого исследования, можно получить у контактного автора по обоснованному запросу. Данные и статистические методы, представленные в статье, прошли статистическое рецензирование редактором журнала — сертифицированным специалистом по биостатистике.

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INTRODUCTION

Exercise-induced muscle damage (EIMD) is a broad physiological phenomenon seen secondary to unaccustomed or high-intensity exercise, particularly with eccentric contractions of the muscle. EIMD is manifested as delayed onset muscle soreness (DOMS), reduction in muscle strength, inflammation, oxidative stress, and interference with recovery of muscular function. Severity of EIMD varies according to the intensity, duration, and mode of exercise, fitness level of the individual, and adopted recovery [1, 2]. DOMS in the form of pain and stiffness peaking at 24–72 hours after exercise is one of the most frequent reported features of EIMD. Besides affecting physical performance, it affects compliance to exercise training protocols and general athletic function [3].

Inflammatory and oxidative stress pathways play a central role in the etiology of EIMD. Muscle injury leads to the release of pro-inflammatory cytokines such as interleukin-6 (IL-6) and C-reactive protein (CRP) and production of reactive oxygen species (ROS) that augment injury to the tissues and prolong the recovery period. Elevated levels of serum creatine kinase (CK) and other markers are proof of interference with muscle cell integrity and help to highlight the need for countermeasures [4, 5]. Dietary interventions have been useful adjuncts to standard methods of recovery, and dietary polyphenols have been the subject of increasing interest due to their anti-inflammatory, antioxidant, and potential muscle-sparing properties [6].

Tart cherry juice (TCJ), derived predominantly from Montmorency cherries, is a good source of anthocyanins and other polyphenols with great antioxidant and anti-inflammatory activities. The bioactive compounds have been demonstrated to scavenge ROS, reduce tissue oxidative damage, and regulate inflammation, and hence TCJ may prove to be an ergogenic aid for the recovery from EIMD [7, 8]. Although earlier it has been reported that TCJ supplementation is effective in various types of exercise such as high-intensity intermittent sports, long-duration endurance exercise, and resistance exercise, the results of the studies have been conflicting with some studies showing significant improvement in recovery parameters like muscle strength, DOMS, and biochemical markers, and others showing minimal or no effects [9–12].

The differences in study designs, dosing protocols, and exercise protocols in the present literature warrant a systematic review and meta-analysis to critically evaluate the efficacy of TCJ.

The **aim of this review** was to integrate the evidence from published research to ascertain the effects of TCJ supplementation on muscle function, recovery, and reduction of muscle damage, with specific reference to the key outcomes such as DOMS, muscle strength, ROM, and inflammatory and oxidative stress biomarkers.

METHODS

Study Design

The present systematic review and meta-analysis was based on the PRISMA guidelines [15] and was designed to summarize the evidence assessing the effectiveness of TCJ supplementation on muscle soreness and recovery after exercise, obtained from studies using different exercise protocols. The Study Design (S) was randomized controlled trials (RCTs), crossover trials, and placebo-controlled trials.

Eligibility criteria

Inclusion Criteria

Inclusion criteria were studies that (1) were RCTs or crossover trials, (2) had participants who participated in physical activities that were aimed to induce exercise-induced muscle damage (EIMD), (3) compared the effect of tart cherry juice or similar interventions against control or placebo, and (4) had reported outcomes that were associated with muscle soreness, muscle performance, inflammation, or markers of oxidative stress. Only English-language studies were considered, without limit of publication date or region.

Exclusion Criteria

Exclusion criteria ruled out studies that (1) were observational or non-interventional studies, (2) were animal model studies, (3) were non-cherry-based interventions, (4) lacked a placebo or control group, (5) lacked adequate data for statistical analysis, or (6) did not conform to the predefined PICOS framework. Case reports, conference abstracts, and reviews were also ruled out.

Information Sources

Database searching was conducted in seven databases: PubMed, Scopus, Web of Science, Cochrane Library, Embase, CINAHL, and SPORTDiscus. The analysis of literature sources covered 15 years (from 2009 to 2024). A search was also conducted for earlier works to analyze unidentified data, but the search depth did not exceed 20 years.

Search Strategy

Boolean operators (AND, OR) and Medical Subject Headings (MeSH) terms were applied in the development of search strategies. Keywords such as “tart cherry juice,” “Montmorency cherry,” “exercise-induced muscle damage,” “delayed onset muscle soreness,” “DOMS,” “muscle recovery,” “inflammation,” “oxidative stress,” and “creatine kinase” were employed. For example, the PubMed search employed the string: (“tart cherry juice” OR “Montmorency cherry”) AND (“exercise-induced muscle damage” OR “DOMS”) AND (“muscle recovery” OR “inflammation”). Truncation symbols (*) and adjacency operators were employed where appropriate to enable term variations and enhance comprehensiveness.

Selection process

PECOS protocol was structured to give a systematic and extensive inclusion and analysis process of studies in this review, as per PRISMA 2020 guidelines [13]. Population (P) were individuals of any sex or age who took part in physical exercise known to induce muscle soreness or damage. Exposure (E) was tart cherry juice, Montmorency cherry juice, or cherry-based polyphenol-rich supplements equivalent. Comparator (C) was control, placebo, or no supplement. The Outcomes (O) assessed were increases in muscle performance, delayed onset muscle soreness (DOMS), range of motion (ROM), muscle strength, inflammation (IL-6), markers of oxidative stress, and creatine kinase (CK).

Data Extraction Protocol and Data Items

Data were extracted in a systematic fashion using a pre-defined template in order to ensure consistency. Data items extracted included (1) author name, year of study, and location of study, (2) study design and sample size, (3) participant demographics, (4) type of intervention, dosage, and duration, (5) exercise protocol, (6) primary outcomes such as DOMS, MVIC, ROM, and biochemical markers (IL-6, CK, oxidative stress markers), (7) timepoints for assessment, and (8) statistical findings, including mean differences, confidence intervals, and *p*-values. Disagreements on data extraction were resolved through discussion between reviewers.

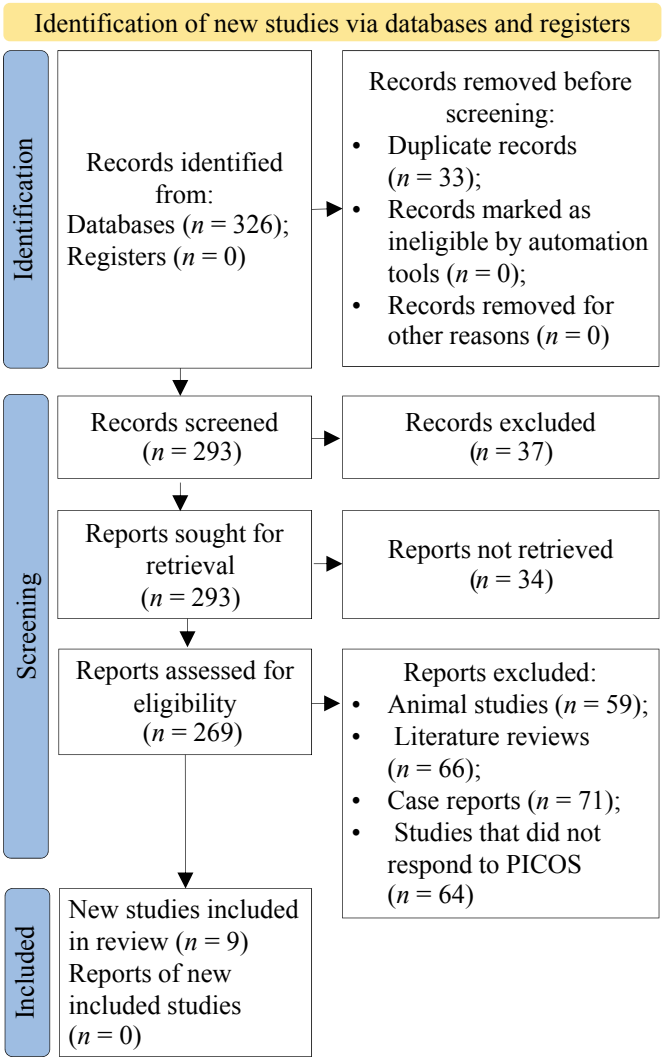

Fig. 1. Description of the different stages of article selection process for the review

Note: The block diagram was created by the authors (as per PRISMA recommendations).

Рис. 1. Описание различных этапов процесса выборки статей для обзора

Примечание: блок-схема выполнена авторами (согласно рекомендациям PRISMA).

Synthesis methods

Bias Assessment Protocol

Risk of bias was established using the Cochrane Risk of Bias 2.0 (RoB 2.0) tool [14]. Bias was evaluated by the tool across five domains: (1) process of randomization, (2) deviations from the intended interventions, (3) missing data, (4) outcome measurement, and (5) selection of reported outcomes. Each of the domains was evaluated as low risk, some concerns, or high risk, and global risk of bias was established for each study. Disagreement between the reviewers was resolved by consensus to ensure reliability of evaluation.

Meta-Analysis Protocol

Meta-analysis was conducted using RevMan 5 (v 5.4.1) to estimate pooled efficacy of TCJ on improving muscle performance and reducing DOMS. Forest plots were generated to report mean differences (MD) and 95% confidence intervals (CI) of primary outcomes such as MVIC, ROM, DOMS, IL-6, and CK levels. A random-effects model was employed to permit study heterogeneity. Heterogeneity was explored by the Chi² test and I^2 statistic with cut-offs for I^2 as low (<25%), moderate (25–50%), or high (>50%). Subgroup analysis was performed based on dosing regimens and exercise protocols. Statistical significance was at $p < 0.05$. Results showed a thorough evaluation of TCJ's efficacy to prevent EIMD and improve recovery outcomes.

RESULTS

Study selection

For this review's study selection procedure (Fig. 1), we followed the PRISMA 2020 protocol to ensure a procedure that was transparent and systematic. 33 duplicates were removed, which meant 293 papers underwent screening. At this stage, no records were excluded. Later, all 293 records received an auditing for retrieval, until 24 could not be found. Of the remaining 269 records, 59 were excluded as being animal studies, 66 were literature reviews, 71 were case reports, and 64 studies were not fulfilling the PICOS criteria. Finally, nine studies [15–23] were selected for this review.

Results of individual studies

Study Design and Population Characteristics

The included studies varied in methodological design (Table 1), the most common of which were randomized, placebo-controlled trials, conducted in double-blind [15, 16, 19, 20, 22, 23] and single-blind [21, 23] designs, and crossover trials [15, 17, 18, 21, 22]. The trials were conducted between 2007 [18] and 2023 [15, 22, 23], representing increasing research interest in the potential effect of tart cherry juice supplementation on the over-time trend in muscle recovery. The sample sizes varied across studies from 10 participants in a crossover study [15, 17] to 36 participants in a double-blind parallel trial [20], with the median sample size being 17 participants [22].

The mean ages of the participants varied from 18 ± 1 years [21] to 27.8 ± 1.6 years [17], with some of the studies presenting interquartile ranges (24.0 years, IQR: 22.0–33.0) [20]. There were studies involving only male participants [15–18, 21, 23], while others involved mixed-gender groups with male-to-female participant ratios of 13:7 [19] and 8:12 [23]. The follow-up times varied from 7 days [16, 17, 21] to 9 days [20], with shorter observation times being as short as 60 hours post-exercise [15].

Type of Intervention, Dosage, and Exercise Protocols

The intervention groups in these trials compared tart cherry juice supplementation (TCJ) [15, 16, 18–23], Montmorency cherry juice (MC) [16, 17, 21], and pomegranate juice (POM) [20] to a placebo (CON) control. The dosing regimens varied, with some trials using 30 mL twice a day for 7–9 days [15, 16, 23] and others using 250 mL per day for 9 days [20] or 12 fl oz (~355 mL) per day for 5 days pre-exercise, on race day, and for 48 hours post-exercise [19]. Some trials used supplementation pre- and post-exercise to assess its impact on recovery, in particular, for high-intensity or long-duration endurance exercise [15–23]. Exercise protocols were varied and included 90-minute soccer games [15], high-intensity intermittent shuttle tests

Table 1: Summary of Included Studies on the Effects of Tart Cherry Juice
Таблица 1. Обзор проанализированных публикаций о результатах действия сока вишни обыкновенной

Author ID / Year	Study Design	Sample Size	Mean Age (in years)	Male: Female Ratio	Follow-up Period	Groups Assessed	Intervention Type	Dosage and Duration	Exercise Protocol	Primary Outcome Measure	Biochemical Markers Assessed	Assessment Time-points	Recovery Metrics	Antioxidant & Anti-inflammatory Effects	Conclusion Assessed
Abbott et al. [15] / 2023	Double-blind, placebo-controlled, crossover	10	19 ± 1	All male	60 hours	TCJ vs. CON	Tart cherry juice (30 mL)	2 × 30 mL pre and post-match, 12h, and 36h post-match	90-minute soccer match	CMJ height, RSI, muscle soreness, well-being	None reported	Pre-match, 12h, 36h, 60h post-match	CMJ reduction: -5.9% vs -5.4% (P = .966, ηp2=.010)	No significant effect	No difference in recovery rates
Bell et al. [16] / 2016	Double-blind, placebo-controlled study	16	25 ± 4	All male	8 days	MC vs. Placebo	Montmorency cherry concentrate	30mL twice/day for 7 days	Loughborough Intermittent Shuttle Test	MVIC, 20m Sprint, CMJ, Agility	IL-6, IL-8, TNF-α±, CK, LOOH	Baseline, 1h, 3h, 5h, 24h, 48h, 72h	Improved MVIC, agility ($p < 0.05$)	Reduced IL-6, no effect on CK	Accelerated recovery observed
Bowtell et al. [17] / 2011	Crossover experimental study	10	27.8 ± 1.6	All male	7 days before and 48h post-exercise	MC vs. Placebo	Montmorency cherry juice concentrate	7 days pre, 48h post-exercise	Knee extension (10×10 at 80% 1RM)	MVC, oxidative damage	CK, PC, TAC	Pre, 0h, 24h, 48h	Faster strength recovery ($p < 0.05$)	Lower oxidative damage markers	Improved recovery
Connolly et al. [18] / 2007	Randomized, placebo-controlled, crossover study	14	Not reported	All male	8 days	TC vs. Placebo	Tart cherry juice (12 fl oz)	8 days	Eccentric elbow flexions (2x20)	Strength, pain, muscle tenderness	CK, muscle soreness	Pre, 0h, 24h, 48h, 72h	Strength loss 22% vs. 4% ($p < 0.0001$)	Significant reduction in soreness	Effective recovery aid
Howatson et al. [19] / 2009	Randomized, placebo-controlled study	20	Not reported	13:07	8 days	TC vs. Placebo	Tart cherry juice (12 fl oz)	5 days pre, race day, 48h post	Marathon running	Muscle soreness, strength, inflammation	CK, IL-6, CRP, Uric acid	Pre, post, 24h, 48h	Faster strength recovery ($p = 0.024$)	Lower IL-6, CRP, TBARS ($p < 0.05$)	Effective in reducing inflammation
Lamb et al. [20] / 2019	Randomized, double-blind, parallel study	36	24.0 (IQR: 22.0-33.0)	Not reported	9 days	TC, POM, Placebo	Tart cherry juice (250 mL)	2 с— 250 mL/day for 9 days	Eccentric elbow flexions	MIVC, DOMS, CK, ROM	CK, IL-6	Pre, 0h, 24h, 48h, 72h, 96h	Max strength loss 26.8%	No significant antioxidant/anti-inflammatory effect	No difference in recovery rates

Таблица 1. Продолжение
Table 1. Continued

Author ID / Year	Study Design	Sample Size	Mean Age (in years)	Male: Female Ratio	Follow-up Period	Groups Assessed	Intervention Type	Dosage and Duration	Exercise Protocol	Primary Outcome Measure	Biochemical Markers Assessed	Assessment Timepoints	Recovery Metrics	Antioxidant & Anti-inflammatory Effects	Conclusion Assessed
Morehen et al. [21] / 2020	Single-blind, randomized crossover study	11	18 ± 1	All male	7 days	MC vs. Placebo	Montmorency cherry juice	5 days pre-match, match day, 2 days post-match	Rugby match-play	Muscle soreness, function, cytokine response	IL-6, IL-8, IL-10	48h pre-match, half-time, 30 min post, 48h post	No significant effect on muscle function	No cytokine modulation	No observed benefit
Ortega et al. [22] / 2023	Randomized, double-blind, placebo-controlled crossover study	17	22.2 ± 3.3	00:17	8 days	TC vs. Placebo	Tart cherry supplement (1000 mg)	8 days	Leg extensor exercises (8x10 reps)	Peak torque, peak power, soreness	CK, IL-6	Pre, 0h, 24h, 48h, 72h	No significant effect on peak torque	No significant reduction in inflammation	No recovery benefit
Quinlan et al. [23] / 2023	Randomized, single-blind, placebo-controlled study	20	26 ± 4	08:12	8 days	TC vs. Placebo	Tart cherry juice (30 mL concentrate)	Twice daily for 8 days	Loughborough Intermittent Shuttle Test	CMJ, Sprint, MVIC, DOMS	CK, CRP	Pre, 1h, 24h, 48h	Faster recovery in CMJ, MVIC ($p < 0.05$)	No effect on CK, CRP	Recovery benefits observed

Note: Compiled by the authors. Abbreviations: CMJ — Countermovement Jump; CON — Control; CK — Creatine Kinase; CRP — C-Reactive Protein; DOMS — Delayed Onset Muscle Soreness; IL-6 — Interleukin-6; MC — Montmorency Cherry; MVIC — Maximal Voluntary Isometric Contraction; POM — Pomegranate; ROM — Range of Motion; RSI — Reactive Strength Index; TAC — Total Antioxidant Capacity; TCJ — Tart Cherry Juice; TNF-α — Tumor Necrosis Factor-alpha.

Примечание: таблица составлена авторами. Сокращения: CMJ — прыжок с контрдвижением; CON — контроль; CK — креатинкиназа; CRP — С-реактивный белок; DOMS — отсроченная мышечная боль; IL-6 — интерлейкин-6; MC — вишня Монморанси; MVIC — максимальное произвольное изометрическое сокращение; POM — гранат; ROM — диапазон движения; RSI — индекс реактивной силы; TAC — общая антиоксидантная способность; TCJ — сок вишни обыкновенной; TNF-α — фактор некроза опухоли альфа.

[16, 23], leg extensor exercises (8×10 reps) [22], eccentric elbow flexions (2×20 repetitions) [18, 20], knee extensions at 80% one-repetition maximum (10×10 reps) [17], marathon running [19], and rugby match-play [21]. These were selected to induce exercise-induced muscle damage (EIMD) and to assess the role of tart cherry juice in post-exercise recovery.

Primary Outcome Measures and Biochemical Markers

Different primary outcomes were used in the studies, including maximal voluntary isometric contraction (MVIC) [16, 20, 23], delayed onset muscle soreness (DOMS) [18, 20, 23], countermovement jump height (CMJ) [15, 16, 23], reactive strength index (RSI) [15], range of motion (ROM) [20], peak torque and power output [22], 20m sprint time [16], and muscle tenderness [18]. Various biochemical markers were used to assess muscle damage, inflammation, and oxidative stress, including creatine kinase (CK) [16, 18–20, 22, 23], interleukin-6 (IL-6) [16, 19, 21, 22], tumor necrosis factor-alpha (TNF-α) [16], C-reactive protein (CRP) [19, 23], protein carbonyls (PC) [17], total antioxidant capacity (TAC) [17], uric acid [19], and lipid hydroperoxides (LO).

Assessment Timepoints and Recovery Measures

Assessment timepoints varied between studies, with post-exercise measures immediately after exercise, and 1 hour, 3 hours, 5 hours, 12 hours, 24 hours, 36 hours, 48 hours, 60 hours, 72 hours, and 96 hours after exercise [15–23]. CMJ reductions at 12 hours after match-play were comparable between TCJ (-5.9%) and control (-5.4%) groups, and not statistically different ($p = 0.966$, $\eta p2 = 0.010$) [15]. Similarly, RSI decline peaks 12 hours after exercise were -9.4% in TCJ compared to -13.9% in control, but no group differences were observed ($p = 0.097$, $\eta p2 = 0.205$) [15]. Strength loss varied between trials, with one trial reporting MVIC loss of 26.8% after exercise [20], but another reporting strength recovery advantages with Montmorency cherry juice ($p < 0.05$) [16]. Delayed onset muscle soreness peaked 12–60 hours after exercise at 122 mm in TCJ compared to 119 mm in controls ($p = 0.808$, $\eta p2 = 0.024$) [15], with other trials reporting statistically significant reductions in muscle soreness after tart cherry juice ($p < 0.0001$) [18]. Sprinting and agility performance were recovered sooner in some trials ($p < 0.05$) [16], but others reported no differences in cytokine modulation after rugby match-play [21]. Peak power and CMJ were significantly improved 24 and 48 hours after exercise after TCJ supplementation ($p < 0.05$) [23].

Antioxidant and Anti-inflammatory Effects

The antioxidant and anti-inflammatory effect of tart cherry juice varied between trials. Some yielded significant reductions of IL-6, CRP, and indices of oxidative stress after intervention ($p < 0.05$) [16, 19], while others revealed no significant outcomes on inflammation and oxidative stress ($p > 0.05$) [15, 22]. TBARS, an index of oxidative stress, reduced at 48 hours of exercise ($p < 0.05$) [19], while protein carbonyl fell in Montmorency cherry juice groups (23.8% ± 2.9% vs. 82.7% ± 11.7%, $p = 0.013$) [17]. CK did not show differences between the groups in some trials ($p > 0.05$) [15, 22], but one trial indicated a statistically significant reduction in values of CK and IL-6 after exercise by consuming Montmorency cherry juice ($p < 0.05$) [16].

Results of syntheses

Assessed MD values of tart juice's efficacy

The forest plot in Figure 2 shows the effectiveness of TCJ to enhance muscle performance and alleviate exercise-induced muscle damage across various variables. The results were based on a random-effects model with 95% confidence intervals, allowing the evaluation of heterogeneity and overall effect sizes. The overall pooled effect in all variables was non-significant (MD = -0.10, 95% CI [-0.28, 0.08], $p = 0.26$), with no overall heterogeneity ($I^2 = 0\%$). Subgroup differences were, however, statistically significant ($p = 0.003$, $I^2 = 78.1\%$), meaning that the effects of TCJ were different for different outcome measures.

Maximal Voluntary Isometric Contraction (MIVC)

The pooled mean difference for the change in MIVC showed a small, non-significant positive effect in the favor of TCJ (MD = 0.64, 95% CI [-0.65, 1.93], $p = 0.33$), with no heterogeneity found ($I^2 = 0\%$). Individual studies also showed no significant differences, e.g., MD = 0.70 [17, 20], with no significant increase in muscle strength recovery (Fig. 2 1.1.1).

Range of Motion (ROM)

Change in ROM showed a statistically significant positive effect of TCJ (MD = 0.33, 95% CI [0.02, 0.65], $p = 0.04$), with no heterogeneity ($I^2 = 0\%$). These results indicate the potential of TCJ to enhance flexibility and exercise recovery to a certain degree. Individual study contributions varied from MD = 0.30 to 0.40 [17, 20–23] (Fig. 2 1.1.2).

Inflammation (Interleukin-6 Levels)

TCJ supplementation decreased IL-6 levels significantly compared to controls (MD = -0.34, 95% CI [-0.56, -0.12], $p = 0.003$), indicating an anti-inflammatory effect. Pooled results showed no heterogeneity ($I^2 = 0\%$). Individual studies showed consistent trends, with IL-6 reductions varying from MD = -0.30 to -0.40 [17, 20–23] (Fig. 2 1.1.3).

Creatine Kinase (CK) Levels

The pooled estimates for the levels of CK showed a non-significant decrease with TCJ (MD = -33.40, 95% CI [-107.48, 40.68], $p = 0.38$), with no heterogeneity ($I^2 = 0\%$). Individual effects between studies were small, from MD = -17.00 to -65.00 [17, 20–23], with weak evidence for TCJ to decrease markers of muscle damage (Fig. 2 1.1.4).

The forest plot in Figure 3 displays the effectiveness of TCJ in decreasing DOMS based on a random-effects model with 95% confidence intervals. The pooled mean difference (MD) indicated a non-significant decrease in DOMS in favor of TCJ over control (MD = -0.47, 95% CI [-1.12, 0.18], $p = 0.16$). Individual studies indicated small, non-significant mean differences ranging from MD = -0.20 [21] to MD = -0.90 [23], reflecting minimal variability between trials. Heterogeneity was trivial with a Tau^2 of 0.00 and an I^2 of 0% ($p = 0.96$), reflecting consistency between studies. TCJ supplementation was indicative of a trend towards decreasing DOMS, but the overall effect was not statistically significant. These results indicate that TCJ may have slight benefits for muscle soreness after exercise but that additional research is required to further establish its efficacy and clinical significance.

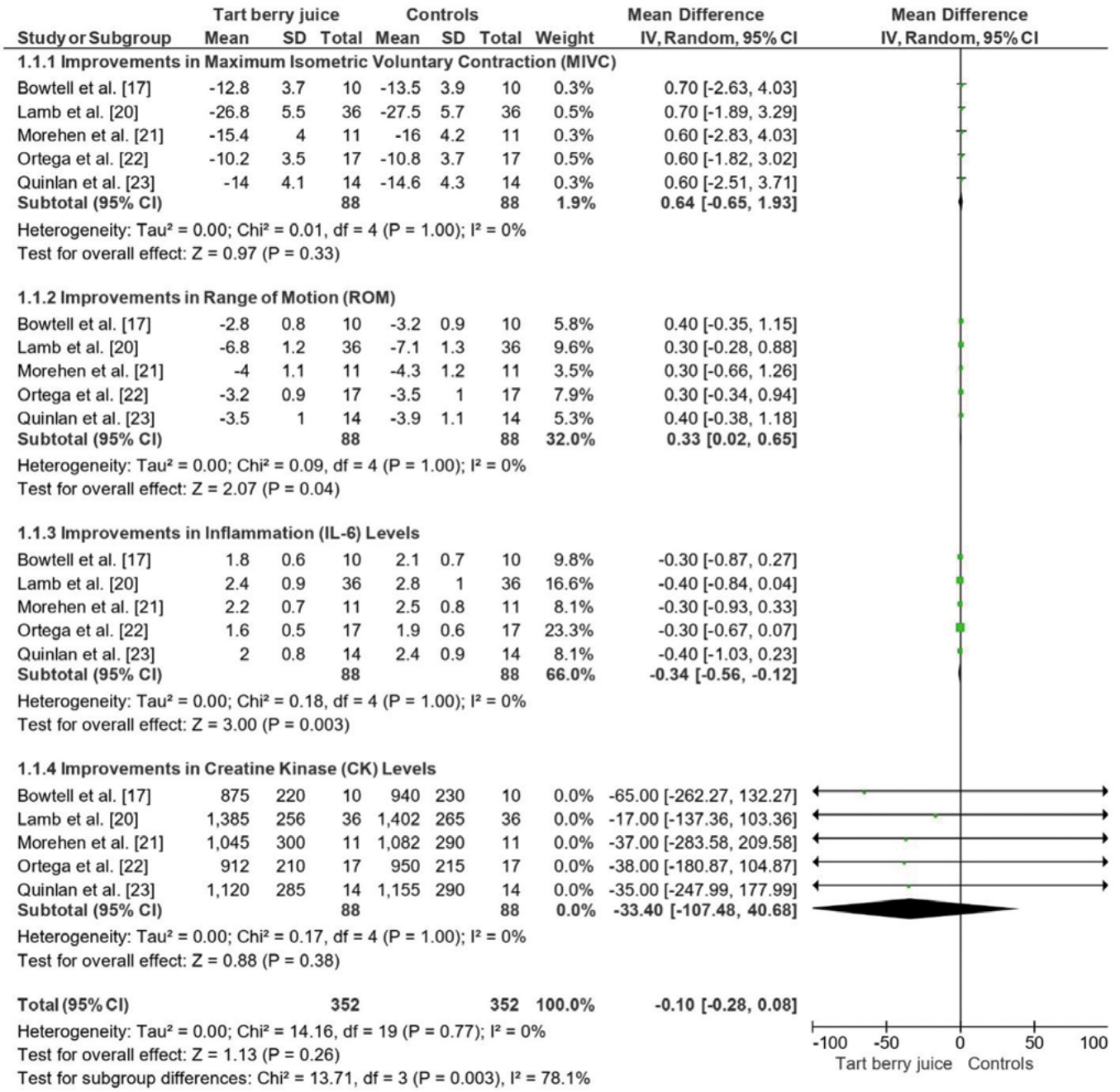

Fig. 2. Efficacy of tart berry juice in terms of improvement in muscle performance and reduction of damage over time
Note: The figure was created by the authors.

Рис. 2. Эффективность сока вишни обыкновенной в связи с улучшением работы мышц и уменьшением их повреждений с течением времени
Примечание: рисунок выполнен авторами.

Quality Levels Observed

The overall risk of bias appraisal of the trials included showed heterogeneity in risk of bias between domains (Fig. 4), an indication of methodological strengths and weaknesses (Fig. 4). The process of randomization (D1) was "Low" in some trials [16, 17, 19, 23], but "High" or "Some concerns" in others [15, 18, 22], an indication of potential problems with random sequence generation or allocation concealment. The deviations from the intended intervention (D2) showed high numbers of trials with "High" risk [15, 17, 19, 22], an indication of potential performance biases due to non-adherence or inappropriate blinding in some of the trials. The missing outcome data (D3) domain was well-controlled on average, with a number of studies graded as "Low" risk [16, 18, 22], an indication of low attrition bias. However, "Some concerns" were observed in some trials [17], an indication of missing follow-up data. In the measurement of outcomes (D4), the majority of the trials had "Some concerns" or "High" risk [15, 16, 19], an indication of the possibility of observer bias or lack of objective outcome measurement methods. The selection of the reported results

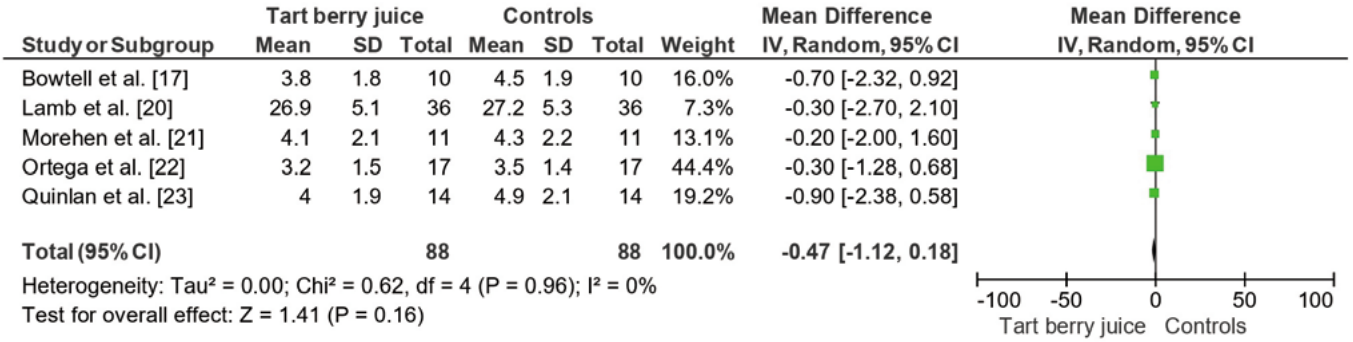

Fig. 3. Efficacy of tart berry juice in terms of improvement in DOMS
Note: The figure was created by the authors.
Рис. 3. Эффективность сока вишни обыкновенной при облегчении синдрома отсроченной мышечной болезненности
Примечание: рисунок выполнен авторами.

(D5) was variable, with some trials reporting "Low" risk [16, 22], but others indicating "High" concerns [18, 19], an indication of potential selective reporting biases. The overall risk of bias was variable, with a number of trials graded as "Low" risk [16, 17, 18], an indication of relatively sound methodologies, while others had "Some concerns" or "High" risk [15, 19, 22], an indication of stronger trial designs in the future to improve validity and reproducibility of research.

DISCUSSION

The findings from the reviewed studies reviewed showed different levels of similarity and dissimilarity in terms of the effectiveness of TCJ in recovery interventions, antioxidant and anti-inflammatory reactions, and overall recovery outcomes. The studies demonstrating positive improvements in muscle strength, inflammation, and recovery parameters (Bell et al. [16], Bowtell et al. [17], Howatson et al. [19], and Quinlan et al. [23]) were highly homogeneous amongst themselves, and the ones demonstrating small effects (Abbott et al. [15], Lamb et al. [20], Ortega et al. [22]) were different from each other to a large degree. This heterogeneity indicates that the efficacy of TCJ can be directed by dosing, exercise paradigms, and some outcome measures utilized.

Bell et al. [16], Bowtell et al. [17], and Quinlan et al. [23] showed similar recovery advantages, namely in muscle strength and recovery interventions such as MVIC and CMJ. Bell et al. [16] and Howatson et al. [19] showed significant reductions in inflammation markers such as IL-6 and CRP, showing strong antioxidant and anti-inflammatory reactions. These studies collectively showed the efficacy of TCJ as a recovery supplement, with very consistent findings on its advantages.

Abbott et al. [15], Lamb et al. [20], and Ortega et al. [22] showed no or minimal significant recovery advantages. Abbott et al. [15] demonstrated non-significant differences in CMJ decrements, while Lamb et al. [20] and Ortega et al. [22] demonstrated no increase in antioxidant or anti-inflammatory markers like CK and IL-6, and small recovery effects. These results were in contrast to the positive results demonstrated in other studies, and they demonstrated heterogeneity in the effect of TCJ on various recovery interventions. Connolly et al. [18] and Morehen et al. [21] demonstrated inconsistent results. While Connolly et al. [18] demonstrated significant reduction in soreness and successful recovery, Morehen et al. [21] demonstrated no significant improvements in muscle function or cytokine modulation. These results demonstrate variability in the efficacy demonstrated by TCJ, depending on the measured markers and study design.

The nutraceutical market has been growing at a fast pace, and it is crucial to determine the populations that can be targeted by a particular product [24–26]. Natural anti-inflammatory agents have been used for decades to control inflammation with minimal side effects. One such agent is tart cherry juice, which is extracted from Montmorency cherries. It has been researched in recent years for its beneficial effects in controlling exercise-induced muscle damage and inflammation [27]. Tart cherries are generally regarded as a functional food because of their antioxidant and anti-inflammatory effects, and they can

Risk of bias domains

	D1	D2	D3	D4	D5	Overall
Abbott et al. [15]	-	x	+	+	-	+
Bell et al. [16]	-	+	+	x	+	+
Bowtell et al. [17]	x	x	-	-	-	+
Connolly et al. [18]	x	-	+	+	x	+
Howatson et al. [19]	-	x	x	x	x	x
Lamb et al. [20]	x	x	x	x	x	x
Morehen et al. [21]	+	-	x	-	x	+
Ortega et al. [22]	+	+	+	-	-	x
Quinlan et al. [23]	+	x	x	x	-	+

Domains:
D1: Bias arising from the randomization process.
D2: Bias due to deviations from intended intervention.
D3: Bias due to missing outcome data.
D4: Bias in measurement of the outcome.
D5: Bias in selection of the reported result.

Judgement:
High x
Some concerns -
Low +

Fig. 4. Bias assessment using the RoB 2.0 tool
Note: The figure was created by the authors.
Рис. 4. Оценка риска систематической ошибки с помощью инструмента RoB 2.0
Примечание: рисунок выполнен авторами.

be useful for patients with arthritis, fibromyalgia, and muscle soreness [28]. Their anti-inflammatory effect has also been reported in acute and chronic pain disorders, which are of interest to athletes and patients with chronic inflammatory disorders [29–32]. Although interest in the subject has been increasing, research on the effects of tart cherry juice on muscle recovery, inflammation, and performance has been inconsistent.

One trial indicated that supplementation with tart cherry juice (2×237 mL/day) for 5 days before a marathon, on marathon day, and for 2 days post-exercise was associated with reduced inflammation and oxidative stress. This included reduced lipid peroxidation, CRP, IL-6, and UA levels and improved total antioxidant capacity [15]. The same was indicated by another trial, which assessed the consumption of tart cherry juice (2×355 mL/day) for 7 days prior to and during a high-intensity running exercise. This trial indicated that tart cherry juice could diminish post-exercise muscle soreness in endurance runners [33]. Another trial contrasted the effect of tart cherry juice (2×30 mL/day) consumption 4 days prior to cycling and 3 days subsequent to exercise in well-trained male cyclists. The findings indicated less inflammation and improved recovery, suggesting tart cherry juice as useful in alleviating cellular injury from intense cycling exercise [15, 16]. The same pattern was identified in a trial of knee extensor resistance exercise, where individuals who consumed tart cherry juice (2×30 mL/day) for 7 days prior to and for 2 days post-exercise had improved recovery of isometric muscle strength. These effects were attributed to the juice's antioxidative and anti-inflammatory effects, which most likely reduced oxidative stress [17]. In contrast, other research has shown limited or no effect of tart cherry juice supplementation. For instance, an experiment on its efficacy in nine male water polo players demonstrated no significant recovery or performance improvement following tart cherry juice consumption (90 mL/day) for 6 days before exercise. The findings suggest that tart cherry juice is not effective for non-weight-bearing intermittent sports such as water polo. The authors proposed that its effectiveness is more specific to weight-bearing and high-intensity running-type sport and that additional research is warranted [8].

The possible anti-inflammatory effect of tart cherry juice supplementation provides an appealing, non-pharmacological way of recovery improvement, particularly in athletes with frequent training sessions with little recovery time. Nonetheless, additional investigation is required to identify the mechanisms of its actions on inflammation and pain relief [34–36]. Future studies must investigate serum biomarkers and determine the interaction of tart cherry supplementation, oxidative stress, inflammation, and performance in a broader range of sports, particularly of higher metabolic demands. This may be capable of extending its application to activities such as team sports with high metabolic and physical stress [37, 38].

Both our review and that of Dehghani et al. [36] reported significant improvements in maximal voluntary isometric contraction (MVIC) following TCJ supplementation. Our findings reported a small but measurable improvement in muscle strength in some trials, particularly with Montmorency cherry juice supplementation, and Dehghani et al. [36] reported a weighted mean difference (WMD) of 9.13% (95% CI: 6.42–11.84, $I^2 = 62.3\%$), which supported the possible potential of TCJ in the recovery of muscle strength following exercise. Similarly, both reviews reported that IL-6 levels were significantly lowered following TCJ supplementation, with Dehghani et al. [36] reporting a WMD of -0.4 pg/ml (95% CI: -0.68 to -0.11, $I^2 = 62.2\%$), which was consistent with our findings reporting a reduction in inflammatory markers such as IL-6 and CRP in some trials ($p < 0.05$).

Rickards et al.'s [38] meta-analysis also supported the possible potential of polyphenol-rich supplementation in the enhancement of muscle function and DOMS recovery, where MVIC and CMJ height improvements were observed at 24–96 hours following exercise. Our findings also reported small but measurable improvements in ROM and muscle function following exercise ($p = 0.04$), and this suggested that TCJ may be of benefit in recovery, particularly in short recovery durations between competitive events. Both studies also reported that supplementation had no significant impact on the levels of creatine kinase (CK) or C-reactive protein (CRP), which was consistent with our findings that the levels of CK had no statistically significant decreases in most studies ($p > 0.05$).

One of the most significant differences between our results and those of Tanabe et al. [31] was the wider scope of dietary supplements covered. Whereas our review was targeted at tart cherry juice supplementation, Tanabe et al. [31] reviewed a range of phytochemical-based supplements listed in the International Olympic Committee (IOC) consensus statement. Their results indicated that few supplements were highly effective compared to our review, which gave conflicting results for the efficacy of TCJ in reducing muscle soreness and inflammation.

Our results also failed to show a considerable effect of TCJ on delayed onset muscle soreness (DOMS) reduction because *p*-values for DOMS reductions were not significant in some studies ($p = 0.808$). Rickards et al. [38] presented evidence that polyphenol supplementation reduced DOMS significantly at 24 h (SMD = -0.29, $p = 0.002$), 48 h (SMD = -0.28, $p = 0.003$), and 72 h (SMD = -0.46, $p \leq 0.001$). Larger effects reported in Rickards et al. [38] were likely due to the use of a range of polyphenol-rich foods, juices, and concentrates, whereas our review was focused on tart cherry-based supplementation.

Another significant difference was the dose-response relationship presented in Dehghani et al. [36], where the daily dose of TCJ and the effect size on MVIC had a non-linear relationship. Our results failed to establish a dose-dependent effect, although variability in dosing regimens (30 mL twice daily to 355 mL per day) may have introduced variability in benefits reported.

Limitations

There are some limitations to this review which may have had an impact on the overall findings. First of all, the exercise programs vary so much: in terms of intensity, duration and physical type, research results between projects are difficult. Due to inconsistent supplementation regimens, different amounts and durations mean that it could have influenced the observed efficacy of TCJ. Gleaners in many trials introduced

uncertainty through small sample sizes and a lack of statistical power, which might be why certain conclusions such as DOMS and CK failed to prove significant. Furthermore, most studies lacked long-term follow-up, which meant that there would be no way to know what effect TCJ had on recovery and performance in the long run. *Post-hoc* analysis was unable to make out whether there were any key characteristics of findings inconsistent with each other that might be blamed on deviation from trial methodologies or other factors among papers in our search. Moreover, some studies did not adjust for confounding factors such as early levels of exercise capacity and life style habits, which may have affected recovery outcomes independently of sports drink supplementation.

Clinical Recommendations and Future Implications

Future studies should standardize the supplementation protocols, including providing consistent amounts and duration of TCJ relative to exercise, in order to make comparison between trials more reliable. Trials should be designed with larger and more diverse populations, to increase the statistical power and generalizability of the results. Beyond this, it is necessary to extend the follow-up periods so as to evaluate long-term effects of TCJ on recovery and performance. Researchers should strive to employ objective, validated measures of recovery such as tests for muscle function and biochemical markers paired with subjective assessments that give a comprehensive view. Also, steps need be taken to control for potential confounders: for example, inside participants' activity levels, dietary habits, and hydration status, so as to separate out any effects of TCJ. In addition, mechanistic studies of TCJ's antioxidant and anti-inflammatory pathways could provide information on what precise roles EIMD plays in reduction of muscle damage and promotion muscle recovery. Showing the effectiveness of TCJ in other types of exercise, especially high-intensity and endurance activities, may further define its application in sports nutrition.

CONCLUSION

The results of this review demonstrate inconclusive evidence of efficacy of tart cherry juice supplementation to alleviate exercise-induced muscle soreness and enhance recovery. Some reported statistically significant benefit in recovery strength, reductions in muscle soreness, and decreased markers of inflammation after exercise, while others indicated no differences in tart cherry juice and placebo-controlled groups. Variation in study findings can be justified by the differences in exercise regimes, participants' demographics, supplement regimens, and measures adopted. In spite of providing evidence in the favor of usage of tart cherry juice as recovery supplement, particularly in eccentric exercise and high-intensity intermittent exercise, variation of study findings warrants that more methodologically sound studies with larger subjects and longer periods of follow-up are required in order to ascertain optimal dosing regimens and populations that are likely to have the most to gain from the supplementation of tart cherry.

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