FOOD FOR EXERCISE-INDUCED MUSCLE DAMAGE RECOVERY: A SYSTEMATIC REVIEW

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ABBREVIATIONS

ASAT Aspartate aminotransferase

ATP Adenosine trisphosphate

BMI Body Mass Index

BTJ Beetroot juice

CMJ Countermovement jump

COR Crossover randomized

CK Creatine kinase

COX-2 Cyclooxygenase-2

DOMS Delayed onset muscle soreness

EIMD Exercise-induced muscle damage

HR Heart Rate

IL-6 Interleukin-6

LHD Lactate dehydrogenase

mRNA Messenger ribonucleic acid

NSAIDS Non-steroidal anti-inflammatory drugs

MIVC Maximal isometric voluntary contraction

PLA Placebo

POMJ Pomegranate juice

RCP Randomized controlled placebo

RM Repetition maximum

ROB2 Risk of Bias 2 tool

TAC Total antioxidant capacity

THP-1 Human leukemia monocytes

ABSTRACT

Introduction: Strenuous exercises training is commonly performed to develop muscle strength, power, and endurance for performance maximization. As a result, exhaustive exercises can produce exercise-induced muscle damage (EIMD). Symptoms of EIMD could be ameliorated with appropriated recovery interventions after strenuous exercise sessions. Several studies have reported the efficacy of a large number of foods and extracts supplements in the reduction of EIDM symptoms compared to the placebo, including pomegranate, bilberry, cacao, beetroot, and blueberry. Therefore, this systematic review aimed to examine the effects of food or concerted food on indices of muscle damage and physical performance measures following muscle-damaging exercise protocols.

Material and Methods: The studies were included by following the PICO criteria; (1) Population: healthy male and female human adults; (2) Intervention: consumption of whole food as supplements that consisted of food or concentrated (e.g., chocolate, milk); (3) Comparison: the acute responses were compared between FOOD and PLA conditions at ≤ 24, 48h, and 72h; (4) Outcome: the acute responses that may include blood biomarkers of indirect muscle damage, inflammation, and oxidative stress. The Cochrane's risk of bias tool was used to critically appraise each study.

Results: Thirty-two studies were included; 22 had a parallel, and 10 had a cross-over design. A total of 768 participants (males and females) were included in the systematic review. Of the 768 participants, 195 were semi-professional athletes (25.4%), 93 athletes (12.1%), 460 (59.9%) were recreationally trained, and 20 were untrained (2.6%). Consumption of foods and concentrates accelerated recovery of DOMS immediately post-exercise conditions at ≤ 24, 48h, and 72h. Compared to the PLA condition, the FOOD condition the studies exhibited significantly lower levels of indirect muscle damage markers, inflammatory markers, and oxidative stress, whilst antioxidant capacity was significantly increased at post-

exercise. The results of the studies showed that consuming foods and concentrates accelerated recovery of muscle function while reducing muscle soreness in humans.

Conclusion: This systematic review suggests that consumption of foods (i.e., cocoa, milk), juices, and concentrates provides practitioners and athletes with a low risk, food-first approach for enhancing recovery in scenarios where optimising rapid recovery is key. These findings demonstrate that whole food could be used as recovery strategies from strenuous exercise sessions.

Keywords: exercise, food, inflammation, muscle damage, oxidative stress

RESUMO

Introdução: O treinamento físico extenuante é comumente realizado para desenvolver força, potência e resistência muscular para maximizar o desempenho. Como resultado, o exercício exaustivo pode produzir danos musculares induzidos pelo exercício (EIMD). Os sintomas de EIMD poderiam ser melhorados com intervenções apropriadas da recuperação após sessões de exercício extenuantes. Vários estudos relataram a eficácia de um grande número de alimentos e extratos na redução dos sintomas do EIDM em comparação com o placebo, incluindo romã, mirtilo, cacau, beterraba e mirtilo. Portanto, esta revisão sistemática teve como objetivo analisar os efeitos de alimentos ou alimentos concentrados sobre os índices de dano muscular e medidas de desempenho físico seguindo protocolos de exercícios prejudiciais aos músculos

Material e Métodos: Foram incluídos 32 estudos, sendo 22 paralelos e 10 transversais. Um total de 768 participantes (homens e mulheres) foram incluídos na revisão sistemática. Dos 768 participantes, 195 eram atletas semi-profissionais (25,4%), 93 atletas (12,1%), 460 (59,9%) foram treinados recreativamente e 20 não eram treinados (2,6%). O consumo de alimentos e concentrados acelerou a recuperação das condições de DOMS imediatamente após o exercício em 24, 48h e 72h. Em comparação com a condição PLA, a condição FOOD exibiu níveis significativamente menores de marcadores de dano muscular indireto, marcadores inflamatórios e estresse oxidativo, enquanto a capacidade antioxidante foi significativamente aumentada no pós-exercício. Os resultados dos estudos mostraram que consumir alimentos e concentrados aceleraram a recuperação da função muscular, reduzindo a dor muscular em humanos. A ferramenta de risco de viés da Cochrane foi usada para avaliar criticamente cada estudo.

Resultados: Foram incluídos 32 estudos, 22 paralelos e 10 transversais. Um total de 768 participantes (homens e mulheres) foram incluídos na revisão

sistemática. Dos 768 participantes, 195 eram atletas semi-profissionais (25,4%), 93 atletas (12,1%), 460 (59,9%) eram treinados recreativamente e 20 não eram treinados (2,6%). O consumo de alimentos e concentrados acelerou a recuperação das condições de DOMS imediatamente após o exercício em 24, 48h e 72h. Em comparação com a condição PLA, a condição FOOD exibiu níveis significativamente menores de marcadores de dano muscular indireto, marcadores inflamatórios e estresse oxidativo, enquanto a capacidade antioxidante foi significativamente aumentada no pós-exercício. Os resultados dos estudos mostraram que consumir alimentos e concentrados aceleraram a recuperação da função muscular, reduzindo a dor muscular em humanos.

Conclusão: Esta revisão sistemática sugere que o consumo de alimentos (ou seja, cacau, leite), sucos e concentrados fornece aos praticantes e atletas uma abordagem de baixo risco, em primeiro lugar, para melhorar a recuperação em cenários onde a otimização da recuperação rápida é fundamental. Esses achados demonstram que a alimentação integral pode ser utilizada como estratégia de recuperação de sessões de exercícios extenuantes.

Palavras-chave: alimento, dano muscular, estresse oxidativo, exercício, inflamação.

INTRODUCTION

Strenuous exercise training is commonly performed for the development of muscle strength, power, and endurance. As a result, exhaustive exercises can induce exercise-induced muscle damage (EIMD), especially following exercises involving eccentric contractions [1,2]. The signs associated with EIMD are characterized by impaired force production, increased muscle soreness, and reduced range of motion [3]. These symptoms can impair subsequent performance and result in edema, inflammation, and an increase in intramuscular proteins in the blood (e.g., creatine kinase) [4,5].

The exact mechanisms causing EIMD are still unclear, but a two-phase process has been proposed [6]: Firstly, mechanical damage to sarcomeres may cause overstretching of some filaments (sarcomere 'popping'); secondly, an acute inflammatory response and disruption of redox balance may further damage the muscle [7]. As inflammation and disruption of redox balance are implicated in the secondary phase of muscle damage, several investigations have been conducted to understand how food and if its antioxidant and anti-inflammatory properties can accelerate muscle recovery.

The symptoms of EIMD could be monitored with appropriate recovery interventions between strenuous training sessions [8]. Several treatment strategies have been introduced to help alleviate the severity of EIMD symptoms and restore the maximal function of the muscles as rapidly as possible, such as stretching, massage, electrotherapy, cryotherapy, and non-steroidal anti-inflammatory drugs (NSAIDS) [9]. In the last decade, the use of dietary supplements, particularly fruit-derived substances (e.g., blackcurrant, berries, pomegranate), has become increasingly popular to ameliorate symptoms of EIMD [10]. Although not fully understood, it has been suggested that phytochemicals in fruits and vegetables downregulate inflammatory and

oxidative stress markers, which are common cellular pathways that exacerbate the level of EIMD symptoms, known as the secondary muscle-damaging response [11]. Additionally, several studies have reported the efficacy of many other foods and extracts in reducing EIDM symptoms compared to the placebo, including pomegranate [12], bilberry [13] cocoa [14], beetroot [15], and blueberry [16]. However, there are also other studies that indicated comparable effects between food supplements and a placebo.

According to recent narrative reviews, supplements including various food products (e.g., fruit and vegetable products, protein, carbohydrate) seem to accelerate recovery after strenuous exercises by attenuating EIDM symptoms and restoring muscular function [4]. The term "food-first" has been widely accepted as the preferred strategy within sports nutrition. There is a proposal that "food-first" should mean “where practically possible, nutrient provision should come from whole foods and drinks rather than from isolated food components or dietary supplements” [17]. There are many reasons to commend a food-first strategy, including the risk of supplement contamination resulting in anti-doping violations. Burd et al. [18] were the first to demonstrate in their review that a food-first approach to post exercise protein intake can be beneficial for both the skeletal muscle adaptive response and diet quality for most people.

To our knowledge, only one systematic review has synthesized the evidence on fruit-derived polyphenols and recovery from EIMD [8]. The authors concluded that supplementation provided a faster recovery of maximal isometric voluntary contraction (MIVC), increased antioxidant capacity, and a reduction of markers of muscle damage, inflammation, and oxidative stress. However, in this systematic review, Doma et al. [8] included studies using food but also with capsules. Nonetheless, it would be interesting to analyse only food in its natural format, avoiding including capsules and food together in the analysis. In this way it would be possible to have more concise results so that the use of food can be better evaluated for the recovery of EIMD.

In the last decade, various studies have been done to elucidate the effects of food and the better strategies to accelerate recovery following strenuous exercise. The results from these studies have not yet been examined systematically nor analysed using valid critical appraisal tools, and in that sense limiting the comparison and critical evaluation of those studies. Hence, a thorough analysis of the studies is necessary to examine the impact of specific food products that are gaining widespread popularity.

Therefore, we aim to systematically review the studies that utilized whole food as the intervention group for EIMD recovery. We also aim to obtain, in a compiled and systematized way, evidence regarding what type of food, instead of traditional supplementation, can be successfully utilized for recovery from EIMD. These results will allow the prescription of more specific dietary recommendations and can be an inspiration for other research in this area, where other foods can be tested.

MATERIAL AND METHODS

The methodology and reporting of this systematic review were conducted in accordance with the PRISMA guidelines, allowing for transparent and comprehensive reporting of systematic reviews (Moher et al., 2009) [19], and the Cochrane Handbook [20]. The protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO) (ID 363353; September 27, 2022) [21]. The Population, Intervention/Exposure, Comparison, and Outcome (PICO) methodology was employed to design both the search strategy and the inclusion/exclusion criteria.

Inclusion/exclusion criteria

We included studies that compared a food, juice or concentrate with a placebo on recovery from EIMD. The studies were included by following the PICO criteria [22]:

(1) Population: healthy male and female human adults.
(2) Intervention: consumption of whole food or concentrated food (e.g., chocolate, milk, berries, pomegranate) after the exposure to muscle-damaging exercise protocols (e.g., resistance training, cycling, eccentric contractions, long-distance running).
(3) Comparison: the acute responses were compared between the FOOD and PLA conditions at ≤ 24, 48h and 72hafter the muscle damaging exercise protocols.
(4) Outcome: the acute responses that may include blood biomarkers of indirect muscle damage, inflammation, oxidative stress, and antioxidant, and/or subjective measures of muscular pain and physical performance measures.

Studies were excluded if: (1) conducted in animals; (2) studies with capsules; (3) benefits of whole foods were examined for chronic training adaptations rather than daily acute responses (e.g., examining strength development 2–6 weeks after training with concentrated foods) (4) they were published in a non-English language; (5) results were published as a conference abstract, review, or case report.

Selection process

Two reviewers (LS and MS) completed the computed literature search. Initially, all abstracts that aligned with the inclusion criteria were categorised as either 'yes' (definitely meeting the criteria), 'maybe' (possibly meeting the criteria) or 'no' (not meeting the criteria). Titles, abstracts, and descriptors of the trials retrieved from the searches were independently screened. Studies that satisfied the inclusion criteria were selected. Full text articles were reviewed and then extracted and further screened according to the inclusion/exclusion criteria. Disagreements were resolved by discussion and consultation by the two reviewers.

Outcome measures

The outcome measures for this systematic review were reported for indirect muscle damage markers, separated into three categories, including: (1) blood biomarkers for muscle damage measures (i.e. CK, myoglobin and lactate dehydrogenase), inflammation (i.e. interleukin-1, interleukin-6, C-reactive protein), and oxidative stress (i.e. malondialdehyde, lipid hydroperoxides, glutathione peroxidase); (2) subjective measures (e.g. delayed onset of muscle soreness); and (3) physical performance measures (e.g. joint range-of-motion, isometric torque, isokinetic torque, vertical jump, running economy and sprint).

Search strategy

A literature search was conducted from April 1st, 2021, to 3rd August 2022 using two electronic databases: PubMed and Scopus. For the PubMed search, mesh term classifications were used in combination: (1) supplemental intervention (Physiological Phenomena or Flavonoids or Polyphenols or Citrullus or Fruit or Vegetable Juices or Dietary Supplements); (2) indirect muscle damage markers (Creatine Kinase/blood OR Inflammation/blood OR Interleukin-6/blood OR L-Lactate Dehydrogenase/blood OR Musculoskeletal Pain OR C-Reactive Protein OR Myalgia OR Interleukin-1/blood OR Cytokines/blood OR Pain/etiology OR (Oxidative Stress OR Reactive Oxygen Species); (3) exercise intervention (High-Intensity Interval Training OR Physical Exertion OR Plyometric Exercise Isometric Contraction OR Exercise Tolerance OR Exercise OR Resistance Training OR Running); and (4) Humans. In addition, free text search was performed in Medline from 10 months prior to the literature search date (Dez 2020-Jan 2022] or strength or resistance or training or exercise) and (muscle damage or creatine kinase or inflammation or soreness or oxidative stress) and (food or blackcurrant or cherry or pomegranate or milk or chocolate or watermelon or berry or polyphenols or supplement or juice). We performed citation chaining using identified studies to find other relevant publications.

Data extraction

For data extraction, a custom-developed electronic form (Microsoft Excel®) was used to obtain information on study aims, participant characteristics (e.g., age, height, weight, BMI, training background), research design (e.g., cross-over randomised, blinding procedures), type of indirect muscle damage, and the time when indirect muscle damage measures were collected.

Risk of Bias in individual studies

Included studies were independently assessed for risk of bias by the reviewer (SL). Studies with a parallel design were assessed using the Risk of Bias 2 tool (ROB 2) [23] and this was adapted for cross-over studies using guidelines provided by Higgins et al. [24]. Each study was assessed for quality across the following categories: (1) randomisation process; (2) deviations from intended interventions; (3) missing outcome data; (4) measurement of the outcome; (5) selection of the reported result. The overall assessment comprised of three ratings: low risk of bias, some concerns or high risk of bias.

RESULTS

A total of 1272 abstracts were extracted from PubMed, Scopus, and additional records identified though other databases and screened according to the inclusion criteria. A further eight studies were identified through citation chaining. Of these, 1247 were screened after removing duplicates. After reviewing the abstracts, 1195 were removed because they did not meet the inclusion criteria. The full text of remaining 52 full text articles were further assessed, leaving 32 articles for inclusion. The PRISMA flow diagram is displayed in Figure 1.

Participants characteristics

A total of 768 participants (622 male and 146 female) (Table 1) were included in this systematic review. Of the 768 participants, 195 were semi-professional athletes (25.4%), 93 athletes (12.1%), 460 (59.9%) participants were recreationally trained and 20 were untrained (2.6%). For studies that utilised a randomized controlled placebo (RCP) design, the FOOD and PLA conditions consisted of 235 and 231 participants respectively, with a total of 466 participants (Table 1). The average age, height and body mass for the FOOD condition were 25.5 years old (19-38 years), 1.8 m (1.7-1.9 m) and 74.6 kg (59.9-89.4 kg), respectively. The PLA group demonstrated comparable physical characteristics, with average age, height, and body mass of 25 years (19-37 years), 1.8 m (1.7-1.8 m) and 75.5 kg (63.6-83.9 kg), respectively. For studies with a crossover randomized 29 years (19-48 years), 1.8 m (1.7-1.8m) and 80.0 kg (61.6-90.0) kg, respectively. When

comparing baseline measures between the FOOD and PLA conditions for COR studies, no significant differences were identified ($p > 0.05$), indicating that the measures collected in each group or condition were relatively stabilised.

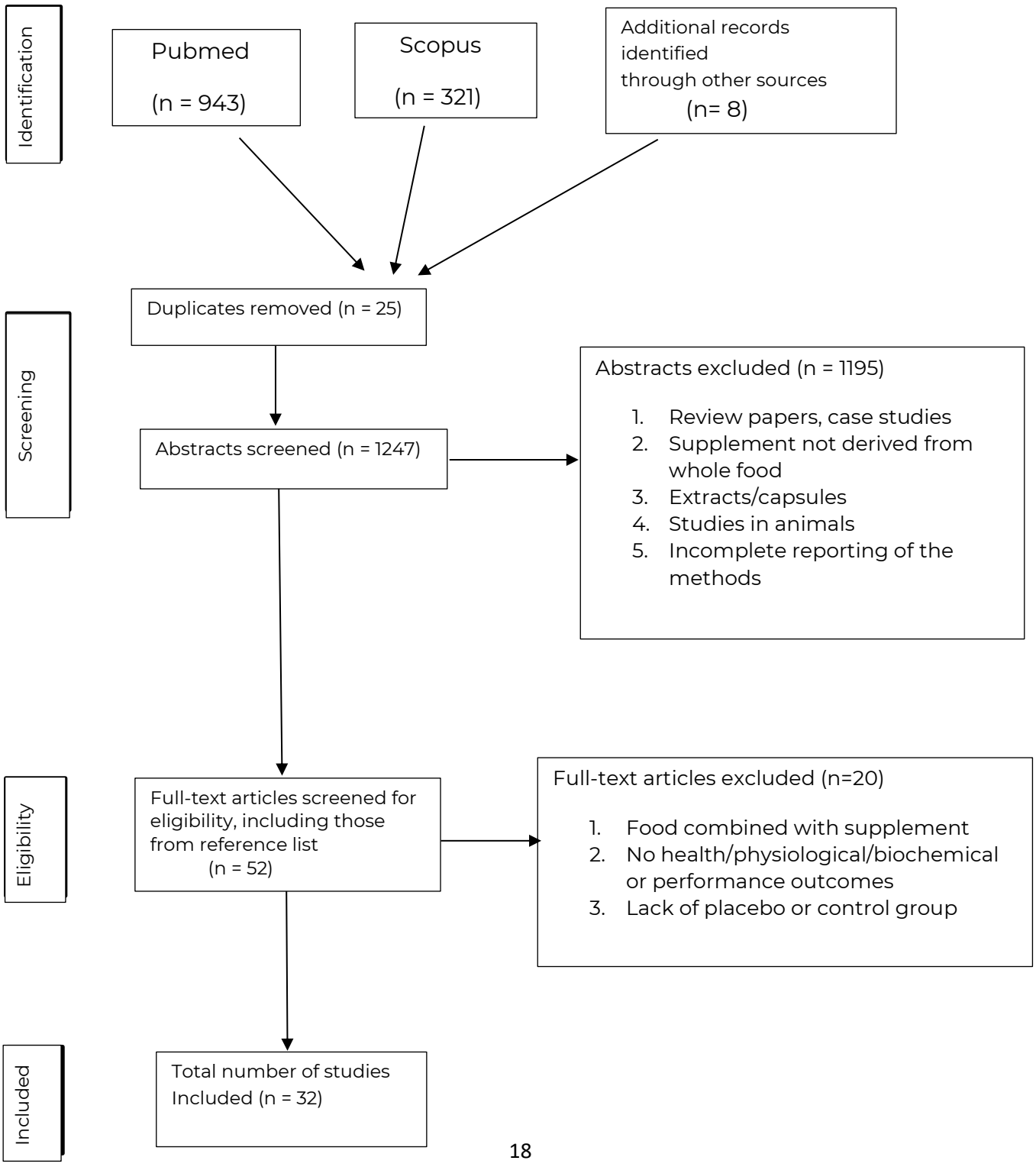

Figure 1. PRISMA flow diagram.

Study characteristics

Of the 32 studies included in the systematic review, 22 employed a randomized controlled placebo (RCP), whilst the remaining 10 studies were based on crossover randomized (COR) (see Table 2 for study details).

A variety of exercise protocols were utilised to cause EIMD, with the most common being eccentric contractions (13 studies) [1,33,37,38-40,42,43,47,49,51,56,57] and cycling (5 studies) [22,31,41,48,53], followed by half and full marathon running (4 studies) [13,34,35,50] traditional resistance exercise (3 studies) [30,36,54], repeated sprint activities (3 studies) [10,32,46] and the least including rowing activities (1 study) [45], and drop jumps (2 studies) [15,46].

Concentrated food interventions administered to ameliorate indirect muscle damage symptoms, with cherry as the most common form (9 nine studies) [10,11,26-32]; followed by milk (5 studies) [33-37], pomegranate (4 studies) [38-41], beetroot (3 studies) [15,42,43], cocoa (2 studies) [44,45], watermelon (2 studies) [46,47], black currant (1 studies) [53], bilberry (1 study) [13], tomato (1 study) [48], banana (1 study) [49], açai (1 study) [25], plum (1 study) [55], and grape (1 study) [54].

Table 1. Characteristics of the studies included in the systematic review

Authors	Participant Characteristics at Baseline	Study Design	Exercise Intervention	Food	Dosage and Duration	Outcome Variables
Abbot et al. 2020 (26)	Age 19 ± 1 years Height 1.8 ± 0.6 m Weight 77.3 ± 6.4 kg SUPP: n = 5 PLA: n = 5	RCP	90 min soccer match	Tart cherry Juice	2 × 30 mL concentrate for 3 days (morning of match until 36 h post-exercise)	DOMS ↔ CMJ ↔
Ammar et al. 2016 (38)	Age ± 21 ± 0.5 Height 175 ± 8.1 cm Weight 80 ± 9.5 kg SUPP: n = 9 PLA: n= 9	COR	1-RM in three trials with 5 min recovery time	Pomegranate Juice	Consumed 250ml tree times per day across 2 days prior the trail (Additional 500ml 1h prior the trail)	↓HR,6* SBP, CK, LDH, ASAT↑
Bell et al. 2015 (10)	Age 30 ± 8 years Height 1.8 ± 0.7m Weight 76.5 ± 9.2 kg VO2peak 61.6 ± 10.4 mL·kg−1·min−1 SUPP: n = 8 PLA: n = 8	RCP	Cycling time trail for 109 min	Cherry: Montmorency tart cherry concentrate juice	Consumed 30 mL juice concentrate twice per day on consecutive days (4 days pre and across three trials per day	↔ CK ↓ IL-6, ↓ IL-8, CRP, ↔ TNF-α, ↔ LOOH
Bell et al. 2016 (27)	Age 25 ± 4 years Height 1.8 ± 0.7m VO2max 54.9 mL·kg−1·min−1 SUPP: n = 16 PLA: n = 16	RCP	A series of 12 x 20m sprints with 60sec rest between each bout, followed by 6 x 15min of the Loughborough Intermittent Shuttle Test	Cherry: Montmorency tart cherry concentrate juice	Consumed 30 mL juice concentrate twice per day on consecutive days (4 days pre and across three trials per day)	↔ CK, ↓ IL-6, ↓ IL-8, ↓CRP, ↔TNF-α, ↔ LH Knee extensor strength 0-200mm VAS

Bowtell et al. 2011 (11)	Age 28 ± 2 years Height 1.8 ± 0.03m Weight 81.3 ± 4.3kg SUPP: n = 10 PLA: n = 10	COR	Single-leg knee extensions at 80% 1RM for 10 set x 10 reps	Cherry: Montmorency tart cherry concentrate juice	Consumed 30 mL twice per day for 10 consecutive days	↑MVC ↔ CK, ↔ TAS, ↓PC
Brown et al. 2019 (28)	Age 19 ± 1 years Height 1.7 ± 0.06m Weight 61.6 ± 5.3 kg SUPP: n = 20 PLA: n = 20	COR	Repeated 15 × 30 maximal sprints with 60sec rest between each bout	Cherry: Montmorency cherry concentrate	Consumed 30 mL twice per day for 8 consecutive days (4 days pre, on the day of, and 3 days post-trial)	↓DOMS, ↑ CMJ ↔ CK, ↔ CR
Carvalho et al. 2018 (51)	Age 19 years SUPP BMI 22.1 ± 1.8 kg·m−2 PLA BMI 22.2 ± 2.6 kg·m−2 SUPP: n = 12 PLA: n = 13	RCP	One month training camp consisting of 60min sessions of general strength and moderate intensity endurance exercises three times a week	Plum: Beverage with 33.3g Jamelon pulp, 100mL water and 4g crystal sugar	Consumed 10 mL kg/day for 28 consecutive days during training	↓CK, ↓LDH, ↑ TAC, ↓MDA ↓LDH ↓
Clifford et al. 2016 a (42)	Age 22 ± 2.5 years Height 1.80 ± 0.70 m Weight 75.1 ± 10.9 kg SUPP: n = 10 PLA: n = 10	RCP	20 × 30 m sprints on day 1 and day 4 (72 h apart)	Beetroot: Beetroot juice	Consumed 2 × 250 mL for 3 days (day of and 2 days post-exercise)	↑MIVC, ↑ CMJ, ↔PC, ↔CK, ↔CRP
Clifford et al. 2016 b (43)	Age 21.3 ± 4 years Height 178 ± 0.76 m Weight 75.6 ± 8.3 kg SUP: n = 15 PLA: n = 15	RCP	5 × 20 drop jump	Beetroot: Beetroot juice	Consumed (250 mL) Per 250 mL 3 × servings on day of exercise and 2 × servings for two days post-exercise	↔MIVC, ↑CMJ, ↔ CK, ↔ IL-6
Clifford et al. 2017 (15)	Age 21.7 ± 2.3 years Height 178.0 ± 6.46 cm Weight 75.1 ± 10.13 kg SUPP: n = 10 PLA: n = 10	RCP	5 × 20 drop jump	Beetroot: Beetroot juice	Consumed (250 mL) Per 250 mL 3 × servings on day of exercise and 2 × servings for two days post-exercise	↑MIVC, ↑CMJ, ↔ CK, ↔CRP

Cockburn et al. 2012 (33)	Age 21 ± 3 years Height 1.81 ± 0.6m Weight 79.7 ± 9.3 kg SUPP: n = 12 PLA: n = 12	COR	6 sets of 10 repetitions, with 90 s rest between sets, of unilateral eccentric–concentric knee flexions at a speed of 1.05 rad s-1	Milk	Consumed respectively 500*, 1000ml milk after trail	↓CK, ↓Mb
Cockburn et al. 2013 (34)	Age 24 ± 4 years Height 1.8 ± 0.07m Weight 81.3 ± 4.3kg SUPP: n = 7 PLA: n = 7	RCP	6 sets of 10 repetitions, with a 90-s rest between sets, of unilateral eccentric–concentric knee flexions at a speed of 1.05 radIs j1	Milk	Consumed 500ml of milk after trail	↔CK, ↔ Mb
Connolly et al. 2006 (26)	Age 22 ± 4 Height 1.8 ± 0.8m Weight 90 ± 18kg SUPP: n = 14 PLA: n = 14	COR	Eccentric elbow flexions for 2 sets x 20 reps of maximal contractions with 3min rest between sets	Cherry & apple: Blend of tart cherry juice and apple juice	Consumed 355mL twice per day across 8 consecutive days (3 days pre, on the	↑Elbow flexor strength ↓Muscle myometer
Davison et al. 2012 (44)	Age 22 ± 1 Weight 71.6 ± 1.6kg VO2max 53.1 ± 1.9 ml kg-1 min-1 SUPP: n = 7 PLA: n = 7	RCP	Cycling 2,.5h at *60% maximal oxygen uptake 2h	Cocoa: Dark chocolate bar	Consumed 100 g dark chocolate (or nothing in the BL trial) and 200 ml of water 2 h prior to beginning exercise	↓IL-6, ↓ ACTH, ↓LDH ↓Cortisol
Dimitriou et al. 2015 (30)	SUPP: Age 37 ± 13 years Height 1.8 ± 0.1m Weight 72.9 ± 9.8kg PLA: Age 38 ± 5 years Height 1.8 ± 0.1 m Weight 73.8 ± 9.5kg SUPP: n = 10 PLA: n = 10	RCP	Full marathon (running 42.2km)	Cherry: Montmorency tart cherry concentrate juice with proprietary apple juice	Consumed 236mL twice prior to trial	↓Cortisol, ↓CRP

Howatson et al. 2010 (31)	SUPP: Age 37 ± 13 years Height 1.8 ± 0.1m Weight 72.9 ± 9.8kg PLA: Age 38 ± 5 years Height 1.8 ± 0.1m Weight 73.8 ± 9.5kg SUPP: n = 10 PLA: n = 10	RCP	Full marathon (running 42.2km)	Cherry: Cherry juice concentrate juice with proprietary apple juice	Consumed 236mL twice per day across 4 days (1 d pre, on the day and 2 days post-trial	↔ CK, ↔ LDH, ↓ IL-6, CRP, ↓TAS, UA, PC Knee extensor strength 0-200mm VAS
Hutchison et al. 2016 (53)	SUPP: Age 20 ± 1 years Height 1.7 ± 0.02 m Weight 64.8 ± 4.8kg PLA: Age 21 ± 1 years Height 1.6 ± 0.04 m Weight 63.6 ± 5.2kg SUPP: n = 8 PLA: n = 8	RCP	Three sets of super-maximal (115% of 1RM), eccentric squatting contractions	Black current & nectar: Black current nectar juice	Consumed 473mL thrice per day across 8 consecutive days (4 days pre, on the day and 3 days post-trial)	↓CK, ↓IL-6, ↓ORAC 0–10 VAS
Iwasa et al. 2013 (35)	Age 21.6 ± 0.8 years Height 1.7 ± 0.01 m Weight 59.9 ± 1.5 kg SUPP: n = 10 PLA: n = 10	RCP	Five sets of leg and bench presses at 70–100% 12 repetition maximum	Milk: Fermented milk	Consumed 200 mL of each beverage 3 times before and after exercise	↓CPK
Lynn et al. 2018 (13)	SUPP: Age 31 ± 9 years Height 1.75 ± 0.11 m Weight 74.3 ± 13.1 kg PLA: Age 31 ± 12 years Height 1.73 ± 0.06 m Weight: 68.6 ± 7.9 kg SUPP: n = 19 PLA: n = 19	RCP	Half marathon (running 21.1km)	Bilberry: Bilberry juice	Consumed 200mL twice per day across 8 consecutive days (5 days prior, on the day and two days post-trial)	↔CK, ↓CRP ↓DOMS 0-200mm VAS

Machin et al. 2014 (39)	Age 22.3 ± 4.1 years Height 174.9 ± 6.2 cm Weight 73.8 ± 11.5 kg SUPP: n = 23 PLA: n = 22	RCP	20 min of downhill running and 40 repetitions of bilateral eccentric elbow contractions	Pomegranate Wonderful juice	Consumed 30ml 1 or 2 × servings for 8 days (3 days pre-exercise, on the day of, 4 days post-exercise)	↓MIVC, ↓ DOMS
Martinez-Sanchez et al. 2017 a (47)	Age 24 ± 4 years Height 1.8 ± 0.05 m Weight 75.2 ± 7.6 kg SUPP: n = 19 PLA: n = 19	COR	Barbell back squats (8RM) for 8 sets x 8 reps with 2min recovery between set	Watermelon: Watermelon juice	Consumed 200mL one hour prior to each trial	↓LDH, VAS”
Martinez-Sanchez et al. 2017 b (46)	Age 35 ± 11 years Height 1.8 ± 0.08 m Weight 73.6 ± 9.1 kg SUPP: n = 21 PLA: n = 21	COR	Half marathon (running 21.1km)	Watermelon: Watermelon juice	Consumed 500mL two hours prior to each trial	↔ CK, ↓MG, ↓LDH, C, CRP, ↔UA
McCormick et al. 2016 (32)	Age 19 ± 1 years Weight 82.7 ± 9.8 kg SUPP: n = 9 PLA: n = 9	COR	One week training microcycle consisting of 90-120min sessions of general strength and moderate intensity endurance exercises three times a week	Cherry: Montmorency cherry juice	Consumed 200mL in the morning and 400mL in the evening daily across 6 consecutive days	0–10 VAS
Morgan et al. 2018 (45)	Age 22.8 ± 3.3 years Height 1.84 ± 0.59 m Weight 85.3 ± 12 kg SUPP: n = 5 PLA: n = 5	RCP	Single leg extension 10 × 10 repetitions at 80% 1RM	Cocoa: Cocoa juice (ZumaCacao®)	Consumed 330 ml per day for 10 days (7 days pre-exercise, on the day of, 2 days post-exercise)	↓MIVC, ↓ DOMS, ↓CMJ, ↔ CK, CRP, PC
Nieman et al. 2018 (49)	Age 40 ± 2 years Height 1.7 ± 0.03 m Weight 71.9 ± 2.5 kg SUPP: n = 20 PLA: n = 20	COR	Cycling time trial for 75km	Banana: Cavendish banana	Consumed 0.4g/kg carbohydrate from Cavendish bananas 20 min prior to trial	MG, ↓ IL-6, ↓IL-8, ↓LKCTS, ↓HODES ↔ 1–10 VAS

O'Connor et al. 2013 (54)	SUPP: Height 1.7 ± 0.02 m Weight 71.4 ± 14.7 kg VO2max 41.8 ± 8.8 PLA: Height 1.7 ± 0.02 m Weight 72.0 ± 13.9 kg VO2max 42.2 ± 8.5 SUPP: n = 20 PLA: n = 20	RCP	Eccentric contractions (120% of concentric 1RM) for 3sets x 6 reps	Grape: Grape beverage	Consumed 236mL daily across 45 consecutive days (including the day of, and 2 days post-trial)	Elbow flexor strength↔ 0-100mm VAS
Rankin et al. 2015 (36)	Age 22 ± 3 years SUPP: n =16 PLA: n = 16	RCP	3 x repetitions of bilateral maximal knee flexion at 60 and 180°/s, with 90 s recovery between speeds and 3 min between legs	Milk	Consumed 500ml of milk after trial	↓CK, ↓ sTnI 0-10 (VAS)
Rankin et al. 2018 (37)	Age 22.1 ± 1.8 years Heigth1.7±00.9 m Weight 61.9±8.1 Kg SUPP: n=5 PLA: n =5	RCP	Intermittent cycling protocol (standardised warm-up, five 2-min blocks of the protocol and one 15s maximal sprint)	Milk	Consumed 500ml of milk after trial	↔ CK, ↔hs-CRP
Terrazas et al. 2019 (25)	Age 33 ± 5 years SUPP: n = 5 PLA: n = 5	RCP	Cycling training routines, with an average training load of 1500 AU/week	Açaí: Açaí pulp	Consumed 400 g of açai pulp daily, immediately after training, for 15 days	↓LHD, ↓ IL-6, ↓TNF-α, ↑ATi
Trombold et al. 2011 (40)	Age 22 ± 2 years Height 1.8 ± 0.08 Weight 80.2 ± 7.5 kg SUPP: n = 17 PLA: n = 17	COR	Eccentric contractions of elbow extensors for 3 sets x 20 reps at maximal effort	Pomegranate: Pomegranate juice	Consumed 250mL twice per day across 15 consecutive days (7 days prior, the day of, and 7 days post-trial)	↑Elbow flexor and knee extensor strength 0–10 VAS

Tsitsimpikou et al. 2013 (48)	SUPP: Age 24 ± 4 years Height 1.7 ± 0.1 m Weight 74.1 ± 16.6 kg PLA: Age 22 ± 3 years Height 1.7 ± 0.06 m Weight 71.5 ± 8.04 kg SUPP: n = 9 PLA: n = 6	RCP	Supine sessions of at least 30 min	Tomato: Tomato juice	Consumed 100ml of tomato juice during and post-exercise sessions	↓CPK, ↓ LHD
Urbaniak et al. 2018 (41)	SUPP: Age 21 ± 1 years Height 1.9 ± 0.07 m Weight 89.4 ± 9.0 kg PLA: Age 21 ± 1 years Height 1.9 ± 0.06 m Weight 83.9 ± 12.0 kg SUPP: n = 10 PLA: n = 9	RCP	A 2000m rowing time-trial test	Pomegranate: Pomegranate juice	Consumed 50mL daily during a 2- month training camp	CK, MG, IL-6, UA ↔ ↑TAC

COR, crossover randomized; design; RCP, randomized controlled placebo: CK, creatine kinase; CMJ, countermovement jump; CRP, c-reactive protein; DOMS, delayed onset muscle soreness; HR, heart rate; hs-CRP high-sensitivity C-reactive protein IL-6, interleukin-6; IL-8, interleukin-8; LDH Lactate dehydrogenase, MG, Myoglobin; MIVC, maximal isometric voluntary contraction; PC, protein carbonyls; RM, repetition maximum; TAS, total antioxidant status; TNF-α tumor necrosis factor TEAC, trolox equivalent antioxidant capacity; VO2max, maximal oxygen uptake; VO2peak, peak oxygen uptake. Significance of the effect (↑↓positive or negative effects and ↔ no effects).

Risk of bias

Of the 32 studies, 19 were valuated as having some concerns and 13 as having high risk of bias. The factors that influenced the results of the studies were: missing of information manuscript; failure to blind participants; issues with randomisation; and lack of information on adherence to the intervention. The problem with the included studies was that none pre-registered their study protocol so there was no way of confirming whether they had a pre-specified data analysis plan.

Study ID	Experimental	Comparator	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Abbot et al. 2020 (30)	Tarty cherry	Placebo	+	+	+	+	!	!
Ammar et al. 2016 (42)	Pomegranate	Placebo	+	+	+	!	+	!
Bell et al. 2015 (10)	Tarry cherry	Placebo	+	+	!	+	+	!
Bell et al. 2016 (31)	Tarty cherry	Placebo	+	+	-	!	!	-
Bowtell et al. 2011 (1)	Tarty cherry	Placebo	+	+	+	+	!	!
Brown et al. 2019 (32)	Tarty cherry	Placebo	!	!	+	+	!	!
Carvalho et al. 2018 (54)	Plum	PLacebo	!	!	+	-	+	-
Clinford et al. 2016 (47)	Beetroot juice	PLacebo	+	!	+	+	!	!
Clinfford et al. 2016 b (46)	Beetroot juice	PLacebo	!	!	+	+	!	!
Clinfford et al. 2017 (15)	Beetroot juice	Placebo	+	!	+	+	!	!
Cockburn et al. 2012 (37)	Milk	Placebo	-	!	+	+	!	-
Cockburn et al. 2013 (38)	Milk	Placebo	-	!	+	!	!	-
Conolly et al. 2006 (33)	Traty cherry/apple blend	Placebo	-	-	+	+	!	-
Davison et al. 2012 (48)	Dark chocolate	Placebo	!	+	+	+	+	!
Dimitriou et al 2015 (34)	Tarty cherry	Placebo	!	!	+	!	+	!
Howatson et al. 2010 (35)	Tarty cherry	Placebo	!	-	+	-	!	-
Hutchison et al. 2016 (56)	Black current nectar	Placebo	!	!	-	!	-	-
Isawa et al. 2013 (39)	Fermented milk	Placebo	+	!	-	+	-	-
Lynn et al. 2018 (13)	Bilberry juice	Placebo	+	+	+	+	!	!
Machin et al. 2014 (43)	Pomegranate juice	Placebo	+	!	+	+	!	!
Martinez et al. 2017 a (51)	Watermelon juice	Placebo	+	+	+	!	+	!
Martinez et al. 2017 b (50)	Watermelon juice	Placebo	+	!	+	!	+	!
McCormick et al. 2016 (36)	Tarty cherry	Placebo	+	+	+	+	!	!
Morgan et al. 2018 (49)	Cocoa juice	Placebo	+	+	!	+	!	!
Niemam et al.2018 (53)	Cavendish banana	Placebo	!	-	!	+	+	-
O'Connor et al. 2013 (57)	Grape beverage	Placebo	!	!	+	!	+	!
Rankin et al. 2015 (40)	Milk	Placebo	!	!	+	+	!	!
Rankin et al.2018 (41)	Milk	Placebo	!	-	+	!	!	-
Terrazas et al. 2019 (22)	Açaí pulp	Placebo	+	!	+	-	!	-
Trombold et al. 2011 (44)	Pomegranate	Placebo	!	!	+	+	!	!
Tsitsimpikou et al. 2013 (52)	Tomato juice	Placebo	!	-	+	+	-	-
Urbaniak et al. 2018 (45)	Pomegranate juice	Placebo	+	-	+	+	!	-

+ Low risk
! Some concerns
- High risk

Figure 2. Risk of bias toll 2 [27].

DISCUSSION

The current systematic review examined whether whole food supplementation ameliorates indices of EIMD. According to strict inclusion criteria, 32 articles were included, with: (1) either utilizing a randomized, controlled, placebo design or cross-over, randomized design; (2) incorporating both food and placebo conditions; (3) demonstrating standardized baseline measures; (4) including food or concentrated food with other component sources. The studies included in this systematic review investigated the effect of thirteen different types of food and the results in the recovery of EIMD. This systematic review demonstrated that the expression “food first” should mean that “whenever possible”, the nutrient supply should come from whole foods and drinks, rather than from isolated food components or dietary supplements.' In general, the nutritional quality of food is primarily based on the relative quantities of each individual nutritional component (e.g., protein, carbohydrates, lipids, and micronutrients). However, the holistic properties of foods and their potential influence on post-exercise muscle protein remodelling and repair have not been extensively studied. The food matrix refers to the overall chemical dynamics of food, which includes how various food components are structured and interact [18]. There are many reasons to utilize a food strategy in the first place, including the risk of contamination by supplements, resulting in anti-doping violations [17]. Our study showed that food first can be utilized as a recovery strategy, allowing to optimize, and improve the performance of the athlete.

This systematic review also suggests that the consumption of polyphenol-rich foods and concentrates provides practitioners and athletes with a low-risk, food-first approach, as strategy that can be used to improve recovery in scenarios where optimizing rapid recovery is key. Different foods vary in their profile of polyphenols and other bioactive compounds (e.g., beetroot is rich in nitrate and betalains) [59], which could determine their ability to accelerate

recovery from EIMD. Our research found many studies that used polyphenol-rich foods showing great results for muscle recovery. Polyphenols are amphipathic, exerting their antioxidant effects in both lipid and water milieu, and act in vivo by several mechanisms on cellular molecular targets [60). This ability of polyphenol supplements to accelerate recovery is expected to be higher in participants who ingested the same amount of polyphenols but resorted to polyphenol-rich foods. Hill et al. [61] conducted a systematic review and meta-analysis on the effect of tart cherry (juices, concentrates, and extracts) on recovery from EIMD. They found moderate beneficial effects on muscular power and recovery of muscular strength and small beneficial effects on DOMS. Doma et al. [8] found a reduction in markers of muscle damage, inflammation, and oxidative stress at 24h and 48h post-exercise. Lynn et al. [13] found similar results with beneficial effects not only at 24h and 48h post-exercise but also at 96h.

Therefore, in addition to physiological markers of stress, the current systematic review identified that fruit supplementation reduced levels of DOMS while acutely improving muscular force measures for the FOOD condition, when compared to the PLA condition. In the current systematic review, a included studies demonstrated significantly lower levels of muscle damage, inflammatory, and oxidative stress markers for the FOOD condition than the PLA condition, suggesting that phytochemicals in the fruits may interfere with the cascade of events leading to the secondary muscle damage response. Thus, it is plausible to consider that fruit supplementation accelerates recovery, reduces symptoms of DOMS, and attenuates the level of decline of muscular function.

Cherries

Tart cherries are considered to have a high content of numerous phytochemicals possessing antioxidant properties, including anthocyanins and quercetin [61]. These fruits also contain vitamins C and E and some carotenoids, especially beta-carotene [62]. The consumption of cherries has also been

associated with anti-inflammatory effects, namely through the inhibition of the activity of cyclooxygenase II [5]. Considering the natural anti-inflammatory and antioxidant capacity of tart cherries, it is plausible that cherry consumption before and after eccentric exercise may have a protective effect [29].

Nine [10,11,26-32] of the thirty-two studies using food as the intervention to attenuate the consequences associated with muscle damage used cherries as the treatment. Among the nine studies, eight showed positive and promising results for performance recovery.

In only one study conducted in professional players [26], the results demonstrated that tart cherry juice does not have a positive effect, namely in the acceleration of recovery.

Milk

Cow's milk and its derivatives represent a very good source of protein, lipids, amino acids, vitamins, and minerals. Milk has several characteristics that make it an interesting recovery drink. One of its advantages is that it contains both casein and whey proteins in a ratio of approximately 3:1, which results in sustained elevations of blood amino acid concentrations [5].

Milk is a source of carbohydrates and antioxidants, including vitamin E, vitamin A, and glutathione, which are effective in reducing lipid peroxidation. [63] The antioxidant activity of milk and dairy products can be enhanced by phytochemical supplementation, while fermented dairy products have been reported to contain higher antioxidant capacity compared to non-fermented dairy products [64].

Five of the thirty-two studies using food as the intervention to attenuate the consequences associated with muscle damage used milk as the treatment. One study used fermented milk, showing that serum creatine phosphokinase that significantly increased by exercise, was inhibited after consuming fermented milk. This result suggests that fermented milk improved glucose

metabolism and alleviated the effects of EIMD, possibly associated with the regulation of antioxidant capacity [35].

In another four studies, one [37] of which utilized the volume of milk as a comparator, authors found that consuming 1000 ml of milk after 72h after exercise limited the decrement in peak torque compared to the placebo. After 48 hours, the milk group had a likely benefit for limiting increases in CK compared to the placebo, but no changes were observed in peak torque and CK when comparing the consume of 500 ml or 100 ml of milk.

Another three studies milk studies [33,34,36] investigated 500 ml of milk as protocol. It was possible to notice that 48h after intervention milk had a possible benefit for limiting increases in 10-m sprint time and a likely benefit in attenuating increases in mean 15-m sprint time during the Loughborough Intermittent Shuttle Test. At 72h, milk had a possible benefit for limiting increases in 15-m sprint time and a likely benefit for the attenuation of increases in agility time. All other effects for measured variables were unclear. This study [34] showed that milk seems to limit decrements in one-off sprinting and agility performance and in the ability to perform repeated sprints during the physiological simulation of field-based team sports.

Pomegranate

Pomegranate has the capacity to inhibit oxidative processes and accelerate the breakdown and removal of oxidized lipids [65]. This fruit has also been studied in the health field, particularly regarding the development of atherosclerosis and its consequent cardiovascular events [66]. Pomegranate is considered a potent polyphenol-rich food, containing mainly ellagitannins and their derived metabolites, which can protect against various types of free radical oxidants [5].

Pomegranate has been studied with interesting and positive results [39-40]. In one study [12] the ingestion of pomegranate juice was associated with the attenuation of weakness, improved strength recovery, and reduction of soreness in the elbow flexor muscles in resistance trained men after eccentric

exercise. In another study [38], that enrolled elite weightlifters, POMj reduced the acuteness of pain, delayed responses of muscle damage and inflammation, and muscle soreness in the knee flexor and accelerate the recovery kinetic of biological parameters and improving weightlifting performance after an Olympic weightlifting training session.

Additionally, a study showed that pomegranate juice supplementation resulted in significantly higher isometric knee extensor and elbow flexor strength throughout the 96-hour period after eccentric exercise compared to a placebo [39]. Another study demonstrated that the administration of pomegranate fruit juice, a dietary supplement with established high antioxidant potential, boosted the total antioxidant capacity (TAC) of the study athletes but had no significant effect on inflammatory markers or other parameters analysed [40].

Beetroot

Beetroot is a vegetable rich in nitrate (NO_3^-), antioxidants, and phenolic compounds that are associated with improvements in cardiovascular function and exercise performance [67]. Beetroot juice (BTJ) is composed of phytonutrients and has a high antioxidant capacity [68], demonstrating the ability to scavenge ROS production in vitro and in vivo and subsequently limit cellular injury. These effects are attributed to the betalain pigments, which give beetroot its violet colour [69]. Betalains, including betanin, are highly effective electron donors known not only to attenuate ROS-mediated injury but also to upregulate endogenous antioxidant enzymes and stimulate host defence mechanisms. Additionally, BTJ is rich in nitrate, which, through its reduction to nitric oxide (NO), might exert indirect antioxidant effects by suppressing the accumulation of leukocytes [42,43].

Clifford and colleagues (15) suggested that BTJ is more effective for attenuating muscle pain associated with EIMD than sodium bicarbonate, and

that any analgesic effects are likely due to phytonutrients in BTJ other than nitrate, or interactions between them. Also, another study (46) demonstrated that consuming BTJ attenuated muscle pain, and decrements in dynamic muscle function, as measured by CMJ. Similar results were observed by the same author (47) where beetroot juice attenuated muscle soreness and decrements in CMJ performance induced by eccentric exercise.

Given its high nitrate, phenolic and betalain content, beetroot juice would, in a dose-dependent manner, help to protect against the potentially harmful effects of acute exercise-induced inflammation.

Berries

Berries are fruits particularly rich in antioxidants, and it is believed that the phenolic compounds – including phenolic acids, tannins, namely ellagitannins, and flavonoids as anthocyanins, flavanols and flavanols – are mainly responsible for their antioxidant properties [5]. Plant derived polyphenols exhibit anti- inflammatory effects and emerging evidence suggests they can reduce exercise- induced inflammation and soreness [13].

The studies that used bilberry juice (BJ) [13] found that it may have a small to moderate effect in preventing the increase in muscle soreness and inflammation. Another study using acai pulp [25] found a notable effects on antioxidant status of athletes, showing that açai pulp can decrease lipid peroxidation and increase serum antioxidant capacity, modulate the blood lactate levels and raise the anaerobic threshold intensity.

Lyall et al [53] showed that blackcurrant consummation for four days after a bout of eccentric leg exercise significantly reduced circulating markers of muscle damage while maintaining circulating antioxidant capacity.

Cocoa

There has recently been a great deal of research interest in the potential beneficial effects of cocoa due to its potent antioxidant properties and the presence of polyphenols, of which cocoa is an abundant source [70]. The potential antioxidant and anti-inflammatory qualities of cacao polyphenols [71] suggest that improvements in recovery could also be achieved with cacao supplementation.

Cocoa was used in two studies [44, 45] in the form of dark chocolate. Its consumption has shown to affect insulin, glucose, antioxidant status, and oxidative stress responses, but had minimal effects on immunoendocrine responses to prolonged exercise. Additionally, cocoa used 7 days prior to and 2 days after intensive knee extensor exercise improved functional recovery, as shown by an improved recovery of CMJ up to 48 h post-exercise [45].

Watermelon

Watermelon is a rich source of lycopene and L-citrulline [72]. Lycopene is an important antioxidant with anticancer properties [73], while L-citrulline, a non-essential amino acid, reduces lactic acid accumulation, allowing for higher resistance exercise performance to exhaustion [74] and a precursor of arginine with positive effects after high-intensity exercise [73]. L-citrulline is an essential component of the urea cycle in the liver, responsible for detoxifying ammonia via conversion to urea [75].

In the two studies that used watermelon juice [46,47], basal levels of muscle damage blood markers such as lactate dehydrogenase and myoglobin were maintained. Additionally, there was a significant maintenance of force during exercise and a significant decrease in the rating of perceived exertion and muscle soreness after exercise was seen [46]. A watermelon juice enriched in L-citrulline dose diminished muscle soreness perception from 24 to 72 hours after the race and maintained lower concentrations of plasma lactate after

exhausting exercise, with muscle soreness perception significantly lower compared to the placebo [47].

Other potential foods

We found potential in other foods, such as tomato [48], bananas [49], plums [51], and grape [54] with interesting results in those studies. The carotenoid lycopene derived from tomatoes has been described for its antioxidant activities on the cellular level [76]. Processed tomato products, like commercially available tomato juice, are the primary dietary source of lycopene in western countries, possessing equal antioxidant properties, and even reducing oxidative DNA damage [77]. Administering tomato juice to anaerobically trained athletes with elevated baseline levels of CPK and LDH led to a significant decrease, possibly reflecting the antioxidant and myocardial protective effect of tomato juice and its main component, lycopene [48].

Bananas are the most widely produced and consumed fruit globally and are an important source of carbohydrate energy, potassium, vitamin B6, vitamin C, and other micronutrients [78]. Of the hundreds of different varieties that exist around the world, the Cavendish banana is the most widely consumed and exported [50]. This banana also contains a unique blend of secondary metabolites such as phenolics (7 mg/100 g fresh pulp), carotenoid compounds (73 µg/100 g), and catecholamines including dopamine (9.1 mg/100 g) and serotonin (2.8 mg/100 g) [79]. In the study that used banana [49], the ingestion of Cavendish banana had influence attenuating metabolic perturbation and inflammation in cycling athletes.

The intake of banana carbohydrate at a rate of 0.2 g/kg every 15 minutes was associated with higher post-exercise plasma glucose and fructose, reduced plasma cortisol levels, diminished perturbation in lipid-related metabolites, and lower inflammation as assessed by total leukocyte count [49].

The health benefits of consumption of plum have been associated with high phenolic compounds, such as gallic acid and flavonoids (catechin, epicatechin,

epigallocatechingallate, and epicatechingallate, in the literature, demonstrating antioxidant and anti-inflammatory activity, as well as hypoglycemic effects [80]. In one study using plums [51], the results showed an improvement of the vertical jump performance, and a decreased fatigue in the athletes, reducing biomarkers of oxidative stress and muscle damage, and improved psychological response.

Compounds in grapes, such as catechins, resveratrol, and quercetin, exhibit anti-inflammatory properties [81] natural products such as grapes allow for interactions among multiple anti-inflammatory agents in EIMD [82]. The effects of resveratrol have now been linked with a wide variety of chronic ailments including cancer, cardiovascular diseases, skin disorders, diabetes, neurological diseases, arthritis, and even the aging process [83]. O'Connor et al used grapes [54] in recreationally active young adults and showed that there was no effect on VO2max, work capacity, mood, perceived health status, inflammation, pain, or physical-function responses to a mild injury induced by eccentric exercise.

Limitations

Out of the 32 studies, nine recruited well-trained athletes, comprising 28.1% of the total participants. Additionally, only 19% of the participants included in this review were female. Male and female participants were combined in eight studies [12, 28, 30, 31, 36, 48, 49, 52]. It has been reported that estrogen may protect muscles from injury by reducing inflammation [55]. However, these studies failed to report whether they controlled for stages of the menstrual cycle. Additionally, it has been reported that estrogen could influence skeletal muscle growth, gene expression, metabolism, contraction characteristics, and maintain muscle mass [56, 57].

CONCLUSION

This systematic review demonstrated that foods (i.e., cocoa, milk), as a juices, or concentrates may accelerate recovery of muscle function and reduce muscle soreness after EIMD. This magnitude of recovery could benefit athletes in scenarios where there is limited time between competitive events and in situations where impaired recovery can negatively impact performance. Using food as the main method for recovery may be useful in situations where EIMD impairs muscle function for extended periods of time, such as after very heavy training loads, or at the initiation of a training program.

The mechanisms through which food enhances recovery is uncertain, but inhibition of inflammation and enhanced antioxidant capacity may play a key role. Knowing the necessary amounts of each food is important for a better use of its components. Some foods have the potential to be considered effective as a recovery option, especially if combined, to ensure delivery of proteins, carbohydrates, antioxidants, and anti-inflammatory nutrients. The use of the combination between them can guarantee a greater potential of the components in the recovery of the EIMD.

It is clear, therefore, that more studies in this specific field are needed. It is fundamental to have scientific evidence about which types or combinations can improve the recovery from EIMD.

In this review, little evidence of a reduction in either inflammation or oxidative stress was evident. This could reflect limitations in the blood-based methods used by the studies included in this review. Future studies should adopt larger methods of determining inflammation and redox status within muscle tissue to unravel the mechanisms through which food can enhance recovery from EIMD.

Additionally, and to elucidate the effects of real food on recovery from EIMD, there is a need for future studies to accurately characterize the composition of the products used, identify the optimal dose, measure the appearance of metabolites of the food supplement in urine and blood. It remains unclear

what the optimal duration of whole food supplementation is, and whether ingestion should start before or after muscle damage has started.

This review also highlighted that females were underrepresented in the literature and no studies had directly compared the differences in the effects of specific food supplementation on recovery between sexes. Thus, future research opportunities exist to address this gap. Most participants included in the studies were recreationally trained athletes. It is important to confirm the effects of supplementation in well-trained and elite athletes who are more likely to experience limited recovery times between competitions. All the studies included in this review were rated as having 'some concerns' or 'high' risk of bias. Thus, there is a need for higher quality randomized controlled trials investigating whole food on recovery from EIMD.

In conclusion, this systematic review suggests that the consumption of foods, juices, and concentrates provides practitioners and athletes with a low-risk, food-first approach for enhancing recovery in scenarios where optimizing rapid recovery is key. Further investigation is required to determine the optimal duration and dosage of food supplementation and explore whether enhanced recovery comes at the expense of impaired adaptation. There is also a need for more studies to investigate the effect in well-trained and elite athletes.

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