Review

Selected root plant supplementation reduces indices of exercise-induced muscle damage: A systematic review and meta-analysis

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Abstract: This systematic review and meta-analysis examined the effects of selected root plants (curcumin, ginseng, ginger and garlic) on markers of muscle damage and muscular performance measures following muscle-damaging protocols. We included 25 studies (parallel and crossover design) with 353 participants and used the PEDro scale to appraise each study. Forest plots were generated to report on standardised mean differences (SMD) and p-values at 24 and 48 hours following the muscle-damaging protocols. The meta-analysis showed that the supplemental (SUPP) condition showed significantly lower levels of indirect muscle damage markers (creatine kinase, lactate dehydrogenase and myoglobin) and muscle soreness at 24 hours and 48 hours ($p < 0.01$) than the placebo (PLA) condition. The inflammatory markers were significantly lower for the SUPP condition than the PLA condition at 24 hours ($p = 0.02$), although no differences were identified at 48 hours ($p = 0.40$). There were no significant differences in muscular performance measures between the SUPP and PLA conditions at 24 hours and 48 hours ($p > 0.05$) post-exercise. According to our qualitative data, a number of studies reported a reduction in oxidative stress (e.g., malondialdehyde, superoxide dismutase) with a concomitant upregulation of anti-oxidant status, although other studies showed no effects. Accordingly, selected root plants minimised the level of several biomarkers of muscle damage, inflammation and muscle soreness during periods of exercise-induced muscle damage. However, the benefits of these supplements in ameliorating oxidative stress, increasing anti-oxidant status and accelerating recovery of muscular performance appears equivocal, warranting further research in these outcome measures.

Keywords: Curcumin, ginseng, ginger, garlic, polyphenol, phytochemical, recovery

Introduction

Exercises consisting of eccentric contractions cause muscle damage for several hours to days post-exercise in athletes of various training backgrounds [1]. The common symptoms of exercise-induced muscle damage (EIMD) include increased stress markers (e.g., creatine kinase [CK]), delayed onset of muscle soreness (DOMS), limited joint range-of-motion and compromised muscular contractility [2]. Studies have shown that these acute responses impair vertical jump ability [3, 4], running economy [5–7], cycling power output [8] and sprint and agility performance [9, 10], which are important determinants for sport performance. Whilst it is believed that the exercise-induced stress stimulus is essential for positive adaptations, undertaking training during extended periods of EIMD may interfere with optimal adaptation, or increase the risk of overtraining and injuries [1, 11]. However, several recovery strategies have been developed to ameliorate the signs and symptoms of EIMD, optimise training adaptation and enhance preparedness for competitive events [12], with dietary supplements derived from root plants becoming increasingly popular in recent years.

Root and rhizome plants originating from Asia have historically been used as herbal medicine to remedy clinical symptoms, improve health and prevent chronic disease in Asian countries [13–15]. The most widely employed root plants considered effective for medicinal purposes includes curcumin, ginseng, ginger and garlic [13]. Curcumin, also referred to as diferuloylmethane, is a polyphenol normally found in the tumeric of the Curcuma long plant, and has been extensively used as a herbal remedy for centuries to treat several diseases by exerting anti-inflammatory, anti-microbial, antiviral, anti-atherosclerotic and anti-cancer effects [14]. For ginseng, the most commercially available types are Panax ginseng grown in China and Korea and

Panax quinquefolius grown in the United States and Canada. Both Panax ginseng and Panax quinquefolius consist of ginsenosides, frequently owing to their antioxidative, anti-inflammatory and anti-diabetic properties [16]. Ginger, a monocotyledonous plant that originated in Southeast Asia, has several pharmacological effects including the amelioration of physiological problems associated with inflammation, diabetes, cancer, gastrointestinal problems, obesity and metabolic syndrome due to its anti-inflammatory, antioxidant, antitumor and antiulcer effects [15, 17]. Garlic is a natural antibiotic, typically incorporated in lipid and blood pressure lowering drugs, and is known to enhance the immune system [13]. Collectively, these root plants are potent anti-inflammatory and antioxidant food sources, and it is these properties that are believed to counteract the stress response that contributes to EIMD following strenuous activity by modulating oxidative stress and inflammation, also referred to as the secondary muscle damaging response [18]. Interventions to ameliorate the negative stress response (i.e., impaired muscular and physiological function due to extended periods of EIMD) is necessary.

For example, when compared to placebo conditions, studies have reported lower levels of EIMD markers (e.g., creatine kinase, inflammation, oxidative stress and muscle soreness), and improved muscular performance (e.g., maximal isometric contractions) with the consumption of curcumin [19, 20], ginseng [21], ginger [22] and garlic [23] for several days after muscle-damaging exercises. However, the degree of effectiveness to ameliorate the signs and symptoms of EIMD appears to vary substantially between studies, making overall interpretations difficult [24–26]. Therefore, a review of literature to systematically address these factors is pertinent, to determine whether commonly used, and commercially available root plants ameliorate EIMD markers.

More recently, narrative reviews have been published examining studies that have reported on the effects of curcumin, ginger and ginseng [14, 27, 28] during periods of EIMD, with findings suggesting these root plants may minimise the level of EIMD and provide ergogenic effects in sport [27, 28]. However, no systematic reviews have examined the effects of root plants on EIMD markers and their consequential effects on physical performance measures via a meta-analysis as far as we are aware. Appraising the quality of studies that have examined the effects of root plants on EIMD markers, and statistically comparing supplements derived from root plants with placebo conditions based on pooled data, will provide a better understanding of the benefits of root plants for recovery following strenuous exercise. Thus, the purpose of the current systematic review and meta-analysis was to examine whether selected supplemented root plants (i.e., ginger, curcumin and ginseng) ameliorate the signs and 101 symptoms of EIMD and improve muscular function and functional performance.

Methods

The PRISMA statement (see Electronic Supplementary Material 1), which guides systematic reviews for transparent and complete reporting of studies, was used to complete this systematic review.

Inclusion/exclusion criteria

Studies were included in the current systematic review using the following inclusion criteria: 1) studies were conducted in humans; 2) studies monitored acute responses following muscle damage-inducing protocols (e.g., isokinetic eccentric contractions, downhill running, resistance training plyometrics) for at least 24 hours post-exercise; 3) studies included measures of blood biomarkers indicative of exercise-induced stress (i.e., muscle damage and inflammation), markers of delayed-onset muscle soreness or muscular force measures; and 4) studies incorporated supplements with ginger, curcumin and/or ginseng. The following exclusion criteria were utilised: 1) the physical performance measures were examined for chronic training adaptations (e.g., several weeks to months of training) with supplements, rather than acute responses; 2) the outcome measures met the inclusion criteria, but were only monitored for less than 24 hours after the muscle damage-inducing protocol; 3) studies were conducted in animals; 4) studies were published in a language other than English or Farsi; and 5) results were published as a conference abstract, review or case report.

Outcome measures

The outcome measures for the current systematic review included the following: 1) biomarkers for exercise-induced stress, separated by muscle damage (i.e., CK, myoglobin and lactate dehydrogenase [LDH]) and inflammation (i.e., interleukin-1 [IL-1], interleukin-6 [IL-6], interleukin-8 [IL-8], C-reactive protein [CRP] and tumour necrosis factor alpha [TNF-α]; 2) DOMS; and 3) isometric and isokinetic muscular contractions.

Search strategy

The literature search was conducted from December 20th–22nd, 2019, via four electronic databases, including PubMed, Cinhal, SportDiscus and Scopus. For the PubMed search, four categories of MeSH terms were combined,

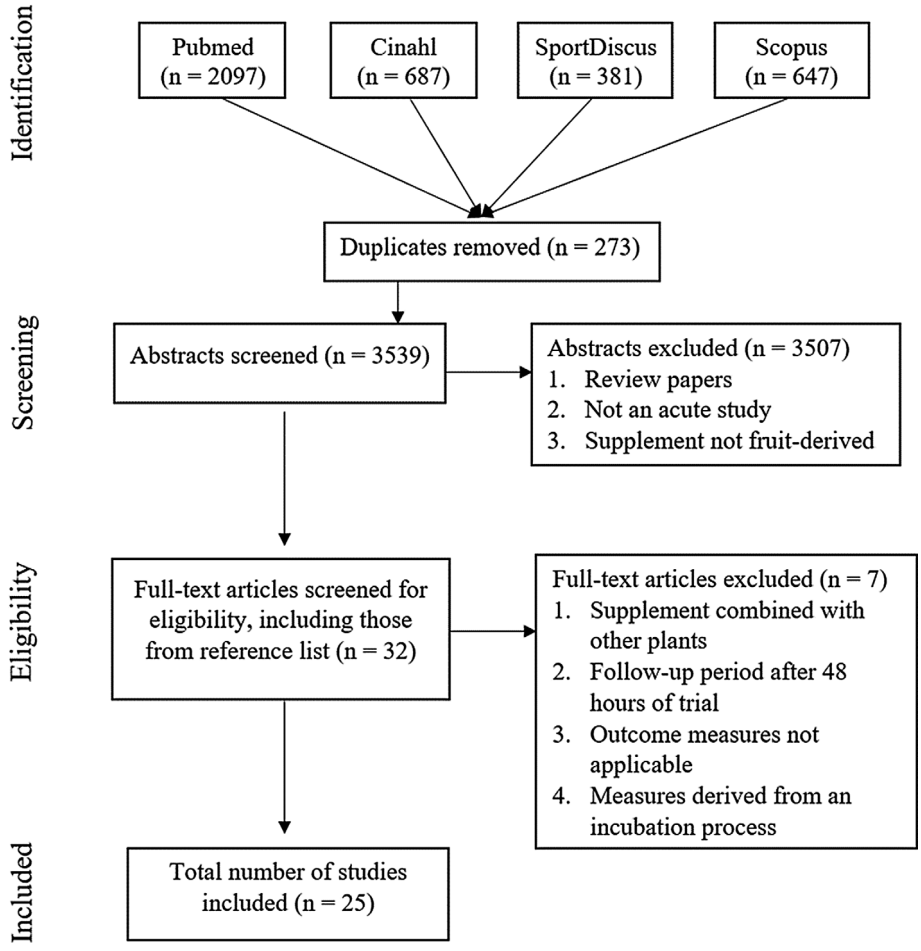

Figure 1. Flow chart according to the PRISMA guidelines.

including: 1) humans; 2) supplements (Anti-Inflammatory Agents or Antioxidants or Fruit or Functional Food or Sports Nutritional Physiological Phenomena or Flavonoids or Polyphenols or Citrullus or Fruit and Vegetable Juices or Dietary Supplements); 3) biomarkers of exercise-induced stress (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); and 4) muscle damage-inducing protocols (High-Intensity Interval Training OR Physical Exertion OR Plyometric Exercise Isometric Contraction OR Exercise Tolerance OR Exercise OR Resistance Training OR Running). The subject headings were treated similarly for the Cinhal database search, with free text search conducted in both PubMed and Cinhal from 18 months prior (June 2018 to current literature search date). The free text terms included: (eccentric or plyometric* or strength or resistance or training or exercise) and (muscle damage or creatine kinase or inflammation or soreness or oxidative stress) and (*root plants*).

Selection process

The literature search was conducted by two authors (KD and BDT) who have graduate degrees in Exercise Science. Firstly, all abstracts written in English were screened using the inclusion/exclusion criteria and were classified as either 'yes' (definitely meeting the criteria), 'maybe' (possibly meeting the criteria) or 'no' (not meeting the criteria) by the first author (KD). Secondly, the first author trained the second author (BDT) on the use of the inclusion/exclusion criteria with the first 300 abstracts. Finally, this co-author screened a random sample of 40% of abstracts to report on the inter-rater reliability of the inclusion/exclusion criteria [29]. Accordingly, the inter-rater reliability was considered 'excellent', with a Weighted Kappa statistic of 0.83 (95% confidence interval: 0.75–0.93). The third author (DG) is an English/Farsi bilingual with post-graduate

Table 1. Participant characteristics and baseline comparisons of included studies

Authors	Design	Sample size (n)	Physical characteristics	Training background	Baseline comparisons
Barzanjeh et al. [40]	RCP	SUPP: n = 10 PLA: n = 10	SUPP: Age 19 ± 1 years; height 1.84 ± 0.09 m; weight 71 ± 1.3 kg PLA: Age 20 ± 2 years; height 1.79 ± 0.09 m; weight 68 ± 1.4 kg	Second division male volleyball players	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Basham et al. [41]	COR	SUPP: n = 19 PLA: n = 19	Age 22 ± 3 years; height 1.78 ± 0.07 m; weight 83.7 ± 12.4 kg	Healthy, physically active males	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Black et al. [42]	COR	SUPP: n = 27 PLA: n = 27	Male: Age 24 ± 5 years; height 1.8 ± 0.07 m; weight 74.9 ± 16.2 kg Female: Age 22 ± 3 years; height 1.65 ± 0.05 m; weight 61.1 ± 5.5 kg	Have not undertaken resistance training for the previous 9 months	Reported as magnitude of change from baseline
Black et al. [43]	RCP	SUPP: n = 20 PLA: n = 20	Raw ginger: Age 21 ± 1 years; height 1.72 ± 0.02 m; weight 70.3 ± 3.8 kg Placebo with raw ginger: Age 21 ± 1 years; height 1.66 ± 0.02 m; weight 62.3 ± 1.7 kg Heated ginger: Age 21 ± 1 years; height 1.73 ± 0.02 m; weight 71.1 ± 3.0 kg Placebo with heated ginger: Age 21 ± 1 years; height 1.7 ± 0.03 m; weight 65.6 ± 2.7 kg	Have not undertaken resistance training for the previous 9 months	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Caldwell et al. [44]	COR	SUPP: n = 19 PLA: n = 19	Male: Age 41 ± 10 years; height 1.77 ± 0.05 m; weight 88.5 ± 5 kg Female: Age 39 ± 8 years; height 1.64 ± 0.05 m; weight 76.0 ± 11.6 kg	Healthy, active participants	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Drobnic et al. [45]	RCP	SUPP: n = 9 PLA: n = 10	SUPP: Age 33 ± 12 years; height 1.77 ± 0.04 m; weight 76.2 ± 3.6 kg PLA: Age 38 ± 11 years; height 1.75 ± 0.03 m; weight 75.8 ± 6.5 kg	NR	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Flanagan et al. [46]	COR	SUPP: n = 19 PLA: n = 19	Male: Age 41 ± 10 years; height 1.77 ± 0.05 m; weight 88.5 ± 5 kg Female: Age 39 ± 8 years; height 1.64 ± 0.04 m; weight 76.0 ± 11.6 kg	Healthy, active participants	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Hamid Abad et al. [47]	COR	SUPP: n = 10 PLA: n = 10	Age 25 ± 2 years; height 1.79 ± 0.04 m; weight 81.1 ± 6.8 kg	NR	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Hoseinzadeh et al. [22]	RCP	GIBE: n = 12 GIAE: n = 12 PLA: n = 12	Age 22 ± 3 years; height 1.59 ± 0.06 m; weight 57.1 ± 8 kg	Untrained participants	Significant greater IL-6 for GIAE and PLA compared to GIBE at baseline ($p < 0.05$), although no differences between groups for the other measures
Jager et al. [48]	RCP	SUPP 50 mg: n = 20 200 mg: n = 21 PLA: n = 21	SUPP 50 mg: Age 21 ± 2 years; height 1.73 ± 0.09 m; weight 72.2 ± 15.2 kg; VO_{2max} 43.2 ± 7.2 mL/kg/min SUPP 200 mg: Age 22 ± 2 years; height 1.69 ± 0.09 m; weight 68.2 ± 14.3 kg; VO_{2max} 43.6 ± 7.3 mL/kg/min PLA: Age 21 ± 2 years; height 1.71 ± 0.08 m; weight 69.8 ± 11.3 kg; VO_{2max} 41.6 ± 6.0 mL/kg/min	Healthy participants who remained physically active for at least three months	Baseline measures not reported for biomarkers, but no significant differences between groups at baseline for DOMS

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Table 1. (Continued)

Authors	Design	Sample size (n)	Physical characteristics	Training background	Baseline comparisons
Jung et al. [21]	RCP	SUPP: n = 9 PLA: n = 9	SUPP: Age 20 ± 1 years; height 1.78 ± 0.01 m; weight 67.7 ± 1.8 kg PLA: Age 20 ± 1 years; height 1.75 ± 0.02 m; weight 67.2 ± 2.0 kg	NR	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Jung et al. [49]	RCP	SUPP: n = 9 PLA: n = 9	SUPP: Age 20 ± 1 years; height 1.78 ± 0.01 m; weight 67.7 ± 1.8 kg PLA: Age 20 ± 1 years; height 1.75 ± 0.02 m; weight 67.2 ± 2.0 kg	NR	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Matsumura et al. [25]	RCP	SUPP: n = 10 PLA: n = 10	SUPP: Age 32 ± 9 years; height 1.7 ± 0.12 m; weight 71 ± 20 kg PLA: Age 27 ± 5 years; height 1.74 ± 0.1 m; weight 72 ± 17 kg	Non-weight trained participants	No significant differences between SUPP and PLA conditions at baseline for all selected measures
McFarlin et al. [50]	RCP	SUPP: n = 16 PLA: n = 12	SUPP: Age 20 ± 1 years; height 1.7 ± 0.09 m; weight 62.4 ± 11.4 kg PLA: Age 19 ± 2 years; height 1.70 ± 0.08 m; weight 65 ± 10.3 kg	Have not undertaken resistance training for the past 6 months	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Nakhostin-Roohi et al. [20]	COR	SUPP: n = 10 PLA: n = 10	Age 25 ± 2 years; height 1.79 ± 0.04 m; weight 81.1 ± 6.8 kg	NR	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Nakhostin-Roohi et al. [51]	RCP	SUPP: n = 11 PLA: n = 9	SUPP: Age 26 ± 3 years; height 1.79 ± 0.08 m; weight 68.8 ± 18.8 kg; VO_{2max} 48.4 ± 3.9 mL/kg/min PLA: Age 24 ± 2 years; height 1.79 ± 0.05 m; weight 76.3 ± 8.7 kg; VO_{2max} 50.3 ± 4.9 mL/kg/min	Healthy, active participants	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Nicol et al. [19]	COR	SUPP: n = 17 PLA: n = 17	Age 34 ± 5 years; weight 83.9 ± 10.0 kg	Healthy physically active participants, but no lower limb resistance training	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Pumpa et al. [24]	RCP	SUPP: n = 10 PLA: n = 10	Age 29 ± 6 years; height 1.79 ± 0.06 m; weight 76.4 ± 9.58 kg; VO_{2max} 49.9 ± 7.3 mL/kg/min	Well trained in a variety of sports	Outcomes reported as change from baseline
Rosidi et al. [52]	RCP	SUPP: n = 7 PLA: n = 7	SUPP: Age 17 ± 1 years; height 1.7 ± 0.06 m; weight 64.6 ± 3.3 kg PLA: Age 16 ± 1 years; height 1.7 ± 0.05 m; weight 59.1 ± 4.1 kg	Football athletes	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Samadi et al. [53]	RCP	SUPP: n = 15 PLA: n = 15	Age 22 ± 2 years; BMI 23.5 ± 1.5 kg/m^2; weight 73.6 ± 4.2 kg	Healthy, untrained young men	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Su et al. [23]	RCP	SUPP: n = 8 PLA: n = 8	SUPP: Age 19 ± 1 years; height 1.7 ± 0.13 m; weight 59.5 ± 13.6 kg PLA: Age 19 ± 1 years; height 1.70 ± 0.11 m; weight 61.3 ± 6 kg	Male and female athletes	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Tanabe et al. [54]	COR	SUPP: n = 14 PLA: n = 14	Age 24 ± 2 years; height 1.7 ± 0.08 m; weight 65.2 ± 11.3 kg	Healthy, untrained young men	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Tanabe et al. [26]	PAR	SUPP: n = 8 PLA: n = 8	SUPP: Age 30 ± 3 years; height 1.73 ± 0.06 m; weight 71.2 ± 5.6 kg PLA: Age 28 ± 2 years; height 1.73 ± 0.03 m; weight 65.7 ± 5.9 kg	Healthy, untrained men	No significant differences between SUPP and PLA conditions at baseline for all selected measures
Tanabe et al. [55]	COR	*Experiment 1* SUPP: n = 10 PLA: n = 10 *Experimental 2* SUPP: n = 10 PLA: n = 10	*Experiment 1* Age 29 ± 3 years; height 1.71 ± 0.05 m; weight 64.9 ± 10.1 kg *Experimental 2* Age 29 ± 4 years; height 1.73 ± 0.05 m; weight 70.7 ± 5.8 kg	Healthy, untrained men	No significant differences between SUPP and PLA conditions at baseline for all selected measures

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Table 1. (Continued)

Authors	Design	Sample size (n)	Physical characteristics	Training background	Baseline comparisons
Wilson et al. [56]	RCP	SUPP: n = 8 PLA: n = 12	*Men* SUPP: Age 21 (20–21) years; height 1.73 (1.73–1.73) m; weight 68.5 (60.8–70.3) kg PLA: Age 22 (21–22) years; height 1.79 (1.73–1.85) m; weight 79.4 (78.9–88.0) kg *Women* SUPP: Age 20 (19–22) years; height 1.68 (1.63–1.78) m; weight 60.8 (52.6–70.8) kg PLA: Age 21 (20–22) years; height 1.65 (1.55–1.78) m; weight 61.0 (50.3–77.1) kg	Participated in marathon training for four months prior to study commencement	No significant differences between SUPP and PLA conditions at baseline for all selected measures

RCP – randomised controlled placebo design; COR – cross-over randomised design; SUPP – supplemental condition; PLA – placebo condition; VO_{2max} – maximal oxygen consumption; NR – not reported.

qualifications in Exercise Science and Nutrition, who screened all abstracts written in Farsi. Prior to screening the abstracts written in Farsi, the first author (KD) trained the abstract screening protocol to the third author (DG) using abstracts written in English to ensure standardisation.

Data extraction, assessment of quality and risk of bias

A custom-built electronic form was built on Microsoft Excel to extract data regarding study aims, participant characteristics (e.g., age, height, weight, BMI, training background), research design (i.e., cross-over randomised or randomised controlled placebo), type of root-plant incorporated in the supplement (i.e., ginger, curcumin or ginseng), the type of biomarker for muscle damage (i.e., CK, myoglobin and lactate dehydrogenase) and inflammation (i.e., interleukin-1, interleukin-6, interleukin-8, C-reactive protein and monocyte chemoattractant protein), the type of physical performance measures and the timing of when outcome measures were collected (i.e., either 24 or 48 hours post-exercise). The data was extracted as mean ± standard deviation to generate forest plots for the post-exercise time points (i.e., after the muscle damage-inducing protocol). A modified PEDro rating scale was used to critically appraise the methodological quality of each study. The original PEDro rating scale is an 11-point scoring system used to determine the quality of randomised controlled trials in the Physiotherapy Evidence Database [30]. We then incorporated additional criteria to assess the strength of the study methodologies using previous recommendations [31], including: 1) whether participants were resistance-trained, or were exposed to resistance training within the last 6-months; 2) the bioavailability of the supplement was confirmed; and 3) the amount of active ingredient in the supplement was confirmed according to the manufacturer's nutritional label. These PEDro items were scored with a 'one' (meeting the time) or 'zero' (not meeting the item). The final additional criteria was either given a score of 'two' if participants refrained from taking medication or supplements both prior to *and* during the study, a 'one' if participants refrained from taking medication or supplements either prior to *or* during the study or 'zero' if the item was not met. Thus, the PEDro scale consisted of a maximum possible score of 16, and the grading scheme of the combined PEDro score for each study was as follows: excellent [14–16]; good [11–13]; fair [8–10]; and poor ($\leq$7) [32]. Each study was rated using the PEDro scale by the first (KD) and second (BDT) authors to report on the inter-rater reliability of the scoring system. The intra-class correlation coefficient (ICC) was assessed using statistical software (SPSS, v25, 189 IBM statistics, IL); ICC was determined to be 0.92 (confidence interval; 0.85–0.97), which was considered 'excellent'. Any discrepancies that resulted from the PEDro scoring were resolved by a third independent reviewer (JC), also with a post-graduate qualification in Exercise Science. Funnel plots were also generated using statistical software (RevMan, Version 5.3, Copenhagen: The Nordic Cochrane Centre, 2014) to determine potential publication bias of the pooled data from each study. Although the current systematic review excluded children, and those with chronic disease conditions, every effort was made to minimise participant selection bias by including studies of all healthy adults, irrespective of gender and training background.

Statistical methods

The data extracted for selected outcome measures (biomarkers of muscle damage and inflammation, DOMS and muscular performance) was pooled to meta-analytically examine the effectiveness of root-plant derived supplements using a statistical software package (RevMan, Version 5.3, Copenhagen: The Nordic Cochrane Centre,

Table 2. Methodological description and qualitative results of functional performance outcome measures

Authors	Root-plant supplement	Administration method	EIMD protocol	Biomarker Muscle performance DOMS	Oxidative stress and anti-oxidant status
Barzanjeh et al. [40]	Curcumin	Ingested capsules with 150 mg Curcumin, 30 mg Curcuminoid, 48 mg Ghatti Gum, 4 mg citric acid, 818 mg dextrin and 450 mg Maltose immediately after the muscle-damaging exercise	Seven sets of 20 reps at 50% RM Smith squats, 2 s concentric and 3 s eccentric with the rest time between sets between 1–2 min	TAC, LDH NR 0–100 mm VAS	*Anti-oxidant status* TAC was sig greater in SUPP than PLA 24 and 48 h after training ($p < 0.05$)
Basham et al. [41]	Curcumin	Ingested three 500 mg capsules of curcumin once per day (total of 1.5 g of cucumin/69 mg of curcuminoids) for 28 days, including follow-up testing sessions	Sit-to-stand exercises for a total of 225 repetitions	TNF-α, TAC, MDA, CK, NR 0–20 cm VAS	*Oxidative stress* No significant differences between SUPP and PLA conditions for MDA ($p > 0.05$) *Anti-oxidant status* No significant differences between SUPP and PLA conditions for TAC ($p > 0.05$)
Black et al. [42]	Ginger	Ingested 2 g of dried ginger capsule for 2 days during the follow-up testing sessions	Three sets of eight eccentric exercises in the non-dominant elbow flexors at approximately 120% of concentric 1 RM	NR NR 0–100 mm VAS	NR
Black et al. [43]	Ginger	Ingested six capsules of dried ginger (2 g of ginger) per day for 3 days, including the followup testing sessions	Performed 18 eccentric contractions of the non-dominant elbow flexors at 120% of concentric 1 RM	NR Elbow flexor isometric strength 0–100 mm VAS	NR
Caldwell et al. (44]	Ginseng	Ingested capsules with 960 mg of ginseng by the high dosage group and 160 mg of ginseng by the low dosage group for 14 days before testing	Performed 5 sets of 12 repetitions at 70% of their participant's pre-determined 1 RM on a leg press machine, with 2 min rest in-between sets	NR Ballistic jump 0–100 mm VAS	NR
Drobnic et al. [45]	Curcumin	Ingested capsules with 200 mg of curcumin for 4 days, including 48 hours before testing, the testing day and the 24 hour follow-up period	Downhill running at −10% gradient for 45-min at anaerobic threshold	CK, CRP, IL-8, MCP-1 NR 0 = no pain to 4 = disabling pain	NR
Flanagan et al. [46]	Ginseng	Ingested capsules with 960 mg of ginseng by the high dosage group and 160 mg of ginseng by the low dosage group for 14 days before testing	Performed 5 sets of 12 repetitions at 70% of their participant's pre-determined 1 RM on a leg press machine, with 2 min rest in-between sets	CK, TGC, SD, TAC NR 0–100 mm VAS	*Oxidative stress* No significant differences between SUPP and PLA conditions for TGC and SD ($p > 0.05$) *Anti-oxidant status* No significant differences between SUPP and PLA conditions for TAC ($p > 0.05$)

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Table 2. (Continued)

Authors	Root-plant supplement	Administration method	EIMD protocol	Biomarker Muscle performance DOMS	Oxidative stress and anti-oxidant status
Hamid Abad et al. [47]	Ginger	Ingested capsules with 3 g of ginger daily for 7 days before the muscle-damaging exercise	Performed 3 sets of 1 repetition at 50%, 75% and 100% of 1RM in seven stations (bench press, biceps curl, shoulder press, Military press with dumbbells, Squats, leg curl, ad calf raises), with 1 min to 1.5 min between reps and 2 min between sets	Cortisol, IL-10, TNF-Alpha NR NR	NR
Hoseinzadeh et al. [22]	Ginger	Ingested capsules with 2 g of dried ginger one hour before the muscle-damaging exercise for on group and immediately after the muscle-damaging exercise for another group	Step test on a 46 cm step at a cadence of 15 steps per minute for 20 min	CK, IL-6 Knee extensor isometric strength 0–100 mm VAS	NR
Jager et al. [48]	Curcumin	Ingested capsules with 200 mg of curcumin by the high dosage group and 50 mg of curcumin by the low dosage group for 56 days up to 48 hours before the muscle-damaging exercise	Downhill running at −15% gradient for 45 min at a speed equivalent to 65% of VO_{2max}	NR Knee flexor and extensor isokinetic strength 0–100 mm VAS	NR
Jung et al. [21]	Ginseng	Ingested 20 g of ginseng extract diluted with 200 mL of water per day for 7 days before the muscle-damaging exercise and for 3 days during the follow-up period	Downhill running at −14% gradient for 2 bouts (6 km/hr and 12 km/hr, respectively), interspersed by 5 min recovery, although duration of each running bout not reported	CK NR NR	NR
Jung et al. [49]	Ginseng	Ingested 20 g of ginseng extract diluted with 200 mL of water per day for 7 days before the muscle-damaging exercise and for 3 days during the follow-up period	Uphill running at 15% gradient at 10 km/h for 2 x 45-min bouts, interspersed by 5 min recovery	CK, IL-6 NR 0–10 cm VAS	NR
Matsumura et al. [25]	Ginger	Ingested capsules with 4 g of ginger power for 5 days before the muscle-damaging exercise	Performed 4 sets of 10 repetitions of concentric/eccentric contractions of the elbow flexors at 80% of concentric 1 RM, followed by 4 sets of 10 repetitions of eccentric contractions at 100% of concentric 1 RM, with 1 min rest in-between each set	CK, LDH 1-RM of elbow flexor strength 0–100 mm VAS	NR

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Table 2. (Continued)

Authors	Root-plant supplement	Administration method	EIMD protocol	Biomarker Muscle performance DOMS	Oxidative stress and anti-oxidant status
McFarlin et al. [50]	Curcumin	Ingested capsules with 400 mg of curcumin per day for 5 days before, during, and 4 days after the muscle-damaging exercise	Performed 6 sets of 10 repetitions of eccentric leg press at an estimated 110% of 1RM, with 5 min of rest in-between each set	CK, IL-8, IL-6, TNF-α, IL-10 NR 0–10 cm VAS	NR
Nakhostin-Roohi et al. [20]	Curcumin	Ingested capsules with 150 mg of curcumin immediately after the muscle-damaging exercise	Performed 7 sets of 20 repetitions of squats in a squat machine at under 50% of 1 RM, with 1-3 min of rest between sets	CK, TAC, ALT, AST NR 0–10 cm VAS	*Anti-oxidant status* TAC significantly higher for SUPP condition than PLA condition ($p < 0.05$) at 24-h and 48-h post-exercise
Nakhostin-Roohi et al. [51]	Curcumin	Ingested capsules with 90 mg of curcumin for 7 days before the muscle-damaging exercise	Ran 14 km at maximum effort	TAC, TBARS, TGC NR NR	*Oxidative stress* No significant differences between SUPP and PLA conditions for TBARS and TGC ($p > 0.05$) *Anti-oxidant status* TAC significantly higher for SUPP condition than PLA condition ($p < 0.05$) at 24-h and 48-h post-exercise
Nicol et al. [19]	Curcumin	Ingested capsules with 5 g of curcumin for 5 days, 2.5 days before, and 2.5 days after the muscle-damaging exercise	Performed 5 sets of 10 eccentric single-leg leg press on a leg-press machine at 120% of concentric 1 RM, followed by 2 sets of 10 repetitions at 100% of concentric 1 RM, with 3 min of rest in-between each set	CK, TNF-α, IL-6 Vertical jump Force reading from an algometer	NR
Pumpa et al. [24]	Ginseng	Ingested capsules with 4000 mg of ginseng 1-h before the muscle-damaging exercise, and then another 4000 mg of ginseng immediately after the muscle-damaging exercise	Downhill running at −10% gradient for 5 bouts of 8 min at 80% of participant's maximal heart rate, with 2 min of rest in-between each bout	CK, MG, CRP, IL-1, IL-6, TNF-α Knee flexor/extensor isokinetic strength 0–100 mm VAS	NR
Rosidi et al. [52]	Curcumin	Ingested capsules with 750 mg of curcumin daily for 21 days before the muscle-damaging protocol and during the 4 day follow-up period	Flat running for 5 km at maximal effort	MDA NR NR	*Oxidative stress* The level of MDA was significantly lower for SUPP than PLA condition at 48-h post-exercise ($p < 0.05$)
Samadi et al. [53]	Curcumin	Ingested capsules with 1000 mg of curcumin for 5 days	Three sets of 15 repetitions at 70% 1 RM eccentric knee extensions	CK, LDH NR 6 point pain scale system	NR

(Continued on next page)

Table 2. (Continued)

Authors	Root-plant supplement	Administration method	EIMD protocol	Biomarker Muscle performance DOMS	Oxidative stress and anti-oxidant status
Su et al. [23]	Garlic	Ingested capsules with 80 mg of allicin (crushed garlic) daily for 2 weeks before, and two days after the muscle-damaging exercise	Downhill running at -10% gradient, with the speed increased by 2 km/h every 3 min, starting at 6 km/h until volitional exhaustion	CK, CK-MM, LDH, IL-6, TAC, SD NR 0 (no pain) to 10 (maximal pain)	*Oxidative stress* No significant differences between SUPP and PLA conditions for SD ($p > 0.05$) *Anti-oxidant status* No significant differences between SUPP and PLA conditions for TAC ($p > 0.05$)
Tanabe et al. [54]	Curcumin	Ingested capsules with 150 mg of curcumin 1-h before and 12 h after the muscle-damaging exercise	Performed 50 eccentric contractions of the elbow flexors	CK, IL-6, TNF-α Elbow flexor isometric strength 0–100 mm VAS	NR
Tanabe et al. [26]	Curcumin	Ingested capsules with 180 mg per day for 7 days after muscle-damaging exercise	Performed 30 eccentric contractions of the elbow flexors	CK Elbow flexor isometric strength 0–100 mm VAS	NR
Tanabe et al. [55]	Curcumin	Ingested capsules with 180 mg per day for 7 days before the muscle-damaging exercise in Experiment 1 and 7 days after muscle-damaging exercise in Experiment 2	Performed 30 eccentric contractions of the elbow flexors	CK, IL-8, TNF-α Elbow flexor isometric strength 0–100 mm VAS	NR
Wilson et al. [56]	Ginger	Ingested capsules with 2.2 g of ginger root per day for 4 days prior to, and 1 day after the muscle-damaging exercise	Performed 32.2–35.4 km of running	NR Vertical jump 0–100 mm VAS	NR

*Level of significance set at $p \leq 0.05$. TAC – total anti-oxidant capacity; GSH – glutathione; MDA – malondialdehyde; TGC – total glutathione concentrations; SD – superoxide dismutase; ALT – alanine aminotransferase; AST – aspartate aminotransferase; TNF-α – tumour necrosis factor alpha; IL – interleukin; CRP – C-reactive protiein; MCP – monocyte chemoattractant protein; CK – creatine kinase; LDH – lactate dehydrogenase; MG – myoglobin; RM – repetition maximum VAS – visual analogue scale; VO_{2max} – maximal oxygen consumption.

2014). The mean ± standard deviation of the selected outcome measures were extracted from each study. This information was then used to compare the level of EIMD between the SUPP and PLA conditions at 24 hours and 48 hours after the muscle damage-inducing protocol. Any measure of dispersion reported as standard error or 95% confidence interval was converted to standard deviation prior to conducting the meta-analysis [33]. A weighted average was calculated for mean ± standard deviation to report on a singular effect estimate for all outcome measures with similar constructs in each study (e.g., CK, myoglobin and lactate dehydrogenase are all biomarkers used to report on the level of indirect muscle damage) [34]. The inter-study heterogeneity of each selected outcome measure was determined using the I^2 test statistic, with classifications of low, moderate and high corresponding to values of 25%, 50% and 75%, respectively. Forest plots were generated to report on the standardised mean differences (SMD) of the root plant-derived supplements on the selected outcome measures using random effects model to control for inter-study heterogeneity. Subgroup analyses were also conducted to compare the effect estimates of each outcome measure between root plants. However, forest plots were not considered for outcome measures with less than six studies, due to inadequate sample size [35]. The SMD values of 0.2, 0.5 and 0.8 were classified as small, moderate and large, respectively [36]. The effect of the pooled data between each condition (supplement vs placebo) was also calculated as a Z-value, with accompanying p-values to assess the level of statistical significance. To account for the variation in study design of each study, we calculated effect estimates and associated variances using separate equations for parallel and cross-over designs [37]. When calculating effect estimates for the cross-over design, the correlation coefficient was set at 0.5 for quantifying confidence intervals, which is a value considered relatively conservative and therefore recommended when dealing with studies that do not report the variance of mean

Table 3. PEDro ratings of all included studies

Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Ratings	Quality
Barzanjeh et al. [40]	1	1	1	0	1	1	0	1	0	0	0	1	1	1	1	10/16	Fair
Basham et al. [41]	1	1	1	0	1	1	0	1	1	0	0	1	1	1	1	11/16	Good
Black et al. [42]	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	13/16	Good
Black et al. [43]	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	13/16	Good
Caldwell et al. [44]	1	2	1	0	1	1	1	1	1	0	0	1	1	1	1	13/16	Good
Drobnic et al. [45]	1	1	1	0	1	1	0	1	0	0	0	1	1	1	0	9/16	Fair
Flanagan et al. [46]	1	2	0	0	1	1	0	1	1	0	1	1	1	1	1	12/16	Good
Hamid Abad et al. [47]	1	1	1	0	1	0	1	1	0	0	1	1	1	1	1	11/16	Good
Hoseinzadeh et al. [22]	0	1	1	0	1	0	0	1	1	0	1	1	1	1	1	10/16	Fair
Jager et al. [48]	1	1	1	0	1	1	0	1	1	0	1	1	1	1	1	12/16	Good
Jung et al. [21]	0	1	1	0	1	0	0	0	0	0	0	1	1	1	1	7/16	Poor
Jung et al. [49]	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	9/16	Fair
Matsumura et al. [25]	0	0	1	0	1	1	1	1	0	0	0	1	1	1	1	9/16	Fair
McFarlin et al. [50]	1	2	1	0	1	1	1	1	1	0	0	1	1	1	1	13/16	Good
Nakhostin-Roohi et al. [20]	1	1	1	0	1	1	0	1	1	0	1	1	1	1	1	12/16	Good
Nakhostin-Roohi et al. [51]	1	1	1	0	1	1	0	1	1	0	1	1	1	1	1	12/16	Good
Nicol et al. [19]	0	0	1	1	1	1	1	1	1	0	1	1	1	1	1	12/16	Good
Pumpa et al. [24]	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	12/16	Good
Rosidi et al. [52]	1	2	1	0	1	1	0	1	1	0	0	1	1	1	1	12/16	Good
Samadi et al. [53]	1	1	1	0	0	0	1	1	0	0	0	1	1	1	1	9/16	Fair
Su et al. [23]	0	1	1	0	1	1	0	1	1	0	0	1	1	1	1	10/16	Fair
Tanabe et al. [54]	1	1	1	0	1	1	1	1	0	1	0	1	1	1	1	12/16	Good
Tanabe et al. [26]	1	1	1	0	1	1	0	1	0	1	0	1	1	1	1	11/16	Good
Tanabe et al. [55]	1	2	0	0	1	1	0	1	1	0	0	1	1	1	1	11/16	Good
Wilson et al. [56]	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	13/16	Good

differences [33, 38]. The effect estimate derived from each equation was then imputed in the meta-analysis to combine parallel and cross-over trials using the generic inverse-variance method in the RevMan software [39].

Results

Systematic literature search

The Pubmed, Cinahl, SportDiscus and Scopus databases identified 3539 abstracts after removal of duplicates (Figure 1). After reviewing the abstracts, 3507 abstracts were excluded and the remaining 32 full-text articles were further reviewed, with 25 articles included in the review. All studies either utilised a randomised controlled placebo (RCP) design with a SUPP and PLA group, or a crossover randomised (COR) design, with SUPP and PLA conditions.

Participants

For the studies that employed the RCP design, there was a total sample size of 353 participants, with 179 and 174 participants in the SUPP and PLA conditions, respectively, whilst the total sample size for studies with the COR design was 145 participants (Table 1). For the SUPP condition, the average age, height and body mass were 24 years (19–33 years), 1.7 m (1.6–1.8 m) and 68.7 kg (57.1–76.4 kg), respectively. Similar measures of physical characteristics were observed for the PLA condition for the average age, height and body mass, with 24 years (19–38 years), 1.7 m (1.6–1.8 m) and 68.4 kg (57.1–76.4 kg), respectively. For the studies that utilised the COR design, the average age, height and body mass were 29 years (22–41 years), 1.7 m (1.7–1.8 m) and 76.0 kg (65.2–83.9 kg), respectively. According to the analyses of the physical characteristics by authors in the included studies, there were no reported significant differences between the SUPP and PLA conditions. Thus, the physical characteristics appeared comparable in the SUPP and PLA conditions.

Methodological descriptions

The most frequent modes of exercise to induce muscle damage were eccentric resistance exercises (7 studies), eccentric/concentric resistance exercises (6 studies) and downhill running (6 studies), whilst sit-to-stand exercises

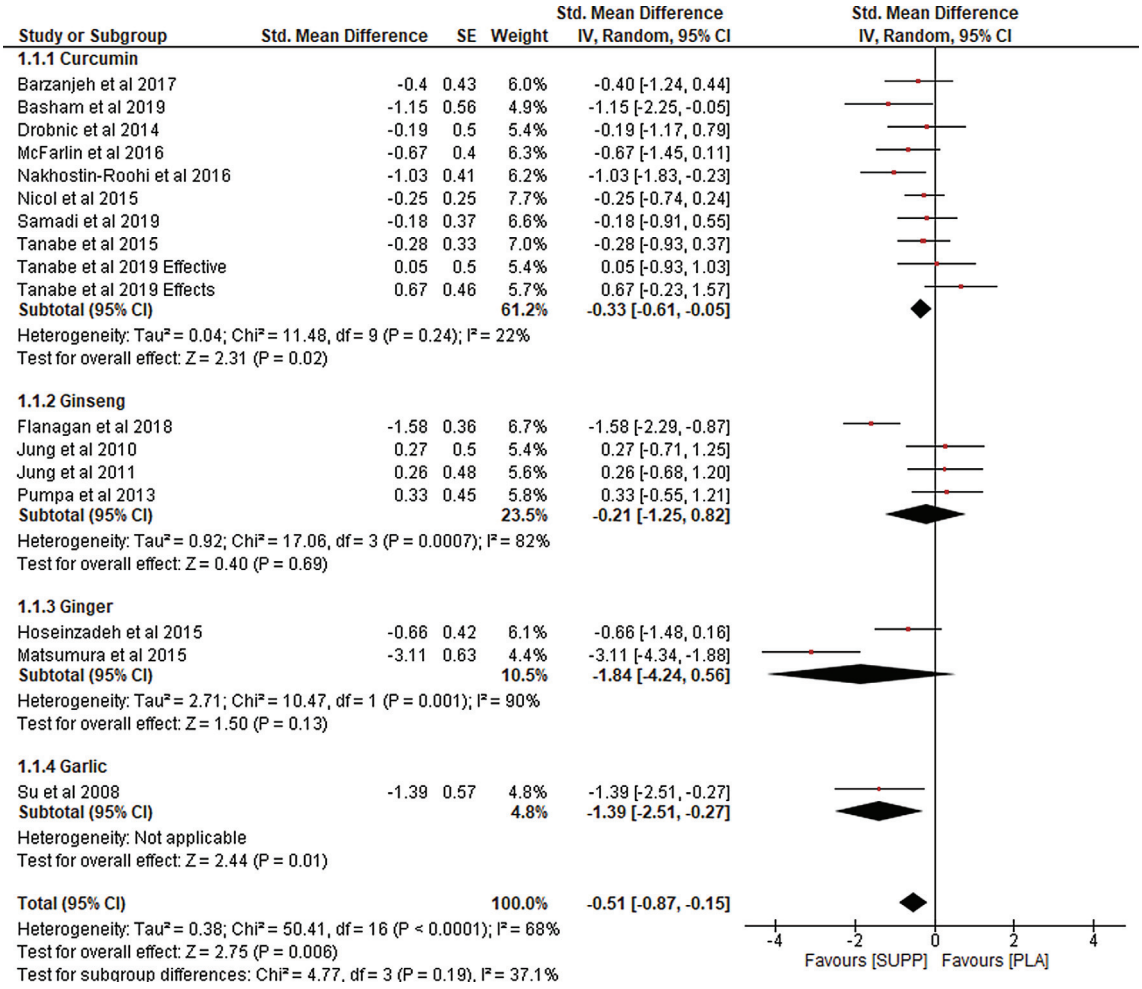

Figure 2. Forest plot for indirect muscle damage markers at 24 hours after the muscle damaging exercise. SUPP – supplementary condition; PLA – placebo condition; IV – inverse variance; SE – standard error; CI – confidence interval.

(1 study), step test (1 study), uphill running (1 study) and flat running (1 study) were the least common (Table 2). For the type of root-plant used as a supplement source, curcumin was the most common form (12 studies), followed by ginseng (6 studies) and ginger (6 studies), whilst only one study implemented a supplement derived from garlic. The most common biomarker on indirect muscle damage was CK (16 studies), whilst only three studies reported on LDH and one study for MG. A relatively larger variation of inflammatory markers were reported, with IL-6 (8 studies) and TNF-alpha (7 studies) as the most common forms, whilst only three studies reported on IL-8, two studies on CRP, and one study on IL-1. For the measure of DOMS, VAS with scales of 0–100 mm was reported most commonly (11 studies), followed by VAS scales of 0–10 (3 studies), and VAS scales of 0–20 cm (1 study) and 0–4 (1 study). The most common muscle performance protocol was the maximal isometric contractions (5 studies), followed by isokinetic contractions (2 studies), vertical jump (2 studies) and 1-RM strength by one study.

Methodological quality

The scores from the PEDro scale ranged from 7–13, or poor to good quality, respectively (Table 3). The PEDro items that were met by all studies included the following: measure of at least one key outcome from more than 85% of the participants initially allocated; incorporation of both SUPP and PLA conditions; all participants for whom outcome measures were available received the treatment or placebo condition; and results for between-group, or between-condition, comparisons were reported. The PEDro items that were not met by all studies, but most frequently reported, included: all data was reported with measures of central tendency and dispersion; confirmed that participants refrained from pain medication/supplements and root-plant products prior to or during study; subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received); the groups were similar at baseline, or an inclusion of a washout period of at least 7 days between the

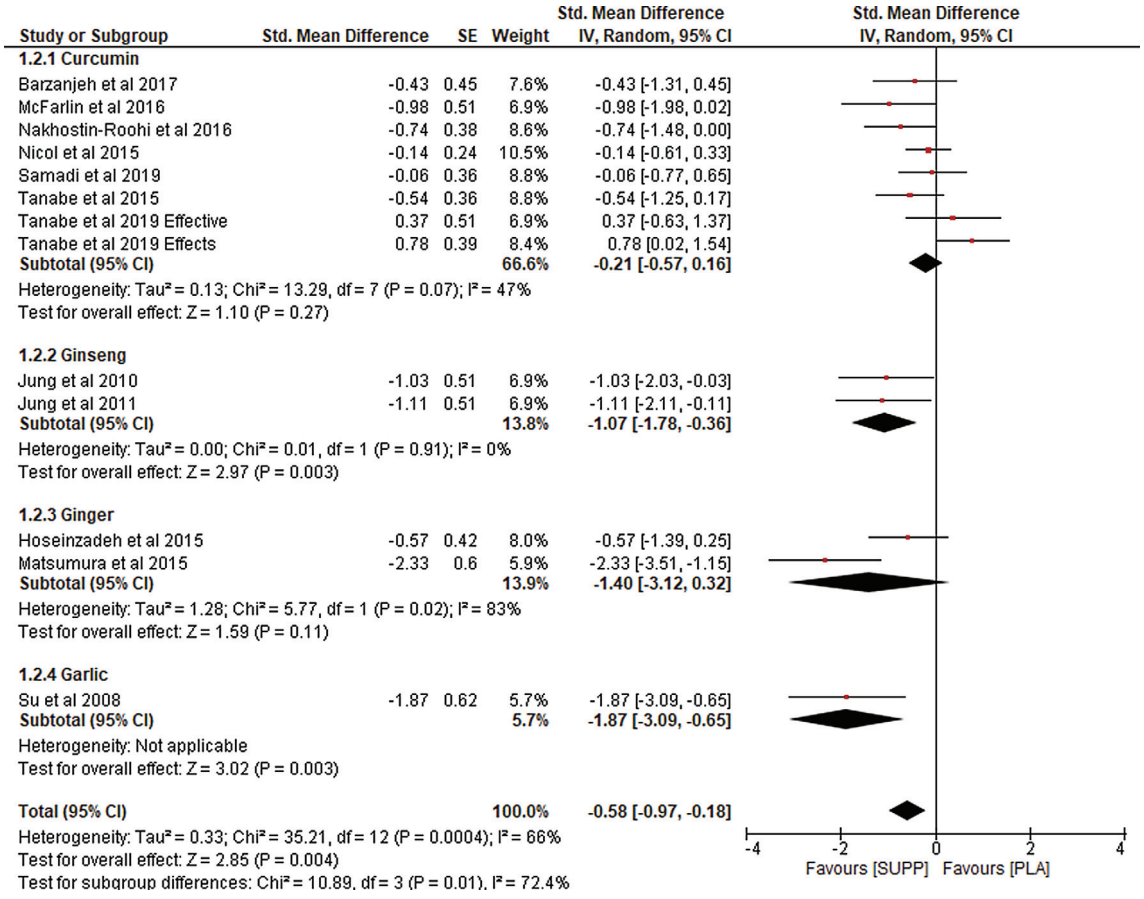

Figure 3. Forest plot for indirect muscle damage markers at 48 hours after the muscle damaging exercise. SUPP – supplementary condition; PLA – placebo condition; IV – inverse variance; SE – standard error; CI – confidence interval.

two baseline periods for a cross-over research design; participants were homogenous; there was blinding of all participants; and there was blinding of all therapists who administered the supplement. The PEDro items with relatively fewer studies included specificity of resistance training background and confirmation of the amount of active ingredient in the supplement. The least reported PEDro items were allocation concealment and confirmation of the bioavailability of the supplement. In addition, only few studies confirmed that both pain medication/supplements and root-plant products were refrained prior to study commencement, with the majority confirming that participants only avoided pain medication/supplements.

Quantitative analyses

For the biomarkers, the SUPP condition exhibited significantly lower levels of indirect muscle damage markers than the PLA condition at 24 hours ($Z = 2.75$; $p = 0.006$; Figure 2) and 48 hours ($Z = 2.85$; $p = 0.004$; Figure 3) post-exercise, with moderate inter-study heterogeneity (I^2 = 68% and 66%, respectively). The inflammatory markers also showed significantly lower levels for the SUPP condition than the PLA condition at 24 hours post-exercise ($Z = 2.39$; $p = 0.02$; Figure 4), although no differences were found between the SUPP and PLA condition at 48 hours post-exercise ($Z = 0.84$; $p = 0.40$; Figure 5), with low and moderate inter-study heterogeneity for both time points ($I^2 = 32\%$ and 50%, respectively). When comparing muscle damage and inflammatory markers between root plants, there were greater effect estimates for ginger and garlic at T24 (SMD = $-1.84 \leq d \leq -0.78$) and T48 ($-1.87 \leq d \leq -1.01$) compared to curcumin and ginseng at T24 (SMD = $-0.35 \leq d \leq 0.52$) and T48 ($-1.07 \leq d \leq 0.41$). For measures of DOMS, the values were significantly lower for the SUPP condition than the PLA condition at 24 hours ($Z = 4.26$; $p < 0.001$; Figure 6) and 48 hours ($Z = 3.19$; $p = 0.001$; Figure 7) post-exercise, with low inter-study heterogeneity (I^2 = 32% and 42%, respectively). Similar effect estimates were found with curcumin, ginseng and ginger at T24 (SMD = $-0.48 \leq d \leq -0.34$) and T48 (SMD = $-0.50 \leq d \leq -0.29$), although garlic exhibited greater effect estimates at T24 (SMD = −1.38) and T48 (SMD = −1.40). Finally, there were no differences in the muscle performance measures between the SUPP condition than the PLA condition at 24 hours ($Z = 0.54$; $p = 0.59$) and 48 hours

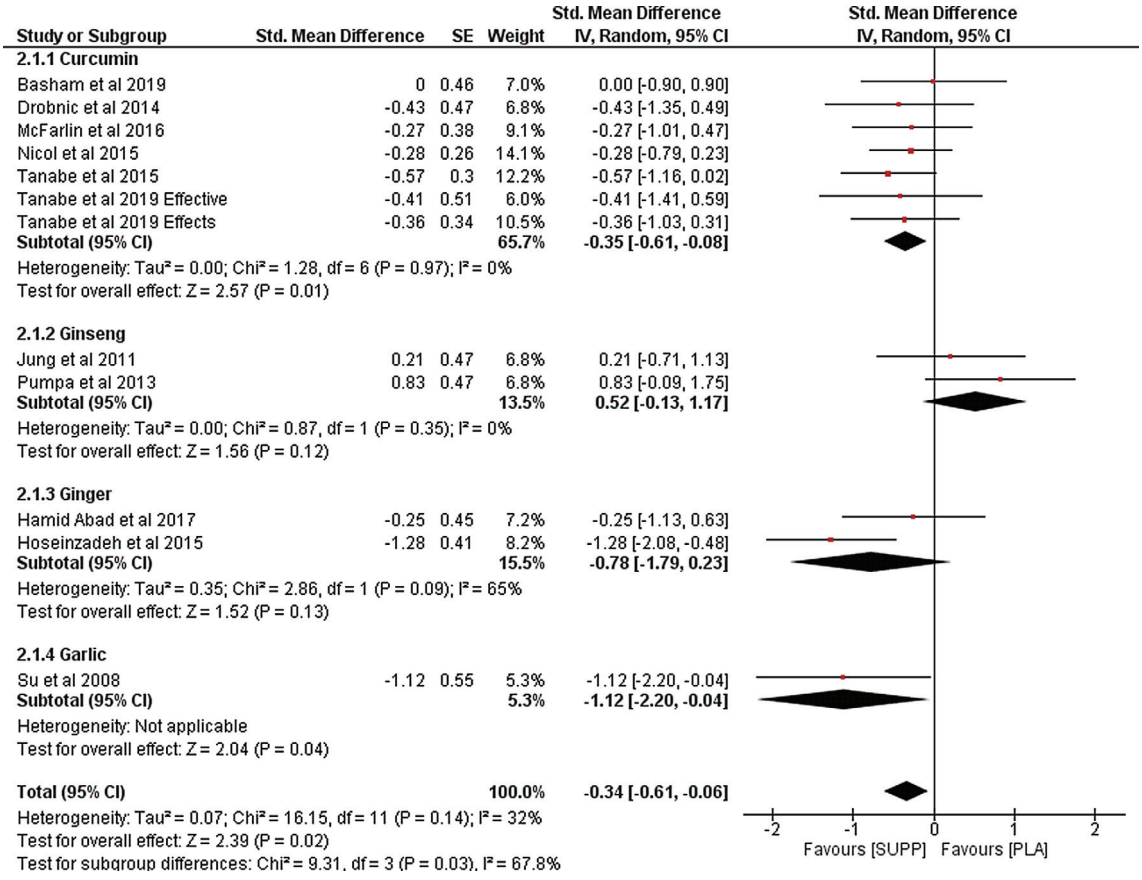

Figure 4. Forest plot for inflammatory markers at 24 hours after the muscle damaging exercise. SUPP – supplementary condition; PLA – placebo condition; IV – inverse variance; SE – standard error; CI – confidence interval.

(Z = 1.09; p = 0.28) post-exercise, with low inter-study heterogeneity (I^2 = 0%, respectively; Figure 8). Furthermore, curcumin, ginseng and ginger showed similar effect estimates at T24 (SMD = $0.12 \leq d \leq 0.00$) and T48 (SMD = $-0.15 \leq d \leq 0.22$), and no studies reported muscle performance measures for garlic.

Discussion

The current systematic review and meta-analysis determined the benefits of root-plants as a supplement to minimise the signs and symptoms of EIMD. The meta-analysis showed significantly lower levels of indirect muscle damage markers and DOMS at 24 and 48 hours post-exercise and significantly lower levels of inflammatory markers at 24 hours post-exercise for the SUPP condition compared to the PLA condition. However, there were no differences in muscle performance at 24 hours and 48 hours post-exercise between the SUPP and PLA conditions. When comparing the individual root plants, ginger and garlic generated larger effect estimates than curcumin and ginseng for muscle damage markers and inflammation, whilst garlic had a larger effect estimate for DOMS than curcumin, ginseng and ginger. However, similar effect estimates were found between curcumin, ginseng and ginger for muscle performance, whilst no studies reported on this outcome measure with garlic. For the qualitative data, a number of studies showed a reduction in oxidative stress markers with a concomitant increase in anti-oxidant status for SUPP than PLA conditions.

To the best of our knowledge, no previous systematic reviews have examined the effectiveness of root-derived supplements on acute recovery dynamics following strenuous exercise. Thus, at present, it is difficult to directly compare data from our meta-analysis and the methodological quality of included studies to previous review papers. Nonetheless, there is a growing body of narrative reviews reporting on the benefits of various supplements derived from root plant extracts to manage signs and symptoms of EIMD. For example, Hewlings and Kalman [14] provided a general overview on the effects of curcumin for various health outcomes, and showed that supplements with curcumin reduced the level of CK, TNF-alpha, IL-6, IL-8 and DOMS following a variety of muscle-damaging protocols

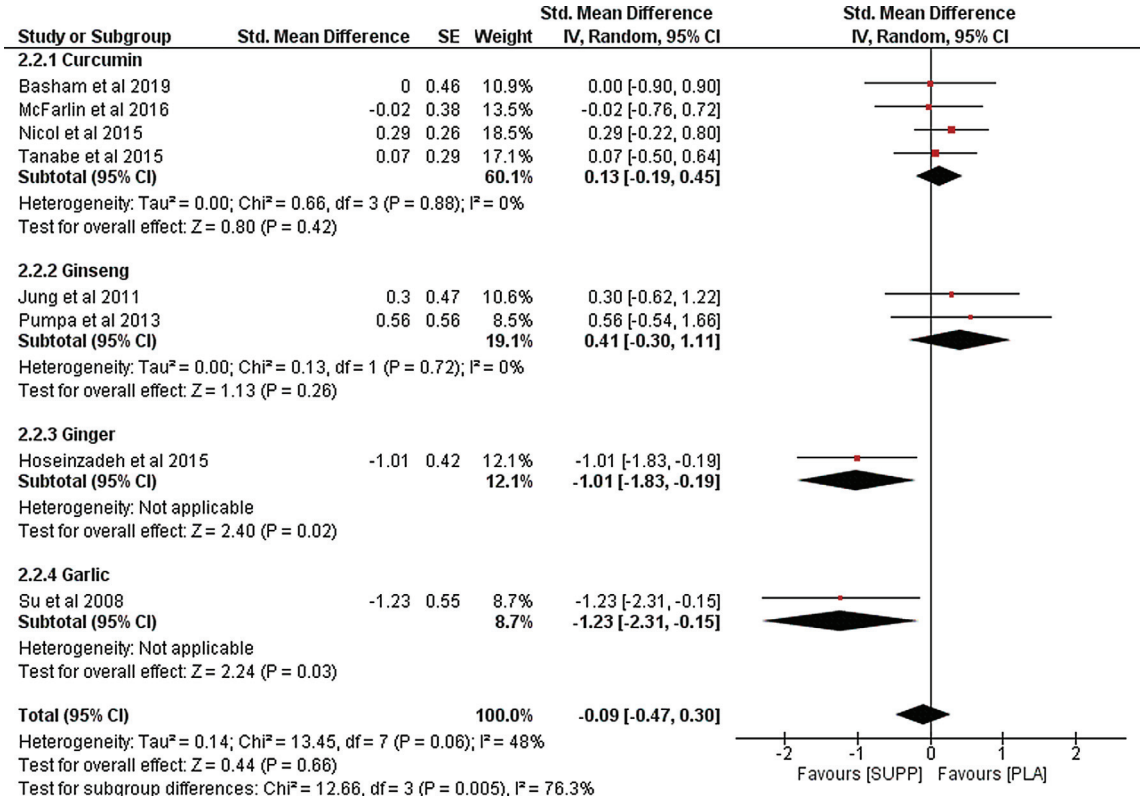

Figure 5. Forest plot for inflammatory markers at 48 hours after the muscle damaging exercise. SUPP – supplementary condition; PLA – placebo condition; IV – inverse variance; SE – standard error; CI – confidence interval.

for several days post-exercise when compared to placebo conditions. Similar results were reported by a more recent narrative review with gingseng and ginger [28], with these root plants exhibiting lower levels of DOMS following muscle-damaging exercises for several days post-exercise from a number of studies when compared to placebo products. These qualitative findings demonstrate important evidence regarding the benefits of various root plants as a potential recovery strategy following strenuous exercises. In addition, the quantitative results from our meta-analysis support the findings from these narrative reviews, with significantly lower levels of indirect muscle damage biomarkers, inflammation and DOMS following ingestion of supplements derived from various root-plants when compared to placebo conditions.

The anti-inflammatory and anti-oxidant properties of root-plants are the two main probable mechanisms that explain the level of protection from EIMD observed in the included studies. Whilst curcumin, ginseng, ginger and garlic are classified as separate types of root plants, and have been known to be used differently for culinary and medicinal purposes due to their distinctive chemical constituents, they all share potent anti-inflammatory and anti-oxidant properties. In fact, polyphenols, which are phenolic compounds largely found in curcumin [14], ginseng [16], ginger [15] and garlic [13], attenuate inflammatory responses. For example, TNF-alpha, IL-1, IL-6, IL-8 and CRP are major mediators of inflammation, and these immunological responses are orchestrated by the activation of a transcription nuclear factor of activated beta cells (NF-κB) [57]. However, root plants have been shown to blunt the NF-κB response [58]. In addition, phytochemicals, which are abundant in root plants [59], have been reported to block cyclooxygenase activity (COX1 and COX2) [60, 61], which is a potent inflammatory mediator [62]. The meta-analytical data in the current review partly support these anti-inflammatory processes, as the level of inflammatory markers was significantly lower at 24 hours post-exercise for the SUPP condition when compared to the PLA condition.

The inflammatory response is closely associated with that of oxidative stress, in that one process can be easily implicated by another. Furthermore, inflammation activated by skeletal muscle damage can increase free radicals, such as reactive oxygen species, which augment the level of oxidative stress. However, phytochemicals in root plants can scavenge free radicals and inhibit enzymes that produce free radicals [63, 64]. Unfortunately, the current systematic review was unable to perform a meta-analysis on oxidative stress markers and anti-oxidant status due to insufficient data available. According to our qualitative data, Rosidi and colleagues [52] found that the MDA levels were significantly lower, whilst three of the included studies

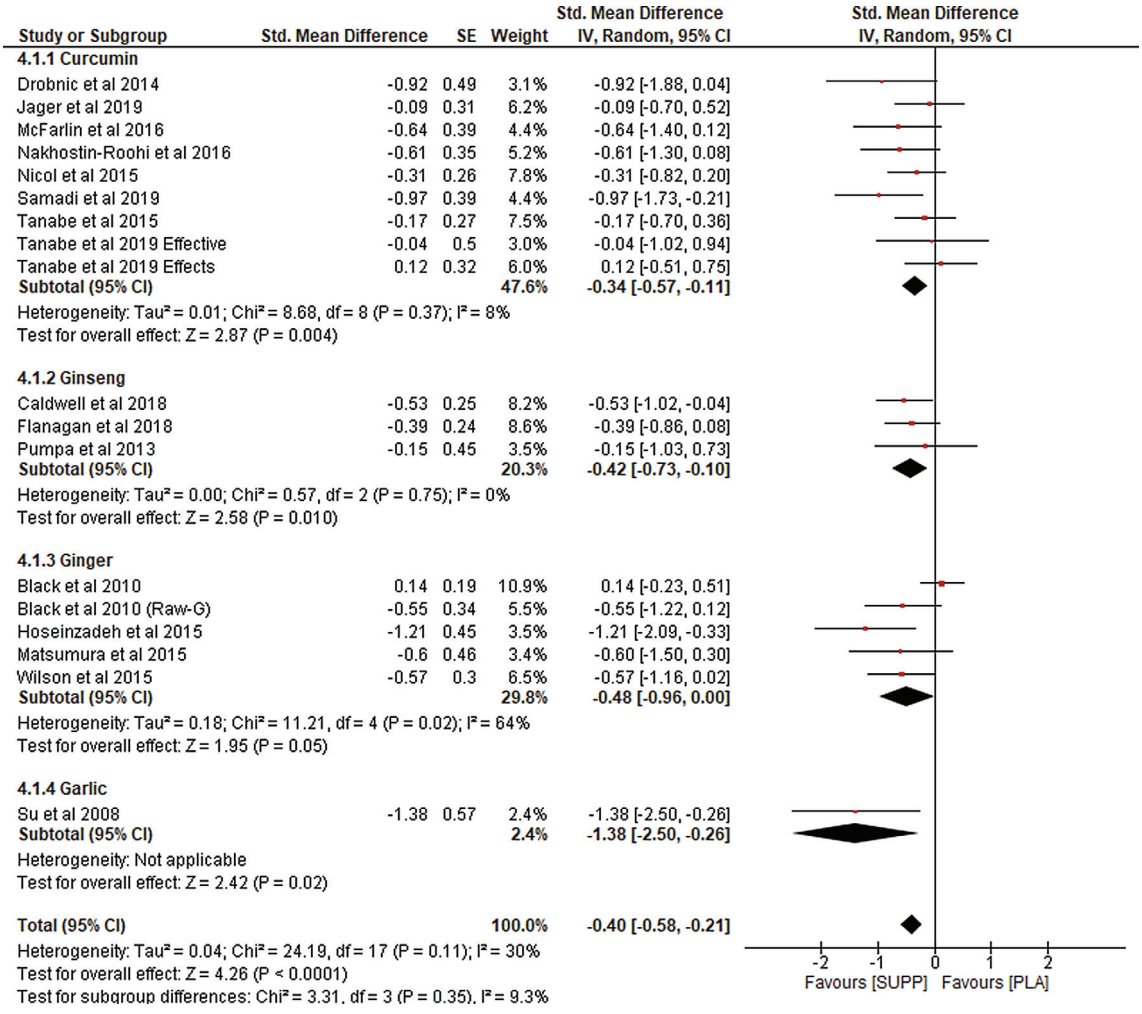

Figure 6. Forest plot for delayed onset of muscle soreness at 24 hours after the muscle damaging exercise. SUPP – supplementary condition; PLA – placebo condition; IV – inverse variance; SE – standard error; CI – confidence interval.

[20, 40, 51] reported significantly greater levels of TAC for the SUPP condition than the PLA condition during periods of EIMD following the ingestion of curcumin. In addition, Nakhostin Roohi et al [51] showed significantly greater levels of glutathione (GSH) activity, or an enzyme active in the neutralization of free radicals, for the SUPP condition compared to the PLA condition [65]. However, three of the included studies [23, 41, 46] also reported no differences in oxidative stress markers (TBARS, SD and MDA) and anti-oxidant status (TAC) between the SUPP and PLA conditions following the ingestion of curcumin, ginseng and garlic. The discrepancy in these findings may be due to differences in the type of root-plants, the amount of active ingredients used, participant background and the method of inducing muscle damage. In addition, Basham and colleagues [41] indicated that the lack of any differences in oxidative stress markers and anti-oxidant status between the SUPP and PLA conditions may be due to poorer sensitivity of these type of assays. Whilst there appears to be some evidence of anti-inflammatory and anti-oxidant properties of root plants to ameliorate signs and symptoms of EIMD, more studies are required to confirm these mechanisms.

The meta-analysis from the current systematic review also showed that the level of DOMS was significantly lower for the SUPP condition than the PLA condition for 24 to 48 hours post-exercise. The activation of groups III and IV afferent nocioceptors has been suggested to contribute to symptoms of muscular pain due to exercise-induced damage of the intermediate filaments [2]. Given that significantly lower levels of indirect muscle damage markers were also demonstrated in the current meta-analysis, it is reasonable to assume that lower levels of EIMD exhibited by supplements derived from root-plants may have contributed to attenuating elevation in the level of DOMS. Whilst root plant supplements appeared to have ameliorated DOMS, no differences were found in muscle

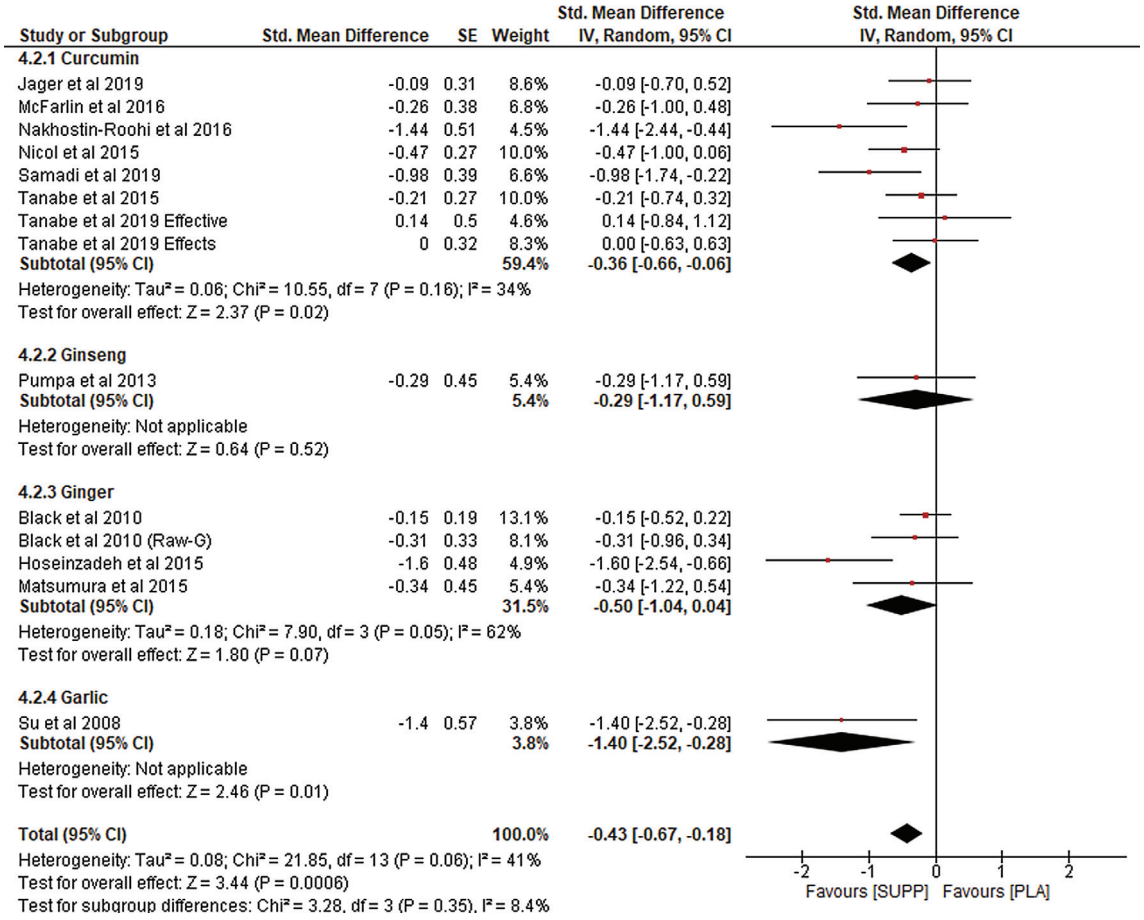

Figure 7. Forest plot for delayed onset of muscle soreness at 48 hours after the muscle damaging exercise. SUPP – supplementary condition; PLA – placebo condition; IV – inverse variance; SE – standard error; CI – confidence interval.

performance measures between the SUPP and PLA conditions. This is interesting, given that a number of studies have reported improvement in muscular force production with root plant supplements following muscle-damaging protocols, possibly by reducing the level of DOMS during maximal voluntary contraction [66]. It has also been suggested that supplements with anti-oxidant and anti-inflammatory properties may improve muscle performance during periods of EIMD, by limiting excitation-contraction coupling failure caused by desensitised calcium-binding receptors from elevated levels of oxidative stress [67]. The comparable measures in muscular force between the SUPP and PLA condition in the current meta-analysis may be due to variation in the method of muscular force measured, with several studies utilising distinct muscular contractions (i.e., isokinetic vs isometric), differences in the muscle groups being tested (i.e., knee extensors vs knee flexors), or limited number of effect points. Thus, whilst it is clear that supplements with root plants are effective in reducing levels of DOMS during periods of EIMD, there is insufficient evidence to support their use to accelerate recovery for muscular contractility.

When comparing individual root plants, ginger and garlic appeared to provide greater protection from the level of muscle damage and inflammation than curcumin and ginseng. Furthermore, garlic appeared to demonstrate greater protection from DOMS than curcumin, ginseng and ginger. These findings suggest that the distinct biochemical constituents of each type of root plant may exhibit varying degrees of attenuation from inflammation and oxidative stress induced by strenuous activity. However, caution should be taken when interpreting these findings, as differences in the level of effect estimates between root plants may have also been attributed to differences in the supplemental method, dose, participant background and the type of muscle-damaging exercises. Furthermore, there were variations in the number of studies included for each type of root plant, with ginger and garlic consisting of the fewest number of studies. Further research is required to compare the type of root plants within the same original investigation (e.g., comparing curcumin with garlic in the same original investigaton), which will optimise comparability of EIMD outcome measures and assist in circumventing several methodological limitations identified earlier.

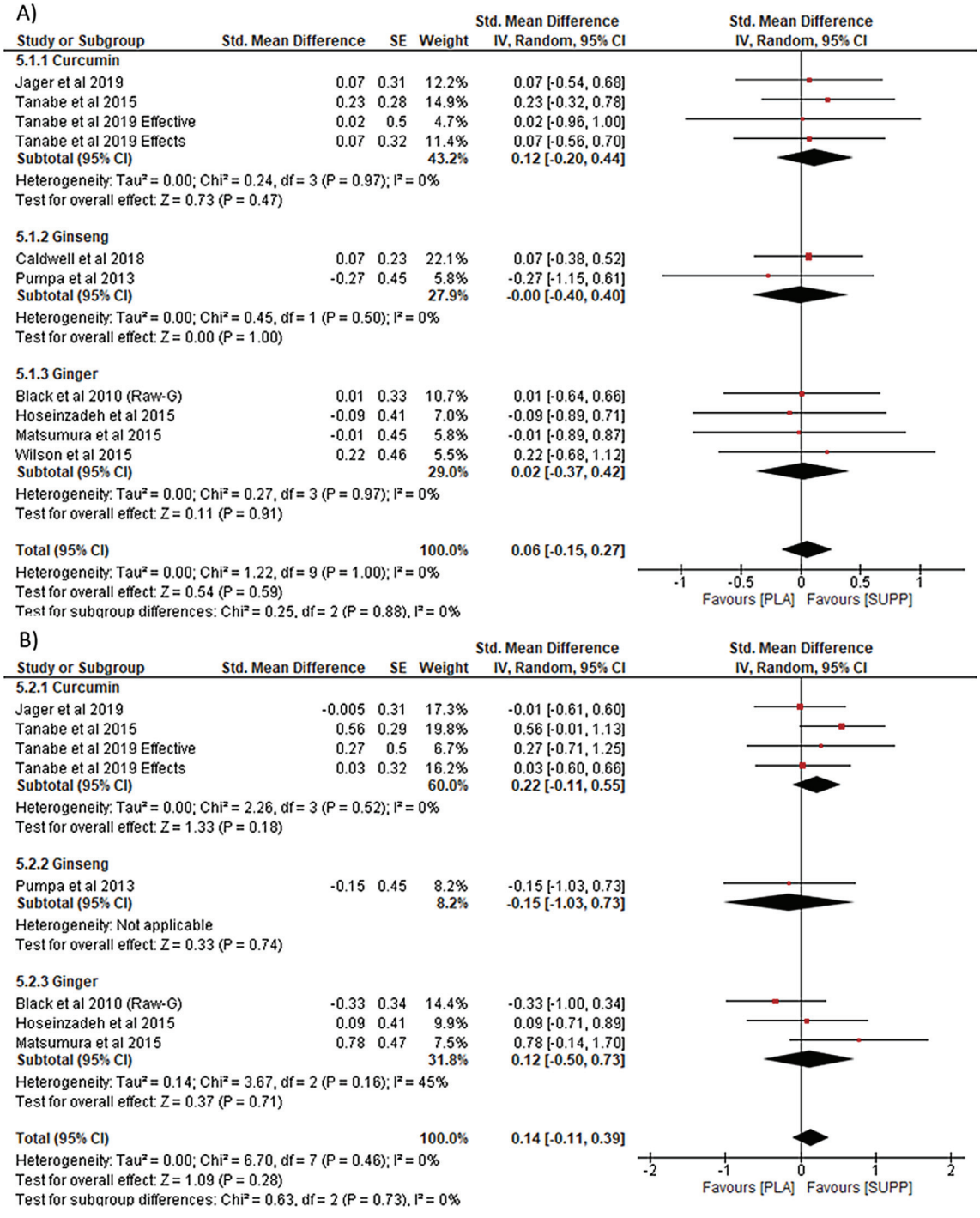

Figure 8. Forest plot for muscle force at 24 hours (A) and 48 hours (B) after the muscle damaging exercise. SUPP – supplementary condition; PLA – placebo condition; IV – inverse variance; SE – standard error; CI – confidence interval.

As per most reviews, there are a number of limitations that should be addressed. Firstly, the I^2 value was above 75% for the indirect muscle damage markers at both 24 and 48 hours post-exercise, indicating high inter-study heterogeneity. However, the rest of the outcome measures (i.e., inflammation, DOMS and muscle force) ranged between 0%–74%, demonstrating low to moderate inter-study heterogeneity. Secondly, different types of root-plants (i.e., curcumin, ginseng, ginger and garlic) were combined, which have varying levels of anti-oxidant and anti-inflammatory properties. Thus, it is possible that the distinct chemical constituents in each type of root plant

may have influenced the degree of change in biomarkers and muscular force in each selected study. Nonetheless, studies that combined root plants with other food sources (e.g., fruits or vegetables) or supplements (e.g., vitamin C or protein) were strictly excluded from our systematic review, and we ensured that supplements were derived solely from the same plant species (i.e., root plants).

With respect to future research, over 85% of studies neither concealed allocation of participants nor confirmed the bioavailability of root plants following ingestion. This could be particularly problematic for supplements with curcumin, given that curcumin is poorly absorbed in its natural state [68], and thus the absorption rate of root plants should be confirmed in future studies. Secondly, several studies have reported only a selection of biomarkers with the intention of understanding the mechanistic pathways exhibiting signs and symptoms of EIMD, and subsequent impairment in muscle function. Future studies examining the effect of oral supplements with ant-inflammatory and anti-oxidant properties should consider reporting on a range of biomarkers that demonstrate mechanisms of oxidative stress (e.g., MDA), inflammation (IL-6, CRP) and EIMD markers (e.g., CK), in conjunction with muscle function, in the one study. Thirdly, the majority of studies examining the effect of root plant supplements only included one type of root plant. Given the possible differences in the level of EIMD protection for each type of root plant, combining different types of root plants may further optimize the recovery dynamics following strenuous exercise. Finally, nearly half of the studies included in this systematic review incorporated pure eccentric contractions (i.e., downhill running, isokinetic exercises) to induce muscle damage. These exercise modes are not ecologically valid, given that exercises in common training modalities known to elevate the level of EIMD typically involve long distance endurance exercise on various terrains, or traditional resistance exercises consisting of multi-articular, concentric and eccentric exercises. Thus, more studies should consider incorporating exercises that replicate real world training situations to improve the practicality of the supplemental methods.

In conclusion, our systematic review showed that supplements derived from root plants reduced indirect markers of muscle damage, inflammation and DOMS for 24–48 hours following muscle-damaging protocols. According to these findings, coaches and athletes could incorporate oral supplements following strenuous training sessions to accelerate their recovery dynamics, which will improve preparation for the subsequent training session, or matches. However, the effect of root plants on muscular force is still unclear, necessitating further studies to confirm the benefit of root plants for muscular recovery during periods of EIMD.

Electronic Supplementary Material

The electronic supplementary material is available with the online version of the article at https://doi.org/10.1024/0300-9831/a000689

ESM 1. PRISMA 2009 Checklist

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Conflict of interest
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