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SCHOLARLY REVIEW

Tart Cherry Supplementation and Recovery From Strenuous Exercise: A Systematic Review and Meta-Analysis

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The aim of this study was to determine the efficacy of tart cherry (TC) supplementation on recovery following strenuous exercise. A systematic review and meta-analysis were conducted using studies investigating TC supplementation on measures of muscle soreness, muscular strength, muscular power, creatine kinase, C-reactive protein, Interleukin-6, and tumor necrosis factor alpha. A literature search ending in July 2020 was conducted in three databases (SPORTDiscus, Web of Science, and PubMed). Data from 14 studies were extracted and pooled for analysis. Tart cherry supplementation had a small beneficial effect in reducing muscle soreness (effect size [ES] = –0.44, 95% confidence interval [CI] [–0.87, –0.02]). A moderate beneficial effect was observed for recovery of muscular strength (ES = –0.78, 95% CI [–1.11, –0.46]). A moderate effect was observed for muscular power (ES = –0.53, 95% CI [–0.77, –0.29]); a further subgroup analysis on this variable indicated a large effect of TC supplementation on recovery of jump height (ES = –0.82, 95% CI [–1.18, –0.45]) and a small significant effect of supplementation on sprint time (ES = –0.32, 95% CI [–0.60, –0.04]). A small effect was observed for both C-reactive protein (ES = –0.46, 95% CI [–0.93, –0.00]) and Interleukin-6 (ES = –0.35, 95% CI [–0.68, –0.02]. No significant effects were observed for creatine kinase and tumor necrosis factor alpha. These results indicate that the consumption of a TC supplement can aid aspects of recovery from strenuous exercise.

Keywords*:* functional foods, inflammation, montmorency cherry, muscle damage, muscle function, prunus cerasus

The use of tart cherry (TC) products to aid recovery from strenuous exercise is becoming increasingly popular. Consumption of tart cherries is thought to enhance recovery and attenuate symptoms of exercise-induced muscle damage (EIMD); this is likely due to the potent antioxidant and anti-inflammatory properties of the cherry (Bowtell et al., 2011; Bongiovanni et al., 2020; Connolly et al., 2006).

Strenuous exercise can cause structural damage to the muscle fiber, leading to an inflammatory response that is characterized by the infiltration of neutrophils and macrophages to the affected area (Clarkson & Sayers, 1999). The activity of these immune cells results in the production of reactive oxygen and nitrogen species (RONS) which can lead to oxidative stress. Oxidative stress is considered an imbalance between the natural antioxidant defense systems of the body and the production of RONS (Betteridge, 2000); if the defense systems become overwhelmed, there may be an exacerbation in the damage to the muscle fibers (Aoi et al., 2004; Halliwell & Chirico, 1993; Lowe et al., 1995; Toumi & Best, 2003). Montmorency tart cherries contain high levels of flavonoids and anthocyanins, and the anti-inflammatory and antioxidant properties of these phytonutrients are purported to reduce inflammation and RONS production via inhibition of the cyclooxygenase (COX-1 and COX-2) pathways (Marzocchella et al., 2011). Due to this, the consumption of TC products is thought to attenuate the inflammatory response and accelerate recovery from muscle damage; however, it is important to note that these observations have been in vitro or animal models, and this has been reviewed in detail by Marzochella et al. (2011).

Research investigating the efficacy of TC products as a recovery strategy has been positive with a number of studies supporting its use (Bell et al., 2014a; Bowtell et al., 2011; Connolly et al., 2006; Howatson et al., 2010), and a few studies finding no benefit (Beals et al., 2017; McCormick et al., 2016). However, there is wide variation in the responses of the dependent variables that have been measured throughout the research. For example, Connolly et al. (2006) observed reduced delayed onset muscle soreness (DOMS) with the consumption of TC juice following an eccentric exercise protocol involving maximal contractions of the elbow flexors, yet Beals et al. (2017) observed no difference between groups following maximal eccentric contractions of the quadriceps. Inconsistencies in findings could be related to differences in exercise modalities, exercise familiarity, duration, and type of supplementation with some studies supplementing with a juice (Howatson et al., 2008; Quinlan & Hill, 2019) and others supplementing with a powder (Levers et al., 2015) or tablet (Kastello et al., 2014).

Exercise modality is likely a factor influencing the effectiveness of TC supplementation, as the underlying cause of symptoms associated with EIMD will vary depending on exercise stimulus

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(Levers et al., 2015; Vitale et al., 2017). The majority of research on TC supplementation following endurance activity supports the use of TC products to attenuate inflammation (Bell et al., 2014a; Howatson et al., 2010; Levers et al., 2016) and oxidative stress (Bell et al., 2014a; Howatson et al., 2010). However, there are inconsistencies in the response of some markers across studies; for example, three studies observed a decrease in the inflammatory marker C-reactive protein (CRP; Bell et al., 2014a, 2014b; Howatson et al., 2007), and two observed no differences (Bell et al., 2016; Quinlan & Hill, 2019). This makes it difficult to draw conclusions on the effectiveness of TC as a strategy to reduce EIMD.

The efficacy of TC supplementation in improving recovery following exercise inducing only mechanical stress, that is, resistance exercise is conflicting with studies supporting the use of TC supplementation (Connolly et al., 2006; Kastello et al., 2014) and others showing no benefit (Beals et al., 2017; Lamb et al., 2019). As such, a systematic review and meta-analysis of the research findings will clarify the efficacy of TC supplementation as a recovery strategy and help to identify the variables most affected by supplementation. Therefore, the aim of this investigation was to conduct a systematic review and meta-analysis on the efficacy of TC supplementation in recovery following exercise.

Materials and Methods

Literature Search

A systematic review and meta-analysis were conducted using guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (Liberati et al., 2009). An electronic search of the literature ending in July 2020 was conducted in SPORTDiscus, Web of Science, and PubMed using combinations of the following search terms: cherry OR Montmorency cherry OR sour cherry OR Prunus cerasus OR Anthocyanin AND recovery OR athlete OR inflammation OR oxidative stress OR muscle damage OR muscle soreness OR muscle function OR jump OR sprint OR strength OR exercise OR interleukin 6 (IL-6) OR C-reactive protein OR tumor necrosis factor alpha OR creatine kinase OR reactive oxygen species OR reactive nitrogen species. The reference lists of all included studies were also examined to identify any further articles. A three-stage search strategy was independently undertaken by two members (JH and KK) of the review team (Title/Abstract Screen; Full Text Screen/Full Text Appraisal), and results were filtered using the population, intervention, comparator, outcomes, and study design criteria described in Table 1.

Outcome Variables

The literature was examined for the effects of cherry supplementation on indices of recovery following exercise that induced muscle damage. The following outcome variables were selected as they reflect the most commonly assessed indices in the EIMD literature: muscular soreness, muscular strength, muscular power, creatine kinase (CK), CRP, IL-6, and tumor necrosis factor alpha (TNFα).

Measurements of muscle soreness were obtained from visual analog or Likert scales. Measurements of muscular strength were obtained from measurements of maximum isometric, isokinetic, or isotonic contraction of the muscle. Measurements of muscular power included any activity that measured the power of the muscle; for example, the countermovement jump (CMJ) or a sprint. Measurements of CK, CRP, IL-6, and TNFα were obtained from capillary or venous sampling.

Inclusion and Exclusion Criteria

Studies were included if they met the following criteria: (a) participants were randomized into a cherry supplement or a placebo group; (b) if at least one outcome variable was measured at baseline and again at 1 and/or 24 and/or 48 and/or 72 h after exercise; (c) the study population could be male or female, of any fitness level or training background; and (d) the supplement could be administered before or after the exercise session. Studies were excluded if (a) the experimental group received multiple treatments, (b) the control group undertook any practice which could have affected recovery, (c) there was insufficient data or studies did not yield change score data, and (d) a crossover design was used but not with a contralateral limb that was due to the contralateral repeated bout effect (Howatson & van Someren, 2008).

Extraction of Data

Mean, *SD*, and sample size data were extracted from all included studies and used to calculate change from baseline scores. Where *SD* change scores were not reported, values were calculated using a correlation coefficient. When it was not possible to calculate change scores for *SD*, imputed *SD* was calculated in accordance with current guidelines (Higgins & Green, 2011). Where necessary, mean and *SD* data were extracted from figures using the software ImageJ (NIH, Bethesda, MD). Risk of bias (Figure 1a and 1b) was assessed following the guidelines outlined by the Cochrane Collaboration (Higgins & Altman, 2008). The risk of bias assessment was carried out by two authors (J.A.H. and G.H.), and any discrepancies were reviewed by a third author (K.M.K.). Data were extracted and compared by two authors (J.A.H. and G.H.); where differences occurred, data were reviewed by a third author (K.M.K.).

Statistical Analysis

Analysis of the overall effect of TC supplementation was carried out using Review Manager 5.3 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, 2011). Data were analyzed

Table 1 Review Inclusion Criteria

Population	Healthy males and females with no restriction on age, activity level, or training status.
Intervention	Supplementation with a tart cherry product before, or before and after a single bout of exercise.
Comparator	The effectiveness of supplementation with a tart cherry product on indices of recovery from exercise-induced muscle damage in comparison with a control or placebo group.
Outcomes	Measurements of muscular soreness, muscular strength, muscular power and blood biomarkers creatine kinase, C-reactive protein, interleukin 6, and tumor necrosis factor alpha.
Study design	Randomized-controlled trials, nonrandomized-controlled trials, and crossover studies using a contralateral limb design.

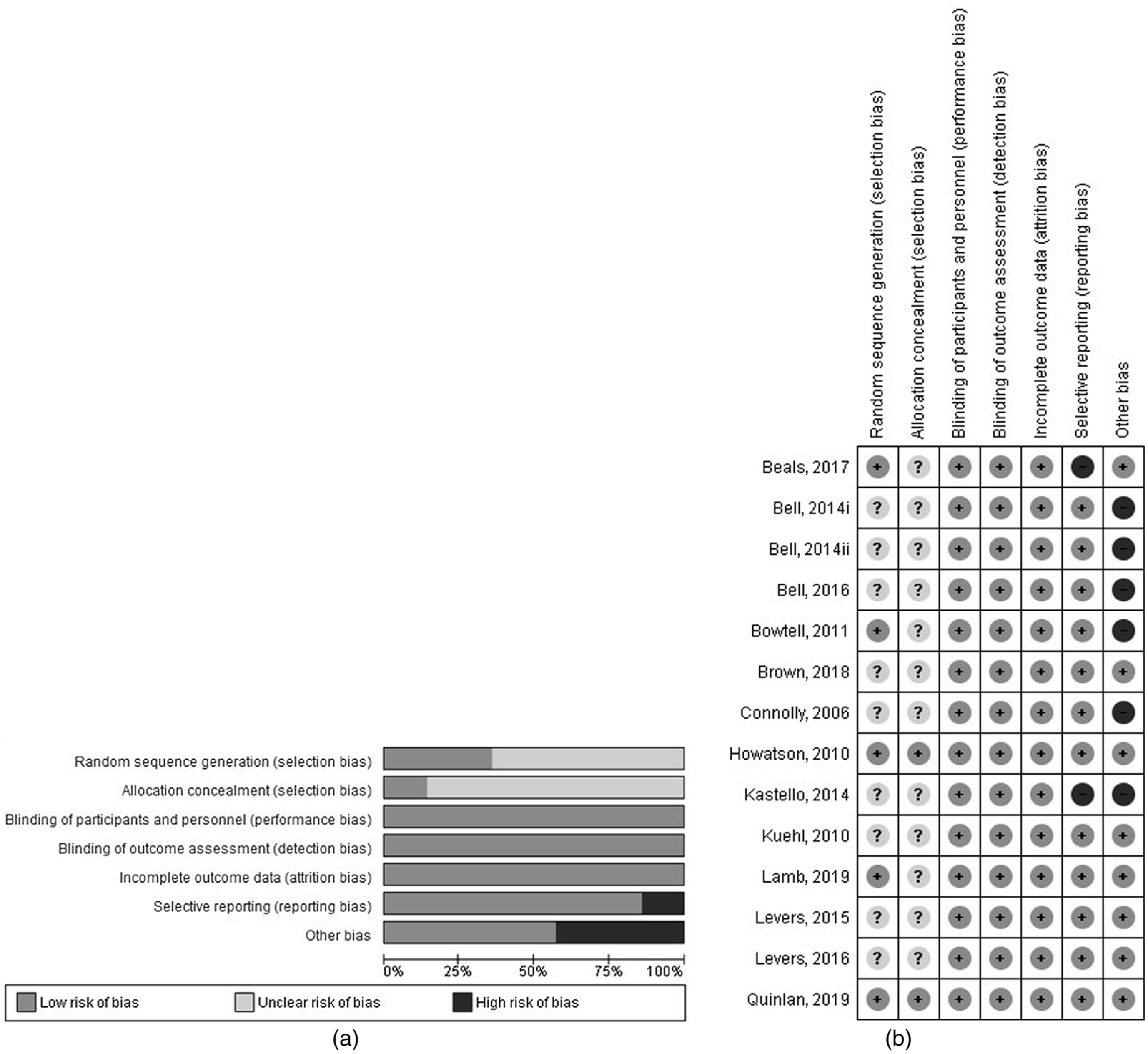

Figure 1 — (a) Risk of bias percentile chart, in accordance with the Cochrane Collaboration (Higgins & Altman, 2008). (b) Risk of bias summary for each included study.

using a random-effect model. Standardized mean effect sizes (ES) and 95% confidence intervals (CIs) were reported as (ES [LCL, UCL]), with LCL and UCL representing lower and upper 95% CIs, respectively. Where sufficient data points allowed, a subgroup analysis was conducted. For measurement of muscular power, subgroup analysis was carried out on the method of assessing power. Studies were categorized based upon whether they assessed a measure of jump height or a sprint. For DOMS, strength, CK, and CRP subgroup analysis were conducted on the type of damaging protocol used. Studies were categorized as either mechanical or metabolic. Where mechanical included studies utilizing repetitive effort maximal contractions or maximal effort sprints and metabolic included studies requiring prolonged engagement of the aerobic system such as a marathon run or the Loughborough Intermittent Shuttle Test (LIST). The classification for each study (mechanical or metabolic) is indicated in Table 2. The threshold values for ES were set at ≤0.2 (trivial), >0.2 (small), >0.5 (moderate), and >0.8 (large; Batterham & Hopkins, 2006). Heterogeneity was assessed using an I^2 statistic indicating the percentage of variability across the studies that is due to heterogeneity (Higgins & Green, 2011). The significance level was set as $p \leq .05$.

Results

Database searches identified a total of 6,608 records. The majority of these records was not relevant to this analysis, with many studies relating to other aspects of health, disease, and nutrition and thus were excluded. Nineteen studies remained for assessment

Table 2 Summary of Literature Included in the Meta-Analysis

Author(s)	Participant cohort (training status, gender, and number)	Exercise intervention	Supplement type	Supplementation protocol	Outcome variables and measurement times (h)
Beals et al. (2017)[a]	Recreationally active $n = 19$ males, $n = 10$ females	Repetitive maximal effort isokinetic eccentric contractions of the quadriceps to fatigue	TC—30 g TartVitaCherry freeze-dried powder with 0.5% anthocyanins mixed with unsweetened BlackCherry Kool-Aid PL-sweetened black cherry mixed with 4 g of nutribiotic plain rice protein powder	Two servings per day for 12 days. Four days prior, the day of and 7 days following the exercise protocol	↔ DOMS (24, 48, 96, 168) ↔ Peak concentric torque (24, 48, 96, 168)
Bell et al. (2014a)[b]	Male trained cyclists $n = 16$	High intensity stochastic cycling trial lasting 109 min completed on three consecutive days	TC—30 ml Cherry Active mixed with 100 ml water PL mixed berry cordial with 100 ml water and maltodextrin	Two servings per day for 7 consecutive days. Four days pre and on each trial day	↔ CK (0, 24, 48) ↓ IL-6 (0, 24, 48) ↓ CRP (0, 24, 48) ↔ TNFα (0, 24, 48)
Bell et al. (2014b)[b]	Male trained cyclists $n = 16$	High intensity stochastic cycling trial lasting 109 min	TC—30 ml Cherry Active mixed with 100 ml water PL mixed berry cordial with 100 ml water and maltodextrin	Two servings per day for 8 consecutive days. Four days pre, the day of, and 3 days posttrial	↔ DOMS (24, 48, 72) ↔ 6-s sprint cycle (24, 48, 72) ↑ MVIC (24, 48, 72) ↔ CK (0, 1, 24, 48, 72) ↓ IL-6 (0, 1, 24, 48, 72) ↓ CRP (0, 1, 24, 48, 72) ↔ TNFα (0, 1, 24, 48, 72)
Bell et al. (2016)[b]	Male semiprofessional soccer players $n = 16$	Adapted Loughborough Intermittent Shuttle Test	TC—30 ml Cherry Active mixed with 100 ml water PL mixed berry cordial with 100 ml water and maltodextrin	Two servings per day for 7 consecutive days. Four days pre, the day of, and 2 days posttrial	↓ DOMS (24, 48, 72) ↑ MVIC (24, 48, 72) ↑ CMJ (24, 48, 72) ↓ 20-m sprint (24, 48, 72) ↔ CK (0, 1, 24, 48, 72) ↓ IL-6 (0, 1, 24, 48, 72) ↔ CRP (0, 1, 24, 48, 72) ↔ TNFα (0, 1, 24, 48, 72)
Bowtell et al. (2011)[a]	Well-trained male participants from intermittent team sports $n = 10$	Ten sets of 10 knee extensions at 80% 1RM with an elongated eccentric phase lasting 3 s	TC—30 ml Cherry Active concentrate. PL—30 ml Iso-energetic synthetically derived fruit concentrate	Two servings per day for 10 days. Seven days before, the day of, and 2 days after	↑ MVIC (1, 24, 48) ↔ CK (1, 24, 48) ↔ CRP (1, 24, 48)
Brown et al. (2018)[a]	Female dancers from a university team $n = 20$	Repeated sprint protocol consisting of 15×30 m maximal sprints with a rapid 10-m deceleration phase, each separated by a 60-s rest	TC—30 ml Cherry Active mixed with 100 ml water PL—25 ml of a synthetically derived fruit concentrate with negligible phytochemical content diluted with 100 ml of water and fortified with maltodexterin and whey protein powder	Two servings per day for 8 days. Four days pre, the day of, and 3 days postexercise	↔ DOMS (0, 24, 48, 72) ↔ MVIC (0, 24, 48, 72) ↑ CMJ (0, 24, 48, 72) ↔ 30-m sprint (0, 24, 48, 72) ↔ CK (0, 1, 24, 48, 72) ↔ CRP (0, 1, 24, 48, 72)
Connolly et al. (2006)[a]	Male college students $n = 14$	40 (2×20) maximal eccentric contractions of the elbow flexors	TC—12 oz bottle of Cherrypharm PL—unsweetened black cherry Kool-Aid mixed with water	Two servings per day for 8 days. Three days prior, the day of, and 4 days postexercise	↓ DOMS (24, 48, 72, 96) ↔ Proximal tenderness (24, 48, 72, 96) ↑ MVIC (24, 48 72, 96)

(continued)

Table 2 ***(continued)***

Author(s)	Participant cohort (training status, gender, and number)	Exercise intervention	Supplement type	Supplementation protocol	Outcome variables and measurement times (h)
Howatson et al. (2007)[b]	Marathon runners $n = 13$ males, $n = 7$ females	A marathon run	TC—12 oz bottle of Cherrypharm PL—fruit-flavored concentrate mixed with 8 fl oz water	Two servings per day for 8 days. Five days before, the day of, and 2 days postexercise	↔ DOMS (1, 24, 48) ↑ MVIC (1, 24, 48) ↔ CK (1, 24, 48) ↓ IL-6 (1, 24, 48) ↓ CRP (1, 24, 48)
Kastello et al. (2014)[a]	Untrained participants $n = 10$ males, $n = 4$ females	Eccentric contractions of the bicep. Ten submaximal contractions followed by five sets of 10 maximal contractions.	TC—a tablet consisting of Cherry Flex paste PL—tablet consisting of cooking oil and red food coloring	One tablet twice a day for 16 days prior to and for 3 days following exercise	↓ DOMS (12, 24, 48, 72) ↔ Peak torque (12, 24, 48, 72) ↔ CK (12, 24, 48, 72) ↓ CRP (12, 24, 48, 72)
Kuehl et al. (2010)[b]	Marathon runners $n = 36$ males, $n = 18$ females	Hood to coast relay. Average total running distance of 26.3 ± 2.5 km	TC—10.5 oz bottle of Cherrish PL—unsweetened fruit punch mixed with water	Two servings per day. Seven days prior to and the day of the race	↓ DOMS (24)
Lamb et al. (2019)[a]	Nonresistance trained males n = 24	Five sets of 10 unilateral eccentric elbow flexions	TC—30 ml of Cherry Active diluted with 220 ml water PL—250 ml of black currant-flavored maltodextrin sports drink	Two servings per day. Four days prior to the day of and 4 days postexercise	↔ DOMS (1, 24, 48, 72, 96) ↔ MVIC (1, 24, 48, 72, 96) ↔ CK (1, 24, 48, 72, 96)
Levers et al. (2015)[a]	Resistance trained males $n = 23$	Ten sets of 10 repetitions of a bar bell back squat at 70% 1RM with 3-min recovery between sets	TC—480 mg powdered tart cherry PL—480 mg rice flour mixed with water	One serving per day for 10 days. Seven days before, the day of and 2 days postexercise	↓ DOMS (1, 24, 48) ↔ MVIC (1, 24, 48) ↔ CK (1, 24, 48) ↔ IL-6 (1, 24, 48) ↔ TNFα (1, 24, 48)
Levers et al. (2016)[b]	Triathletes $n = 18$ males	21.1 km run under simulated race conditions	TC—480 mg powdered tart cherry PL—480 mg rice flour mixed with water	One serving per day for 10 days. Seven days before, the day of, and 2 days postexercise	↓ DOMS (1, 24, 48) ↔ CK (1, 24, 48) ↓ IL-6 (1, 24, 48) ↔ TNFα (1, 24, 48)
Quinlan and Hill (2019)[b]	Team sport players n = 8 males, n = 12 females	Adapted LIST test	TC—30 ml of Montmorency tart cherry concentrate Holland and Barrett brand mixed with 70 ml water PL—25 ml of Robinsons summer fruit squash mixed with water	Two servings per day. Five days before the day of and 2 days postexercise	↔ DOMS (1, 24, 48) ↑ MVIC (1, 24, 48) ↑ CMJ (1, 24, 48) ↓ 20-m sprint (1, 24, 48) ↔ CK (1, 24, 48) ↔ CRP (1, 24, 48)

Note. CMJ = countermovement jump; CK = creatine kinase; CRP = C-reactive protein; DOMS = delayed-onset muscle soreness; IL-6 = Interleukin 6; MVIC = maximum voluntary isometric contraction; PPT = pressure pain threshold; TNFα = tumor necrosis factor alpha; TC = tart cherry; PL = placebo. Increases or decreases represent improved performance or attenuations in a variable.
[a]Denotes a study with an exercise protocol considered mechanical, [b]denotes a study with an exercise protocol considered metabolic.

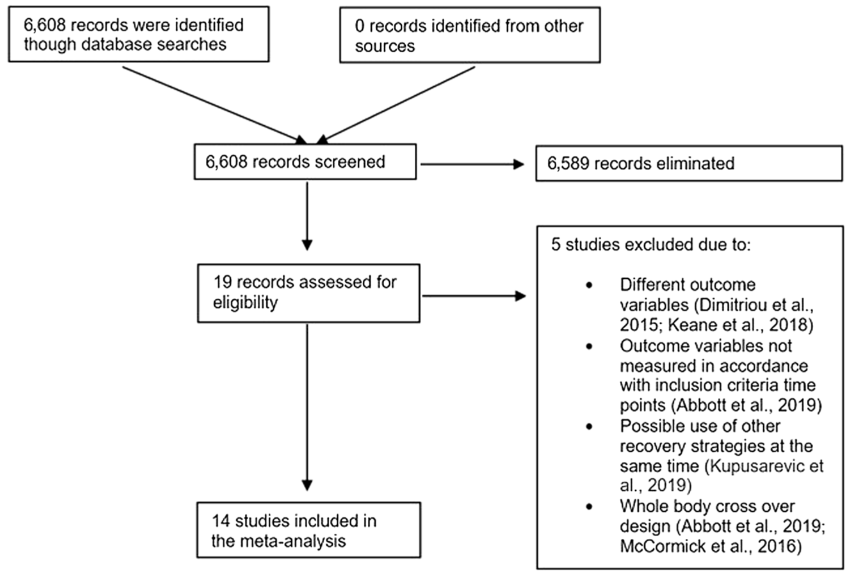

Figure 2 — Study selection from initial identification to inclusion.

of eligibility. Five studies were further excluded due to outcome variables not consistent with the inclusion criteria, variables measured at time points not consistent with the inclusion criteria, missing data, or if people were exposed to another treatment in addition to cherry supplementation which may have influenced the results (see Figure 2). Following this process, 14 studies remained for inclusion in this meta-analysis (see Table 2).

A total number of 303 male and female participants were included in the data set with a mean and SD age of 26.8 (5.8) years. The training status of the participants was varied ranging from untrained to well-trained athletes in a range of sports. The risk of bias assessment is demonstrated in Figure 1. Adequate sequence generation and allocation concealment were unclear for the majority of the included studies, with five of the 14 studies reporting how participants were allocated to groups and just one study reporting adequate allocation concealment. Adequate blinding occurred in all included studies with the use of a placebo treatment, in addition outcome data appeared to be addressed in all included studies. Selective outcome reporting was rated high for two studies as outcome data were not fully reported or omitted completely. Six of the included studies were considered at risk of other bias and so were rated high. Of these studies, four implemented either a low phenolic diet or a dietary washout period and three studies used a crossover study design.

A total of 52 data points was extracted from original research papers and included in the analysis for DOMS (see Figure 3). A significant difference between groups in favor of cherry supplementation was evident ($p < .05$, Z = 2.06). Supplementation with cherry products appears to have a small beneficial effect in attenuating soreness following strenuous exercise (ES = −0.44, 95% CI [−0.87, −0.02]). The I^2 statistic indicated high heterogeneity in the results (90%, $\text{Chi}^2 = 530.19$; Higgins & Green, 2011). A subgroup analysis of exercise type revealed no meaningful reduction in heterogeneity, with I^2 values of 90% ($\text{Chi}^2 = 255.90$) and 89% ($\text{Chi}^2 = 273.89$) for the metabolic and mechanical groups, respectively. However, the subgroup analysis revealed that TC supplementation had a significant effect on attenuation of soreness in the mechanical group ($p < .05$) but not the metabolic group ($p > .05$).

Analysis of 39 data points from 11 studies was included in the analysis for muscle strength (Figure 4). Analysis indicated a significant and moderate effect with the use of TC supplementation on the recovery of muscle strength ($p < .001$, Z = 4.76, ES = −0.78, 95% CI [−1.11, −0.46]). A large amount of heterogeneity was observed across the studies ($I^2 = 80\%$, $\text{Chi}^2 = 186.10$; Higgins & Green, 2011). Further subgroup analysis indicated heterogeneity was reduced to 59% ($\text{Chi}^2 = 26.65$) in the metabolic exercise group indicating minor heterogeneity in this group; however, heterogeneity remained high in the mechanical exercise group (84%, $\text{Chi}^2 =$ 186.10).

There were 23 data points used in the analysis for power. When considering the overall results for power recovery, TC supplementation had a significant and moderate benefit ($p < .001$, Z = 4.39, ES = −0.53, 95% CI [−0.77, −0.29]; Figure 5). A small amount of heterogeneity was observed across the studies ($I^2 = 29\%$ $\text{Chi}^2 = 31.17$; Higgins & Green, 2011). A subgroup analysis carried out on the type of measure for power revealed that supplementation with TC has a significant and large effect on recovery of jump height ($p < .001$, Z = 4.41, *ES* = −0.82, 95% CI [−1.18, −0.45]), with small heterogeneity ($I^2 = 28\%$, $\text{Chi}^2 =$ 12.53). The analysis on sprint data revealed a small significant effect of TC supplementation ($p = .02$, Z = 2.26, *ES* = −0.32, 95% CI [−0.60, 0.04]). Heterogeneity was also low ($I^2 = 10\%$, $\text{Chi}^2 =$ 13.33).

Consumption of TC had no significant effect on concentrations of CK between groups ($p = .26$, $Z = 0.26$; Figure 6). Analysis was conducted on a sample of 32 data points revealing small heterogeneity ($I^2 = 17\%$, $\text{Chi}^2 = 6.87$; Higgins & Green, 2011). Subgroup analysis showed no significant benefit of TC supplementation on CK for metabolically induced ($p = .79$) or mechanically induced ($p = .10$) muscle damage.

An overall small and significant effect in favor of TC supplementation was observed on concentrations of CRP, conducted on a sample of 20 data points ($p = .05$, Z = 1.96, *ES* = −0.46, 95% CI [−0.93, −0.00]; Figure 7). Considerable heterogeneity was observed across the data points ($I^2 = 78\%$, $\text{Chi}^2 = 87.59$; Higgins & Green, 2011). Further subgroup analysis on exercise reduced the heterogeneity to nothing in the metabolic group ($I^2 = 0\%$, $\text{Chi}^2 = 9.98$) and indicated a large positive effect of consuming TC on concentrations of CRP following metabolically induced muscle damage ($p < .001$,

	Experimental			Control				Std. mean difference
Study or subgroup	**Mean**	***SD***	**Total**	**Mean**	***SD***	**Total**	**Weight**	**IV, Random, 95% CI**
2.1.1 Metabolic								
Bell 2014ii (24 hr)	18.99	24.5	8	24.75	19.38	8	2.0%	−0.25 [−1.23, 0.74]
Bell 2014ii (48 hr)	13.24	19.41	8	21.55	18.4	8	2.0%	−0.42 [−1.41, 0.58]
Bell et al. (2014)ii (72 hr)	9.11	12.38	8	24.17	27.82	8	1.9%	−0.66 [−1.68, 0.35]
Bell et al. (2016) (24 hr)	52	27	8	86	45	8	1.9%	−0.87 [−1.91, 0.17]
Bell et al. (2016) (48 hr)	36	23	8	83	50	8	1.9%	−1.14 [−2.22, −0.06]
Bell et al. (2016) (72 hr)	2	3	8	26	19	8	1.9%	−1.67 [−2.85, −0.48]
Howatson et al. (2010) (1 hr)	115	51	10	115	60	10	2.0%	0.00 [−0.88, 0.88]
Howatson et al. (2010) (24 hr)	91	39	10	82	45	10	2.0%	0.20 [−0.67, 1.08]
Howatson et al. (2010) (48 hr)	58	37	10	46	28	10	2.0%	0.35 [−0.53, 1.24]
Kuehl et al. (2010) (1 hr)	6.5	3.3	28	39.2	12.6	26	2.0%	−3.56 [−4.44, −2.68]
Levers et al. (2016) (1 hr)a	2.47	1	11	0.99	0.41	16	2.0%	2.03 [1.06, 2.99]
Levers et al. (2016) (1 hr)b	0.97	0.35	11	0.75	0.36	16	2.0%	0.60 [−0.19, 1.39]
Levers et al. (2016) (1 hr) c	1.84	0.44	11	1.76	0.13	16	2.0%	0.26 [−0.51, 1.03]
Levers et al. (2016) (24 hr) a	2.35	1.28	11	0.45	0.25	16	2.0%	2.21 [1.21, 3.21]
Levers et al. (2016) (24 hr) b	0.36	0.44	11	0.56	0.01	16	2.0%	−0.70 [−1.49, 0.10]
Levers et al. (2016) (24 hr)c	0.89	0.47	11	1.39	0.14	16	2.0%	−1.53 [−2.42, −0.65]
Levers et al. (2016) (48 hr)a	2.02	0.89	11	−0.04	0.07	16	1.8%	3.53 [2.26, 4.81]
Levers et al. (2016) (48 hr)b	−0.07	0.36	11	−0.24	0.47	16	2.0%	0.38 [−0.39, 1.16]
Levers et al. (2016) (48 hr)c	1.25	0.66	11	−0.24	0.14	16	1.8%	3.35 [2.12, 4.58]
Quinlan and Hill (2019) (0 hr)	64.1	10.1	10	78.2	1.4	10	1.9%	−1.87 [−2.96, −0.78]
Quinlan and Hill (2019) (24 hr)	39.7	0.1	10	70.9	1.4	10	0.2%	−30.11 [−40.56, −19.66]
Quinlan and Hill (2019) (48 hr)	19.4	9.5	10	74.3	16.8	10	1.7%	−3.85 [−5.45, −2.26]
Subtotal (95% CI)			**235**			**278**	**41.2%**	**−0.30 [−1.05, 0.44]**
Heterogeneity: Tau² = 2.80; Chi² = 255.90, df = 21 (*p* < .00001); *I*² = 92%								
Test for overall effect: *Z* = 0.79 (*p* = .43)								
2.1.2 Mechanical								
Beals et al. (2017) (168 hr)	0.7	1.3	15	0	0.1	14	2.1%	0.72 [−0.03, 1.48]
Beals et al. (2017) (24 hr)	20.1	17.7	15	12.9	14.5	14	2.1%	0.43 [−0.31, 1.17]
Beals et al. (2017) (48 hr)	21.1	24.8	15	10.1	15	14	2.1%	0.52 [−0.23, 1.26]
Beals et al. (2017) (96 hr)	7.7	14.3	15	2.5	4.6	14	2.1%	0.47 [−0.27, 1.21]
Brown 2018 (0 hr)	14.1	11.4	10	13.5	4.9	10	2.0%	0.07 [−0.81, 0.94]
Brown 2018 (24 hr)	45.1	21.1	10	66.1	14.5	10	2.0%	−1.11 [−2.07, −0.15]
Brown 2018 (48 hr)	39.9	17.2	10	42.5	14.4	10	2.0%	−0.16 [−1.04, 0.72]
Brown 2018 (72 hr)	10.1	4	10	26.6	0.7	10	1.4%	−5.50 [−7.60, −3.41]
Connolly et al. (2006) (24 hr)	3.48	0.26	14	4.11	0.36	14	2.0%	−1.95 [−2.87, −1.03]
Connolly et al. (2006) (48 hr)	3.17	0.33	14	4.63	0.47	14	1.8%	−3.49 [−4.72, −2.26]
Connolly et al. (2006) (72 hr)	2	0.26	14	2.8	0.42	14	2.0%	−2.22 [−3.20, −1.25]
Connolly et al. (2006) (96 hr)	1.25	0.26	14	1.46	0.26	14	2.0%	−0.78 [−1.56, −0.01]
Kastello et al. (2014) (12 hr)	1.76	0.28	14	1.69	0.31	14	2.1%	0.23 [−0.51, 0.97]
Kastello et al. (2014) (24 hr)	3.42	0.33	14	3.83	0.31	14	2.0%	−1.24 [−2.06, −0.42]
Kastello et al. (2014) (48 hr)	4.06	0.33	14	4.75	0.28	14	2.0%	−2.19 [−3.15, −1.22]
Kastello et al. (2014) (72 hr)	3.7	0.38	14	2.8	0.46	14	2.0%	2.07 [1.13, 3.02]
Lamb et al. (2019) (0 hr)	17.83	15.55	12	7.92	7.309	12	2.0%	0.79 [−0.05, 1.62]
Lamb et al. (2019) (24 hr)	19.278	19.36	12	13.878	9.089	12	2.0%	0.34 [−0.46, 1.15]
Lamb et al. (2019) (48 hr)	30.672	23.365	12	16.312	6.19	12	2.0%	0.81 [−0.03, 1.65]
Lamb et al. (2019) (72hr)	23.118	22.128	12	18.302	19.49	12	2.0%	0.22 [−0.58, 1.03]
Lamb et al. (2019) (96 hr)	11.293	14.49	12	11.255	21.997	12	2.0%	0.00 [−0.80, 0.80]
Levers et al. (2015) (1 hr) a	−0.21	0.1	11	1.19	0.63	12	1.8%	−2.93 [−4.16, −1.69]
Levers et al. (2015) (1 hr) b	1.84	0.44	11	1.76	0.13	12	2.0%	0.24 [−0.58, 1.06]
Levers et al. (2015) (1 hr) c	1.08	0.51	11	0.17	0.59	12	2.0%	1.59 [0.62, 2.55]
Levers et al. (2015) (24 hr) a	1.7	0.18	11	3.44	0.41	12	1.5%	−5.21 [−7.06, −3.37]
Levers et al. (2015) (24 hr)b	0.89	0.47	11	1.39	0.14	12	2.0%	−1.42 [−2.35, −0.48]
Levers et al. (2015) (24 hr) c	2.21	1.2	11	3.3	1.15	12	2.0%	−0.89 [−1.76, −0.03]
Levers et al. (2015) (48 hr) a	2.19	0.73	11	3.6	0.4	12	1.9%	−2.34 [−3.44, −1.23]
Levers et al. (2015) (48 hr) b	1.25	0.66	11	−0.24	0.14	12	1.8%	3.08 [1.80, 4.35]
Levers et al. (2015) (48 hr) c	2.96	1.07	11	2.93	0.71	12	2.0%	0.03 [−0.79, 0.85]
Subtotal (95% CI)			**371**			**376**	**58.8%**	**−0.55 [−1.06, −0.04]**
Heterogeneity: Tau² = 1.76; Chi² = 273.89, df = 29 (*p* < .00001); *I*² = 89%								
Test for overall effect: *Z* = 2.13 (*p* = .03)								
Total (95% CI)			**606**			**654**	**100.0%**	**−0.44 [−0.87, −0.02]**
Heterogeneity: Tau² = 2.10; Chi² = 530.19, df = 51 (*p* < .00001); *I*² = 90%								
Test for overall effect: *Z* = 2.06 (*p* = .04)								
Test for subgroup differences: Chi² = 0.29, df = 1 (*p* = .59), *I*² = 0%								

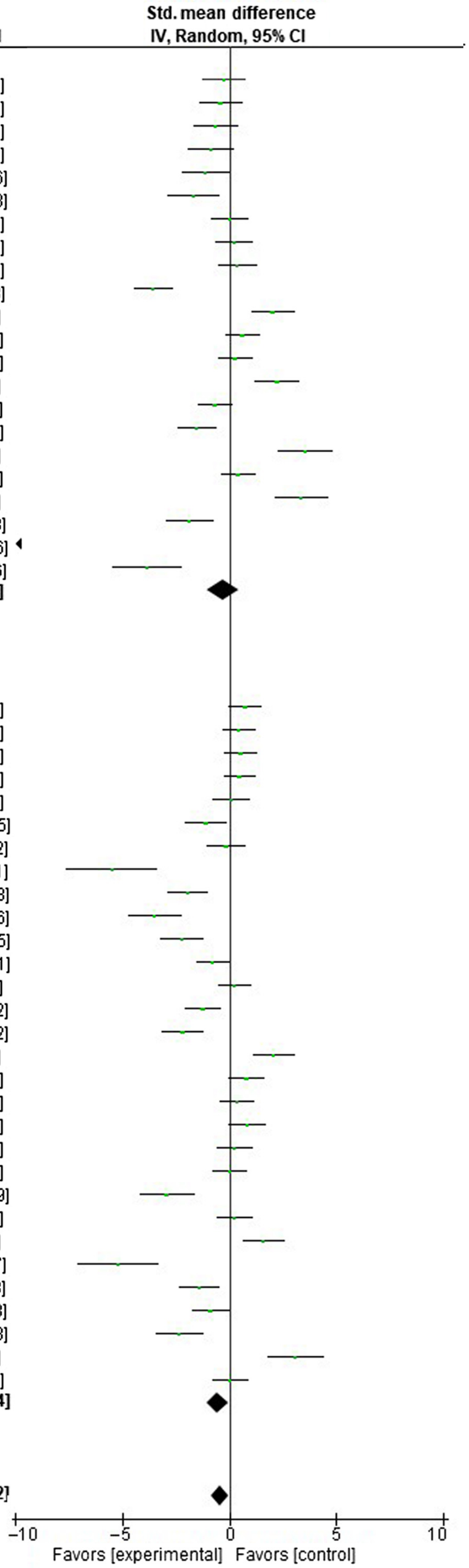

Figure 3 — Forest plot demonstrating a comparison between the consumption of a tart cherry supplement or a placebo for measures of delayed-onset muscle soreness. The time point of measurement postexercise is displayed in brackets on the first column. a, b, and c displayed in column 1 refer to soreness measured in different locations within the same study.

Study or subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. mean difference IV, Random, 95% CI
2.2.1 Metabolic								
Bell 2014ii (24 hr)	−2.42	12.12	8	8.18	7.56	8	2.4%	−0.99 [−2.05, 0.06]
Bell 2014ii (48 hr)	0.61	10.61	8	12.43	7.88	8	2.4%	−1.20 [−2.29, −0.11]
Bell 2014ii (72 hr)	−7.57	10.91	8	13.64	10.91	8	2.2%	−1.84 [−3.06, −0.61]
Bell 2016 (24 hr)	−1.6	12	8	15.86	10	8	2.3%	−1.49 [−2.64, −0.35]
Bell 2016 (48 hr)	−7.73	10	8	11.3	7	8	2.2%	−2.08 [−3.37, −0.80]
Bell 2016 (72 hr)	−4.02	13	8	5.81	7	8	2.5%	−0.89 [−1.93, 0.15]
Howatson et al. (2010) (1 hr)	122	51.7919	10	108	58.2632	10	2.6%	0.24 [−0.64, 1.12]
Howatson et al. (2010) (24 hr)	45	50.4301	10	71	55.692	10	2.6%	−0.47 [−1.36, 0.42]
Howatson et al. (2010) (48 hr)	−3	50.1019	10	35	49.0551	10	2.6%	−0.73 [−1.65, 0.18]
Quinlan and Hill (2019) (0 hr)	−49.9	50.45	10	−54.7	71.82	10	2.7%	0.07 [−0.80, 0.95]
Quinlan and Hill (2019) (24hr)	−20.3	50.25	10	−58.7	68.12	10	2.6%	0.61 [−0.29, 1.52]
Quinlan and Hill (2019) (48 hr)	−4.7	52.63	10	54.5	70.85	10	2.6%	−0.91 [−1.84, 0.02]
Subtotal (95% CI)			**108**			**108**	**29.8%**	**−0.73 [−1.18, −0.28]**
Heterogeneity: Tau² = 0.37; Chi² = 26.65, df = 11 (*p* = .005); *I*² = 59%								
Test for overall effect: *Z* = 3.17 (*p* = .002)								
2.2.2 Mechanical								
Beals et al. (2017) (168 hr)	−16.9	22.6816	15	−29.2	18.3116	14	2.8%	0.58 [−0.17, 1.32]
Beals et al. (2017) (24 hr)	−1	21.5608	15	−4.7	17.2023	14	2.8%	0.18 [−0.55, 0.91]
Beals et al. (2017) (48 hr)	2.6	23.3795	15	−11.1	17.3076	14	2.8%	0.64 [−0.11, 1.39]
Beals et al. (2017) (96 hr)	−6.6	22.521	15	−11.6	17.1306	14	2.8%	0.24 [−0.49, 0.97]
Bowtell et al. (2011) (1 hr)	34.7	2.8	10	34.7	3	10	2.7%	0.00 [−0.88, 0.88]
Bowtell et al. (2011) (24 hr)	9.8	3	10	15.3	2.8	10	2.4%	−1.82 [−2.89, −0.74]
Bowtell et al. (2011) (48 hr)	9.8	2.7	10	12.5	2.7	10	2.6%	−0.96 [−1.89, −0.02]
Brown 2018 (0 hr)	7.7	38.9447	10	38.1	39.7337	10	2.6%	−0.74 [−1.65, 0.17]
Brown 2018 (24 hr)	31.6	42.4952	10	36.8	39.5336	10	2.7%	−0.12 [−1.00, 0.76]
Brown 2018 (48 hr)	13	42.5747	10	30.4	40.2966	10	2.6%	−0.40 [−1.29, 0.49]
Brown 2018 (72 hr)	17.8	32.8236	10	16.3	42.3413	10	2.7%	0.04 [−0.84, 0.91]
Connolly et al. (2006) (24 hr)	12.2	3.73	14	30.3	4.4	14	2.0%	−4.31 [−5.73, −2.88]
Connolly et al. (2006) (48 hr)	6.9	4.1	14	26.6	3.4	14	1.8%	−5.08 [−6.69, −3.46]
Connolly et al. (2006) (72 hr)	2.2	4.7	14	16.9	3.4	14	2.2%	−3.48 [−4.71, −2.25]
Connolly et al. (2006) (96 hr)	−6.25	4.4	14	12.2	3.4	14	1.9%	−4.56 [−6.04, −3.07]
Kastello et al. (2014) (12 hr)	17.9	4.2	14	23.5	4	14	2.7%	−1.33 [−2.16, −0.50]
Kastello et al. (2014) (24 hr)	21	4	14	28.5	5	14	2.7%	−1.61 [−2.48, −0.74]
Kastello et al. (2014) (48 hr)	22	4.8	14	24.5	4.5	14	2.8%	−0.52 [−1.28, 0.23]
Kastello et al. (2014) (72 hr)	11	5	14	13.3	6.7	14	2.8%	−0.38 [−1.13, 0.37]
Lamb et al. (2019) (0 hr)	19.36	16.13	12	28.088	20.33	12	2.7%	−0.46 [−1.27, 0.35]
Lamb et al. (2019) (24 hr)	24.16	17.15	12	25.343	15.45	12	2.7%	−0.07 [−0.87, 0.73]
Lamb et al. (2019) (48 hr)	21.18	21.74	12	22.696	20.55	12	2.7%	−0.07 [−0.87, 0.73]
Lamb et al. (2019) (72 hr)	12.99	22.42	12	15.245	22.42	12	2.7%	−0.10 [−0.90, 0.70]
Lamb et al. (2019) (96 hr)	9.804	20.72	12	13.627	21.91	12	2.7%	−0.17 [−0.98, 0.63]
Levers et al. (2015) (1 hr)	310	299.847	11	453	169.193	12	2.7%	−0.57 [−1.41, 0.26]
Levers et al. (2015) (24 hr)	197	320.671	11	311	177.833	12	2.7%	−0.43 [−1.26, 0.40]
Levers et al. (2015) (48 hr)	311	300.557	11	348	163.614	12	2.7%	−0.15 [−0.97, 0.67]
Subtotal (95% CI)			**335**			**334**	**70.2%**	**−0.81 [−1.23, −0.40]**
Heterogeneity: Tau² = 1.00; Chi² = 158.86, df = 26 (*p* < .00001); *I*² = 84%								
Test for overall effect: *Z* = 3.82 (*p* = .0001)								
Total (95% CI)			**443**			**442**	**100.0%**	**−0.78 [−1.11, −0.46]**
Heterogeneity: Tau² = 0.82; Chi² = 186.10, df = 38 (*p* < .00001); *I*² = 80%								
Test for overall effect: *Z* = 4.76 (*p* < .00001)								
Test for subgroup differences: Chi² = 0.07, df = 1 (*p* = .79), *I*² = 0%								

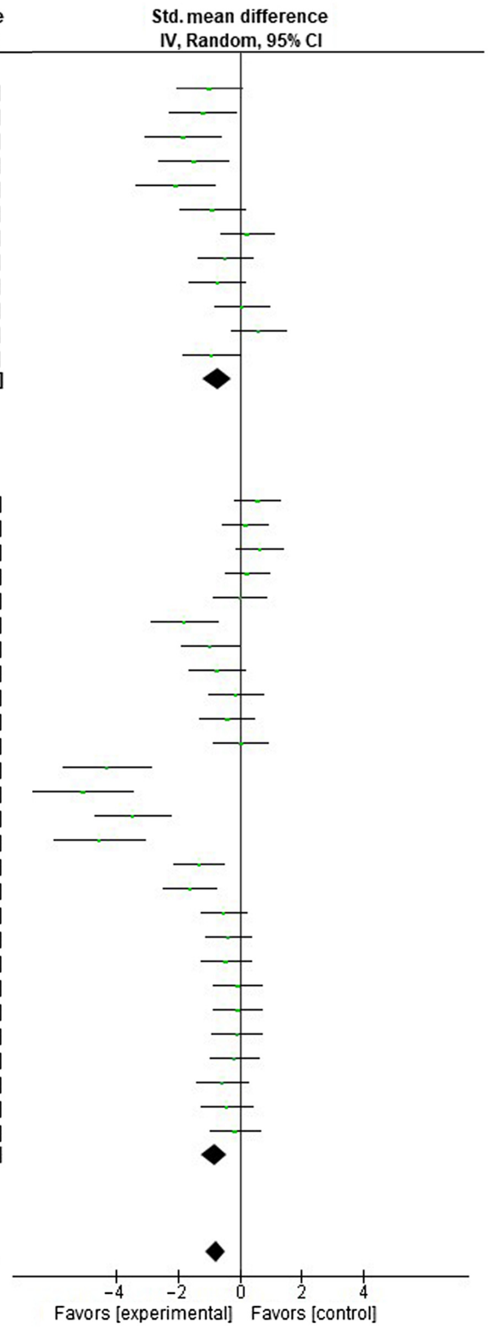

Figure 4 — Forest plot demonstrating a comparison between the consumption of a tart cherry supplement or a placebo for measures of strength. The time point of assessment postexercise is displayed in brackets on the first column.

Z = 5.62, *ES* = –0.84, 95% CI [–1.13, –0.54]). Contrasting this, the subgroup analysis revealed no significant group differences for CRP following mechanically induced muscle damage ($p = .79$).

Analysis for IL-6 carried out on 21 data points across six studies revealed a small significant benefit of TC supplementation on concentrations of IL-6 ($p < .05$, Z = 2.08, *ES* = –0.35, 95% CI [–1.68, –0.02]; Figure 8). Moderate heterogeneity was evident in the data set ($I^2 = 56\%$, $\text{Chi}^2 = 40.95$); however, no subgroup analysis was carried out as only one study induced muscle damage using a protocol categorized as mechanical. No significant effects of TC supplementation were observed for TNFα ($p = .27$, Z = 1.09; Figure 9). The heterogeneity across 19 data points was low ($I^2 = 0\%$; Higgins & Green, 2011). Subgroup analysis was not conducted as only one study induced muscle damage using a protocol categorized as mechanical.

Discussion

There is an increasing body of literature investigating the effectiveness of TC supplementation as a recovery strategy; however, the variation in methodological design, study population, and exercise stimulus have resulted in inconsistent findings throughout

Study or subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. mean difference IV, Random, 95% CI
2.3.1 Jump								
Bell et al. (2016) (24 hr)	7	5	8	12	3	8	3.6%	−1.15 [−2.23, −0.06]
Bell et al. (2016) (48 hr)	5	4	8	11	5	8	3.6%	−1.25 [−2.35, −0.15]
Bell et al. (2016) (72 hr)	6	4	8	9	4	8	4.0%	−0.71 [−1.73, 0.31]
Brown 2018 (0 hr)	11.5	7.5	10	16	5	10	4.7%	−0.68 [−1.58, 0.23]
Brown 2018 (24 hr)	8	6	10	15	15	10	4.8%	−0.59 [−1.49, 0.31]
Brown 2018 (48 hr)	4	4.5	10	14	4.5	10	3.3%	−2.13 [−3.27, −0.98]
Brown 2018 (72 hr)	1.5	7.5	10	13	7	10	4.0%	−1.52 [−2.54, −0.50]
Quinlan and Hill (2019) (0 hr)	2.31	7.2	10	3.05	5.22	10	4.9%	−0.11 [−0.99, 0.76]
Quinlan and Hill (2019) (24 hr)	1.17	6.83	10	3.32	5.16	10	4.9%	−0.34 [−1.22, 0.54]
Quinlan and Hill (2019) (48 hr)	0.05	6.87	10	2.75	5.32	10	4.8%	−0.42 [−1.31, 0.47]
Subtotal (95% CI)			**94**			**94**	**42.6%**	**−0.82 [−1.18, −0.45]**
Heterogeneity: Tau² = 0.10; Chi² = 12.53, df = 9 (*p* = .19); *I*² = 28%								
Test for overall effect: *Z* = 4.41 (*p* < .0001)								
2.3.2 Sprint								
Bell 2014ii (24 hr)	−80	157.0003822	8	8	129.0004	8	4.1%	−0.58 [−1.59, 0.43]
Bell 2014ii (48 hr)	−123	181.4369312	8	−24	131.034	8	4.0%	−0.59 [−1.60, 0.42]
Bell 2014ii (72 hr)	−126	167.0013174	8	−24	127.6064	8	4.0%	−0.65 [−1.66, 0.36]
Bell 2016 (24 hr)	0.06	0.09444575	8	0.13	0.11257	8	4.0%	−0.64 [−1.65, 0.38]
Bell 2016 (48 hr)	0.03	0.08634813	8	0.18	0.162776	8	3.7%	−1.09 [−2.16, −0.02]
Bell 2016 (72 hr)	−0.01	0.09444575	8	−0.12	0.120316	8	3.8%	0.96 [−0.09, 2.01]
Brown 2018 (0 hr)	0.1	0.23026072	10	0.18	0.185365	10	4.9%	−0.37 [−1.25, 0.52]
Brown 2018 (24 hr)	0.07	0.21718656	10	0.09	0.172	10	4.9%	−0.10 [−0.97, 0.78]
Brown 2018 (48 hr)	0.13	0.21501163	10	0.3	0.259368	10	4.7%	−0.68 [−1.59, 0.22]
Brown 2018 (72 hr)	0.05	0.24758837	10	0.15	0.180466	10	4.8%	−0.44 [−1.33, 0.45]
Quinlan and Hill (2019) (0 hr)	0.158	0.35	10	0.242	0.32	10	4.9%	−0.24 [−1.12, 0.64]
Quinlan and Hill (2019) (24 hr)	0.66	0.33	10	0.215	1.122	10	4.8%	0.52 [−0.38, 1.41]
Quinlan and Hill (2019) (48 hr)	0.01	0.34	10	0.144	0.33	10	4.8%	−0.38 [−1.27, 0.50]
Subtotal (95% CI)			**118**			**118**	**57.4%**	**−0.32 [−0.60, −0.04]**
Heterogeneity: Tau² = 0.03; Chi² = 13.33, df = 12 (*p* = .35); *I*² = 10%								
Test for overall effect: *Z* = 2.26 (*p* = .02)								
Total (95% CI)			**212**			**212**	**100.0%**	**−0.53 [−0.77, −0.29]**
Heterogeneity: Tau² = 0.10; Chi² = 31.17, df = 22 (*p* = .09); *I*² = 29%								
Test for overall effect: *Z* = 4.39 (*p* < .0001)								
Test for subgroup differences: Chi² = 4.59, df = 1 (*p* = .03), *I*² = 78.2%								

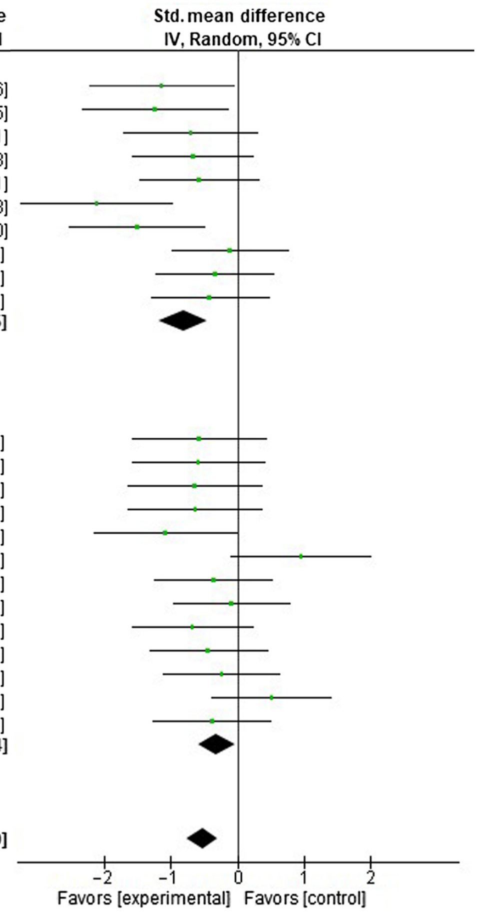

Figure 5 — Forest plot demonstrating a comparison between the consumption of a tart cherry supplement or a placebo for measures of power. The time point of assessment postexercise is displayed in brackets on the first column.

the literature, with the exception of CK for which no between-group difference has consistently been observed. To the authors' knowledge, this is the first study that has used a meta-analysis approach to evaluate the effectiveness of consuming TC as a recovery strategy. This analysis suggests that supplementation with TC can attenuate losses in strength and power, reduce the severity of DOMS, and attenuate concentrations of CRP and IL-6. No significant benefits were observed on concentrations of CK and TNFα following TC supplementation.

Both metabolic and mechanical factors contribute to the aetiology of EIMD, the contribution of which will vary depending on the type of exercise (Howatson & van Someren, 2008). Exercise modalities with a large endurance component are predominantly fueled by aerobic pathways and are associated with high metabolic costs (Bell et al., 2014a; Vitale et al., 2017). Conversely, modalities with large eccentric components are typically fueled via anaerobic pathways and are associated with higher mechanical stress (Bell et al., 2014a; Levers et al., 2015). Differences in relative contribution from the different energy systems are likely to impact the type and magnitude of stress caused by the exercise protocol (Bell et al., 2014a). Research has suggested that cherry supplementation is suited to facilitating recovery from exercise with a large metabolic component (Bell et al., 2014a). Due to this, a subgroup analysis was carried out on exercise type, mechanical, or metabolic.

A significant and large effect was observed for muscle strength indicating that TC supplementation was able to accelerate the recovery of muscle strength. The subgroup analysis on exercise type indicated this observation was consistent between the metabolic and mechanical exercise groups. Overall analysis for muscular power revealed a significant and moderate benefit. For this, variable subgroup analysis was carried out on the method of assessment, jump height, or sprint test. Subgroup analysis revealed a significant and large beneficial effect of TC supplementation on jump height and a significant but small beneficial effect on sprint speed. These differences in effect size between subgroups could be due to the mechanics of the different movements, with the CMJ utilizing the stretch-shortening cycle and containing both an eccentric and concentric phase within the movement. In addition, previous research has indicated a large learning effect with sprint trials (Bell et al., 2014a). This study observed an improvement in sprint performance overtime throughout the 72-h posttrial period, and this increase in performance was attributed to a learning effect and could explain a smaller effect size for this measure.

Muscle damaging exercise leads to a decrease in the force-generating capacity of the affected muscle, and this is attributed to myofibrillar disruption and damage to the muscle fiber architecture (Clarkson & Hubal, 2002). Previous research has indicated that supplementation with TC can protect against the declines in muscle

Study or subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. mean difference IV, Random, 95% CI
2.4.1 Metabolic								
Bell 2014i (0 hr)	99.8	61.09136	8	51.7	47.83513	8	2.5%	0.83 [-0.21, 1.86]
Bell 2014i (24 hr)	42	50.71625	8	94	54.96472	8	2.5%	-0.93 [-1.98, 0.12]
Bell 2014i (48 hr)	23	39.39414	8	164	177.7351	8	2.4%	-1.04 [-2.10, 0.03]
Bell 2014ii (0 hr)	53	72.00694	8	-31	53.09049	8	2.3%	1.26 [0.15, 2.36]
Bell 2014ii (1 hr)	23	105.8386	8	19	56.93681	8	2.8%	0.04 [-0.94, 1.02]
Bell 2014ii (24 hr)	-12	62.36185	8	7	63.00794	8	2.8%	-0.29 [-1.27, 0.70]
Bell 2014ii (48 hr)	75	154.7605	8	-1	74.64181	8	2.7%	0.59 [-0.42, 1.60]
Bell 2014ii (72 hr)	-3	67.60621	8	-16	102.5095	8	2.8%	0.14 [-0.84, 1.12]
Bell et al. (2016) (0 hr)	398	228.16	8	242	213.5907	8	2.6%	0.67 [-0.35, 1.68]
Bell et al. (2016) (1 hr)	592	349.4865	8	338	299.1675	8	2.6%	0.74 [-0.29, 1.76]
Bell et al. (2016) (24 hr)	1,258	1,297.83	8	837	985.3427	8	2.7%	0.35 [-0.64, 1.34]
Bell et al. (2016) (48 hr)	666	654.0661	8	455	496.0762	8	2.7%	0.34 [-0.65, 1.33]
Bell et al. (2016) (72 hr)	267	245.29	8	206	221.8621	8	2.8%	0.25 [-0.74, 1.23]
Howatson et al. (2010) (1 hr)	477	284.0158	10	725	504.5721	10	3.2%	-0.58 [-1.48, 0.32]
Howatson et al. (2010) (24 hr)	2,118	1,454.198	10	2,627	2,063.227	10	3.3%	-0.27 [-1.15, 0.61]
Howatson et al. (2010) (48 hr)	1,009	873.3298	10	1,300	1,012.64	10	3.3%	-0.29 [-1.18, 0.59]
Levers et al. (2016) (1 hr)	246	152.2275	11	256	376.2938	16	4.1%	-0.03 [-0.80, 0.74]
Levers et al. (2016) (24 hr)	642	628.7324	11	631	411.4134	16	4.1%	0.02 [-0.75, 0.79]
Levers et al. (2016) (48 hr)	262	267.944	11	317	327.6049	16	4.1%	-0.17 [-0.94, 0.59]
Quinlan and Hill (2019) (0 hr)	105.4	71.53	10	158.1	115.34	10	3.2%	-0.53 [-1.42, 0.37]
Quinlan and Hill (2019) (24 hr)	189.1	151.26	10	378.2	196.1	10	3.0%	-1.03 [-1.98, -0.09]
Quinlan and Hill (2019) (48 hr)	112.9	125.44	10	138.9	97.33	10	3.3%	-0.22 [-1.10, 0.66]
Subtotal (95% CI)			**197**			**212**	**66.0%**	**-0.03 [-0.27, 0.20]**
Heterogeneity: Tau² = 0.09; Chi² = 29.30, df = 21 (*p* = .11); *I*² = 28%								
Test for overall effect: *Z* = 0.26 (*p* = .79)								
2.4.2 Mechanical								
Bowtell et al. (2011) (1 hr)	32.5	176.4574	10	14.1	71.03274	10	3.4%	0.13 [-0.75, 1.01]
Bowtell et al. (2011) (24 hr)	325.8	313.2936	10	202	116.7247	10	3.3%	0.50 [-0.39, 1.40]
Bowtell et al. (2011) (48 hr)	71.9	194.5102	10	126.8	89.51659	10	3.3%	-0.35 [-1.23, 0.54]
Brown et al. (2018) (0 hr)	21.8	38.48129	10	12	45.27693	10	3.3%	0.22 [-0.66, 1.10]
Brown et al. (2018) (24 hr)	298.7	213.8151	10	437	305.587	10	3.3%	-0.50 [-1.40, 0.39]
Brown et al. (2018) (48 hr)	137.5	102.9672	10	261.1	226.3188	10	3.2%	-0.67 [-1.58, 0.23]
Brown et al. (2018) (72 hr)	147	167.5083	10	263.2	242.2581	10	3.2%	-0.53 [-1.43, 0.36]
Levers et al. (2015) (1 hr)	96	119.4454	11	129	162.8754	12	3.7%	-0.22 [-1.04, 0.60]
Levers et al. (2015) (24 hr)	511	363.9011	11	645	526.2024	12	3.7%	-0.28 [-1.11, 0.54]
Levers et al. (2015) (48 hr)	156	130.1084	11	533	799.9982	12	3.6%	-0.62 [-1.46, 0.22]
Subtotal (95% CI)			**103**			**106**	**34.0%**	**-0.23 [-0.51, 0.04]**
Heterogeneity: Tau² = 0.00; Chi² = 6.87, df = 9 (*p* = .65); *I*² = 0%								
Test for overall effect: Z = 1.67 (*p* = .10)								
Total (95% CI)			**300**			**318**	**100.0%**	**-0.10 [-0.28, 0.08]**
Heterogeneity: Tau² = 0.04; Chi² = 37.42, df = 31 (*p* = .20); *I*² = 17%								
Test for overall effect: *Z* = 1.13 (*p* = .26)								
Test for subgroup differences: Chi² = 1.20, df = 1 (*p* = .27), *I*² = 16.4%								

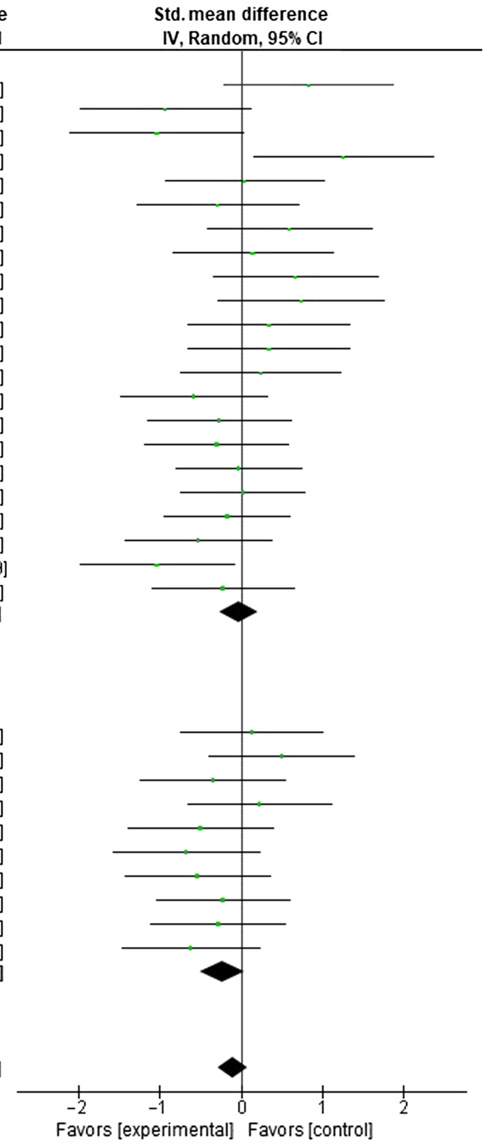

Figure 6 — Forest plot demonstrating a comparison between the consumption of a tart cherry supplement or a placebo for creatine kinase. The time point of assessment postexercise is displayed in brackets on the first column.

function that are observed following strenuous exercise (Bell et al., 2016). This has been proposed to occur as a result of a reduced acute inflammatory response (Bell et al., 2016). This is supported by attenuated inflammatory markers observed in this meta-analysis.

Supplementation with TC resulted in an overall significant but small effect on both CRP and IL-6 with lower concentrations observed following TC consumption. Interestingly, the subgroup analysis carried out for CRP revealed that TC supplementation had no significant effect on exercise protocols categorized as mechanical and a large and significant effect on exercise categorized as metabolic. Reduced concentrations of CRP have previously been attributed to a reduction in cell damage that occurs as a result of oxidative stress (Bell et al., 2014a). Thus, it might be that TC supplementation is more beneficial to exercise that is more metabolically challenging. It is also possible that prolonged endurance exercise such as marathon running could induce a systemic inflammatory response, enhancing the ability of the TC supplement to have a greater blunting effect on the secondary muscle damage response (Bell et al., 2014b). A possible explanation for the reduced inflammatory response is that anthocyanins contained in the TC are able to inhibit the activity of prostaglandin enzymes, which has been shown to mediate inflammation (Lanier, 2003). It should also be noted that the exercise modalities classified as metabolic are not all free of mechanical damage. For example, marathon running has huge metabolic consequences, but the repetitive eccentric contractions occurring as part of the gait cycle will also induce mechanical damage. No benefit of supplementation with TC was observed for TNFα. A subgroup analysis was not carried out for TNFα and IL-6 due to the limited number of studies that measured these variables.

Data from this study indicate that the consumption of TC can attenuate the severity of DOMS, with the observation of a small beneficial effect in favor of TC. The subgroup analysis revealed there was no significant effect of TC supplementation on soreness following exercise that is metabolic in nature; however, there was a significant and moderate reduction in soreness following exercise

Study or subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. mean difference IV, Random, 95% CI
2.5.1 Metabolic								
Bell 2014i (24 hr)	18.75	79.69	8	134.38	115.63	8	4.8%	−1.10 [−2.17, −0.03]
Bell 2014i (48 hr)	25	100	8	162.5	167.19	8	4.8%	−0.94 [−1.99, 0.11]
Bell 2014ii (24 hr)	−0.03	0.61	8	0.4	0.21	8	4.9%	−0.89 [−1.93, 0.15]
Bell 2014ii (48 hr)	−0.4	0.61	8	0.11	0.05	8	4.8%	−1.11 [−2.19, −0.04]
Bell 2014ii (72 hr)	−0.58	0.79	8	0	0.2	8	4.8%	−0.95 [−2.00, 0.10]
Bell 2016 (24 hr)	1.24	0.02	8	1.69	1.35	8	5.0%	−0.45 [−1.44, 0.55]
Bell 2016 (48 hr)	0.69	0.23	8	1.05	0.25	8	4.7%	−1.42 [−2.55, −0.29]
Bell 2016 (72 hr)	0.3	0.32	8	0.49	0.16	8	4.9%	−0.71 [−1.73, 0.31]
Howatson et al. (2010) (24 hr)	18	5	10	27	7	10	4.9%	−1.42 [−2.42, −0.41]
Howatson et al. (2010) (48 hr)	10	3	10	15	4	10	5.0%	−1.35 [−2.35, −0.36]
Quinlan and Hill (2019) (24 hr)	0.554	0.959	10	0.933	0.74	10	5.2%	−0.42 [−1.31, 0.46]
Quinlan and Hill (2019) (48 hr)	0.924	1.775	10	0.759	0.459	10	5.2%	0.12 [−0.76, 1.00]
Subtotal (95% CI)			**104**			**104**	**58.9%**	**−0.84 [−1.13, −0.54]**
Heterogeneity: Tau² = 0.00; Chi² = 9.98, df = 11 (*p* = .53); *I*² = 0%								
Test for overall effect: *Z* = 5.62 (*p* < .00001)								
2.5.2 Mechanical								
Bowtell et al. (2011) (24 hr)	−0.2	0.7	10	−0.4	0.7	10	5.2%	0.27 [−0.61, 1.16]
Bowtell et al. (2011) (48 hr)	−0.2	1	10	−0.5	0.7	10	5.2%	0.33 [−0.55, 1.22]
Brown 2018 (24 hr)	0.52	1.75	10	−0.08	0.2	10	5.2%	0.46 [−0.43, 1.35]
Brown 2018 (48 hr)	0.5	0.02	10	−0.52	0.79	10	4.8%	1.75 [0.68, 2.81]
Brown 2018 (72 hr)	−0.07	0.64	10	−0.1	0.62	10	5.2%	0.05 [−0.83, 0.92]
Kastello et al. (2014) (24 hr)	1.81	0.65	14	3.83	1.61	14	5.2%	−1.60 [−2.46, −0.73]
Kastello et al. (2014) (48 hr)	1.2	0.39	14	3.09	1.19	14	5.1%	−2.07 [−3.02, −1.13]
Kastello et al. (2014) (72 hr)	2.52	0.9	14	1.09	0.48	14	5.1%	1.92 [1.01, 2.84]
Subtotal (95% CI)			**92**			**92**	**41.1%**	**0.13 [−0.82, 1.08]**
Heterogeneity: Tau² = 1.65; Chi² = 60.44, df = 7 (*p* < .00001); *I*² = 88%								
Test for overall effect: *Z* = 0.27 (*p* = .79)								
Total (95% CI)			**196**			**196**	**100.0%**	**−0.46 [−0.93, 0.00]**
Heterogeneity: Tau² = 0.88; Chi² = 87.59, df = 19 (*p* < .00001); *I*² = 78%								
Test for overall effect: *Z* = 1.96 (*p* = .05)								
Test for subgroup differences: Chi² = 3.65, df = 1 (*p* = .06), *I*² = 72.6%								

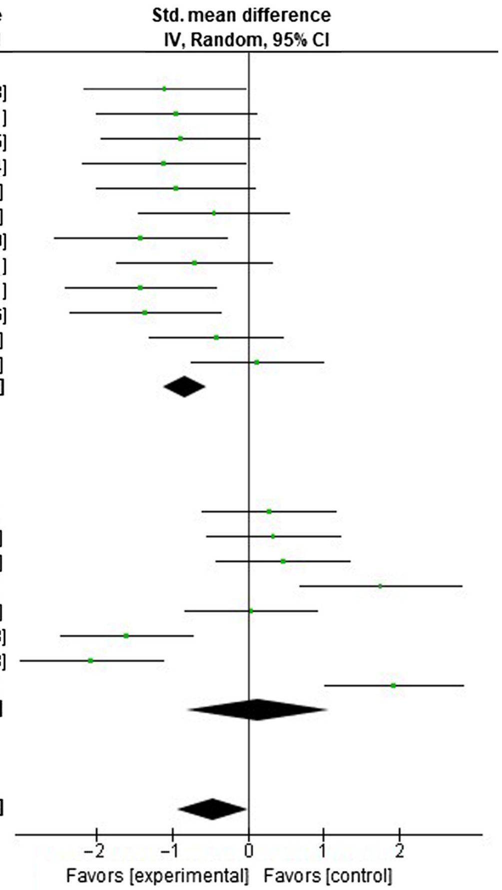

Figure 7 — Forest plot demonstrating a comparison between the consumption of a tart cherry supplement or a placebo for C-reactive protein. The time point of assessment postexercise is displayed in brackets on the first column.

Study or subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. mean difference IV, Random, 95% CI
Bell 2014i (0 hr)	1.75	0.994706	8	3.65	1.809005	8	4.7%	−1.23 [−2.33, −0.13]
Bell 2014i (24 hr)	1.11	0.917388	8	3.05	2.437324	8	4.8%	−1.00 [−2.05, 0.06]
Bell 2014i (48 hr)	0.95	0.360333	8	2.48	1.390971	8	4.5%	−1.42 [−2.56, −0.29]
Bell 2014ii (0 hr)	2.6	0.770101	8	3.73	1.887786	8	5.0%	−0.74 [−1.76, 0.28]
Bell 2014ii (1 hr)	0.75	0.478539	8	1.34	0.696276	8	4.9%	−0.93 [−1.98, 0.11]
Bell 2014ii (24 hr)	0.27	0.353667	8	−0.39	0.381293	8	4.3%	1.70 [0.51, 2.89]
Bell 2014ii (48 hr)	−0.35	0.311987	8	−0.62	0.39982	8	5.0%	0.71 [−0.31, 1.73]
Bell et al. (2016) (0 hr)	3.8	1.19499	8	6.2	2.761902	8	4.8%	−1.07 [−2.13, 0.00]
Bell et al. (2016) (1 hr)	2	0.368782	8	3.8	1.931321	8	4.7%	−1.22 [−2.32, −0.13]
Bell et al. (2016) (24 hr)	0.25	0.324037	8	0.3	0.50448	8	5.2%	−0.11 [−1.09, 0.87]
Bell et al. (2016) (48 hr)	−0.2	0.363318	8	−0.35	0.497293	8	5.2%	0.33 [−0.66, 1.31]
Bell et al. (2016) (72 hr)	−0.2	0.5	8	−0.35	0.497293	8	5.2%	0.28 [−0.70, 1.27]
Howatson et al. (2010) (1 hr)	41.8	0.2	10	80.3	36.02515	10	5.1%	−1.45 [−2.46, −0.44]
Howatson et al. (2010) (24 hr)	0	0	10	−0.6	2.717057	10		Not estimable
Howatson et al. (2010) (48 hr)	0	0	10	−0.9	2.807063	10		Not estimable
Levers et al. (2015) (1 hr)	0.45	0.874172	11	0.27	0.985657	12	6.0%	0.19 [−0.63, 1.01]
Levers et al. (2015) (24 hr)	0.11	0.923146	11	−0.01	0.888063	12	6.0%	0.13 [−0.69, 0.95]
Levers et al. (2015) (48 hr)	−0.02	0.89509	11	−0.08	0.844779	12	6.0%	0.07 [−0.75, 0.88]
Levers et al. (2016) (1 hr)	1.18	1.038194	11	1.58	1.014735	16	6.3%	−0.38 [−1.15, 0.40]
Levers et al. (2016) (24 hr)	−0.25	0.779357	11	−0.06	0.325644	16	6.3%	−0.33 [−1.11, 0.44]
Levers et al. (2016) (48 hr)	−0.35	0.815772	11	−0.07	0.325143	16	6.2%	−0.47 [−1.25, 0.31]
Total (95% CI)			**192**			**210**	**100.0%**	**−0.35 [−0.68, −0.02]**
Heterogeneity: Tau² = 0.30; Chi² = 40.95, df = 18 (*p* = .002); *I*² = 56%								
Test for overall effect: *Z* = 2.08 (*p* = .04)								

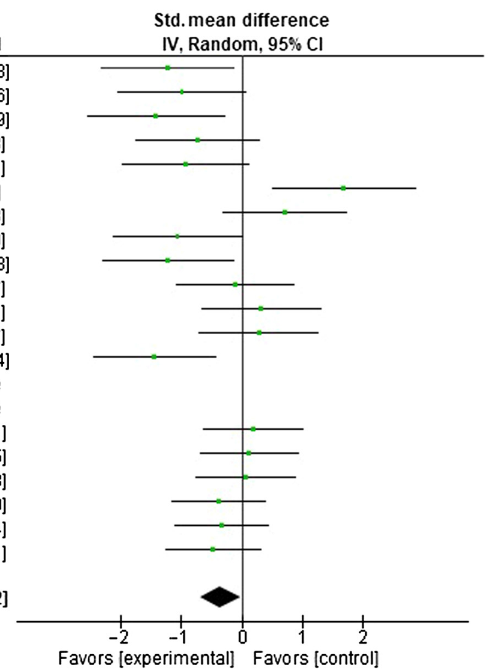

Figure 8 — Forest plot demonstrating a comparison between the consumption of a tart cherry supplement or a placebo for IL-6. The time point of assessment postexercise is displayed in brackets on the first column. IL-6 = interleukin 6.

Study or subgroup oup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. mean difference IV, Random, 95% CI
Bell 2014i (0 hr)	0.25	0.36093	8	0.07	0.523393	8	4.5%	0.38 [−0.61, 1.37]
Bell 2014i (24 hr)	0.25	0.352	8	−0.25	0.550863	8	3.9%	1.02 [−0.04, 2.08]
Bell 2014i (48 hr)	0.04	0.319	8	−0.11	0.539231	8	4.5%	0.32 [−0.67, 1.31]
Bell 2014ii (0 hr)	0.12	0.31882	8	0.02	0.52192	8	4.6%	0.22 [−0.77, 1.20]
Bell 2014ii (1 hr)	0.03	0.319	8	−0.14	0.525623	8	4.5%	0.37 [−0.62, 1.36]
Bell 2014ii (24 hr)	−0.12	0.31882	8	−0.37	0.521268	8	4.4%	0.55 [−0.46, 1.55]
Bell 2014ii (48 hr)	−0.27	0.32259	8	−0.44	0.521584	8	4.5%	0.37 [−0.62, 1.36]
Bell 2014ii (72 hr)	−0.27	0.34037	8	−0.21	0.525623	8	4.6%	−0.13 [−1.11, 0.85]
Bell et al. (2016) (0 hr)	−0.43	0.25764	8	0.19	0.558627	8	3.6%	−1.35 [−2.47, −0.23]
Bell et al. (2016) (1 hr)	0.02	0.20955	8	−0.01	0.539559	8	4.6%	0.07 [−0.91, 1.05]
Bell et al. (2016) (24 hr)	0.2	0.24123	8	0.06	0.577096	8	4.6%	0.30 [−0.69, 1.29]
Bell et al. (2016) (48 hr)	0.06	0.23636	8	0.01	0.549618	8	4.6%	0.11 [−0.87, 1.09]
Bell et al. (2016) (72 hr)	0.2	0.32658	8	0.11	0.605485	8	4.6%	0.17 [−0.81, 1.16]
Levers et al. (2015) (1 hr)	0.06	0.71099	11	0.03	1.157395	12	6.6%	0.03 [−0.79, 0.85]
Levers et al. (2015) (24 hr)	−0.11	0.71061	11	−0.32	0.993937	12	6.6%	0.23 [−0.59, 1.05]
Levers et al. (2015) (48 hr)	−0.32	0.70578	11	−0.45	0.986913	12	6.6%	0.14 [−0.67, 0.96]
Levers et al. (2016) (1 hr)	0.11	0.85187	11	0.28	0.950326	16	7.5%	−0.18 [−0.95, 0.59]
Levers et al. (2016) (24 hr)	−0.22	0.58658	11	−0.26	0.751862	16	7.5%	0.06 [−0.71, 0.82]
Levers et al. (2016) (48 hr)	−0.4	0.56246	11	−0.25	0.750706	16	7.5%	−0.21 [−0.98, 0.56]
Total (95% CI)			**170**			**188**	**100.0%**	**0.12 [−0.09, 0.33]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 12.89$, df = 18 ($p = .80$); $I^2 = 0\%$
Test for overall effect: $Z = 1.09$ ($p = .27$)

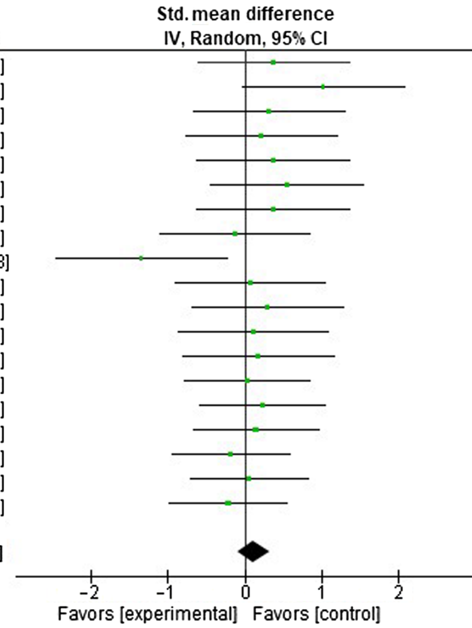

Figure 9 — Forest plot demonstrating a comparison between the consumption of a tart cherry supplement or a placebo for TNFα. The time point of assessment postexercise is displayed in brackets on the first column. TNFα = tumor necrosis factor alpha.

that is mechanical in nature. Soreness following damaging exercise has been attributed to increased oxidative stress and inflammation (Beals et al., 2017), increased sensitivity of nociceptors and mechanoreceptors to noxious chemicals, including prostaglandins, released during muscle damage (Clarkson & Hubal., 2002) and microinjury to surrounding tissues that are exacerbated by immune-mediated inflammation (Sonkodi et al., 2020). It is possible that supplementation with TC can inhibit the cyclooxygenase pathway, reducing the synthesis of prostaglandins (Marzocchella et al., 2011), and dampening the secondary muscle damage response (Levers et al., 2015), this could result in reduced muscle soreness. Damage to the connective tissue and structures within the muscle fibers is likely to be greater following exercise that is mechanical in nature giving rise to a greater inflammatory response, and this may explain why TC supplementation has a greater effect following exercise of a mechanical nature.

No significant effect of TC supplementation was observed compared with placebo for creatine kinase. This is not surprising given that none of the 11 studies included in the analysis observed a significant difference between groups for CK. High variability exists in the CK response between individuals and in response to different types of exercise (Brancaccio et al., 2007). In addition to this, the training status of the participants greatly affects the CK response to exercise. The variability in population, training status, and exercise modalities used within the studies included in this meta-analysis may explain why no significant effects were observed. In addition to high inter-individual variability, there is wide variability in the magnitude of change in CK across studies; for example, Levers et al. (2016) observed peak values of 870 IU/L in the TC group compared with Howatson et al. (2010), who observed peak values of 2,227 IU/L in the TC group. Due to this, CK may not be a good marker for exercise recovery but is a good indicator of the presence of EIMD.

Supplementation with TC is thought to attenuate RONS-induced membrane damage therefore limiting muscle damage and facilitating recovery. The results from this meta-analysis provide some evidence to suggest that supplementation with TC can enhance certain aspects associated with exercise recovery. A limitation of the present study is that oxidative stress was not included in the analysis due to a lack of studies measuring the same markers of oxidative stress; therefore, it is difficult to get a mechanistic understanding of the effects of TC. In addition, while we tried to classify exercise modalities based upon exercise type, mechanical, or metabolic, many exercise modalities often incur both mechanical and metabolic stress. This is important to note. Further research should investigate exercise modalities that isolate metabolic or mechanical stress to better identify whether TC supplementation is more effective under specific conditions.

Finally, it is important to note that meta-analyses are limited by the data available, and there are several limitations in the literature: (a) the participants of several studies were of mixed gender, there is no indication of how the menstrual cycle was controlled for in these studies; (b) the mode of exercise and muscle groups involved varies greatly between studies, this is likely to induce different levels of muscle damage via different mechanistic pathways, there was also variation in the training status of the participants, this will affect the severity of the muscle damage experienced; (c) the type of TC supplement and supplementation protocol varies between studies, with studies administering various brands of juice (Bell et al., 2016; Howatson et al., 2007; Quinlan & Hill, 2019) and some using a powder that is mixed with water (Beals et al., 2017; Levers et al., 2015, 2016). In addition to this, several studies implemented dietary restrictions asking participants to follow a low phenolic diet. This could lead to an overestimation of the intervention effect and has been acknowledged in the risk of bias assessment. Limitations a–c could all have had an influence on the variability of the data and may explain why there was large heterogeneity in some of the variables. Finally, (d) independent variables were only included in the meta-analysis if three studies had measured and reported them. While some studies have assessed markers of oxidative stress, there is not one marker that has been assessed by three separate studies.

Conclusion

The results of this systematic review and meta-analysis indicate that supplementation with TC can aid the recovery of muscle function and attenuate soreness following strenuous exercise. It is possible that this occurs via a mediated inflammatory response as indicated by attenuations in the concentration of CRP and IL-6. Further research is needed that investigates the effects of TC supplementation on markers of oxidative stress while taking into consideration the limitations of these markers. Although the physiological mechanisms are yet to be fully understood, this meta-analysis provides support for the use of TC to facilitate recovery following strenuous exercise.

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