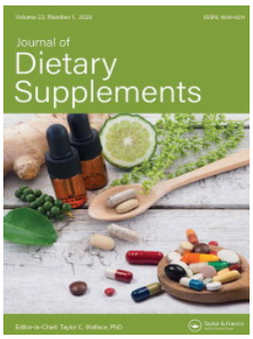
Blackcurrant Anthocyanin Supplementation Alters Exercise-Induced Substrate Utilization - A Systematic Review and Meta-Analysis



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Blackcurrant Anthocyanin Supplementation Alters Exercise-Induced Substrate Utilization - A Systematic Review and Meta-Analysis

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ABSTRACT

Blackcurrant anthocyanins have been investigated for their effects on exercise-induced substrate utilisation. Previous research has examined the influence of supplementation dose, duration, and exercise modality, with mixed findings. This systematic review and meta-analysis examined the effect of blackcurrant supplementation on exercising substrate utilisation. Electronic searches were conducted in PubMed, Web of Science, and EBSCOhost between the 1st May and 14th November 2025 using a predefined search strategy. Controlled trials investigating the effects of blackcurrant supplementation on fat and carbohydrate oxidation during exercise in physically active adults (18–65 years) were included. All forms, doses, and supplementation durations were eligible, provided outcomes were reported as absolute rates of substrate utilisation during exercise. Two authors independently extracted data and assessed for risk of bias using the Cochrane RoB 2 tool, with a random-effects meta-analysis undertaken on the mean difference between control or placebo and consumption of blackcurrant extract on exercise substrate utilisation. Searches returned 263 articles, with 15 studies included with 226 participants after full-text screening. Meta-analysis demonstrated blackcurrant extract to increase fat oxidation (0.042 g·min-1, $P < 0.001$) and decrease carbohydrate oxidation (-0.099 g·min-1, $P = 0.012$). Blackcurrant can increase fat oxidation and decrease carbohydrate oxidation during exercise. However, this finding is not consistent for individuals and factors such as training status, sex, dosage, duration of intake may determine responses. The review was registered on the 28th April 2025 in PROSPERO (CRD420251030222).

Abbreviations: confidence interval: CI; messenger ribonucleic acid: mRNA; respiratory exchange ratio: RER; Prisma in Exercise, Rehabilitation, Sport medicine and SporTs science: PERSiT; Population, intervention, comparison and outcome: PICO

KEYWORDS

Anthocyanins; polyphenols; lipid metabolism; carbohydrate metabolism; exercise; ribes

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Introduction

The berry fruit blackcurrant has a high content (590 mg/100 g) of the flavonoid anthocyanin, which is mostly derived from the anthocyanidins delphinidin (66.1%) and cyanidin (31.6%) in glucoside and rutinoside forms (Rothwell et al. 2013). These anthocyanins give dark pigmentation to the berry and confer multiple health benefits through anti-inflammatory and antioxidant effects (Cerletti et al. 2017; Cappellini et al. 2021). This may contribute to mechanisms of blackcurrant extract supplementation increasing exercise performance (Cook and Willems 2019; Braakhuis et al. 2020; Willems and Blacker 2022; Willems et al. 2025) and responses that would support exercise performance such as altered cardiovascular function (Willems et al. 2015) and substrate utilization (Cook et al. 2015).

Oxidation of fat during exercise is linked to performance. For example, in circumstances where the use of limited stored carbohydrates is important, increasing fat oxidation during exercise could be important for preserving these stores. For instance, performance in the ironman-distance triathlon is associated with fat use during exercise in men (R^2=0.27, $p < 0.0001$) (Frandsen et al. 2017) and women (R^2=0.22, $p < 0.005$) (Vest et al. 2018). Furthermore, Wang et al. (2015) showed that fat oxidation during exercise may also have implications for those wanting to lose fat mass, whereby 10 wk training at the intensities where fat oxidation is at its highest, demonstrated decreased body mass (Pre: 71.5 ± 7.3, vs. Post: 68.5 ± 6.8 kg), fat mass (Pre: 28.2 ± 3.6, vs. Post: 25.8 ± 3.7 kg) and abdominal fat (Pre: 2.4 ± 0.4 vs. Post: 2.2 ± 0.4 kg).

Intake of New Zealand blackcurrant extract has been shown to influence exercising substrate utilization during exercise, with an increase in fat oxidation and a decrease in carbohydrate oxidation. This was observed during cycling in men (Cook et al. 2015), treadmill walking and running in men and women (Shan and Cook 2023; Cook et al. 2025), and treadmill walking in women (Willems et al. 2022). The mechanisms for increasing fat oxidation during exercise are not fully clear, but blackcurrant anthocyanins have been shown to increase messenger ribonucleic acid (mRNA) of genes involved with energy expenditure, including peroxisome proliferator-activated receptor alpha in C57BL/6 J mice (Benn et al. 2014). Recent observations have also identified that the magnitude of change in fat oxidation response is linked to body fat percentage in women but not men (Cook et al. 2025), and that responses are highest in those who have a high respiratory exchange ratio (RER) during exercise when not taking blackcurrant (Willems and Cook 2025).

To date, studies using blackcurrant have examined the effects of supplementation on substrate utilization during exercise with varying outcomes. Variations of dosing protocol, training status of the participants, and modality and intensity of exercise have different outcomes, with some studies showing blackcurrant to increase fat oxidation, while other studies have shown effect. The aim of this systematic review and meta-analysis was to analyze the effect of blackcurrant supplementation extract on fat and carbohydrate oxidation rate during exercise in men and women.

Methods

Literature search

A systematic review and meta-analysis were developed in accordance with the guidelines of the International Prospective Register for Systematic Reviews and pre-registered

on PROSPERO on 28th April 2025 (CRD420251030222). The study was approved by the University of Worcester Health and Science Research Ethics Panel (ANHS23240025). In addition, the Prisma in Exercise, Rehabilitation, Sport Medicine and SporTs science (PERSiT) was also implemented (Ardern et al. 2022).

Search strategy

The primary research focused on studies reporting on the effect of blackcurrant extract supplementation on fat and carbohydrate oxidation rate during exercise. An electronic database search was undertaken between the 1st May and the 5th June 2025 and a follow-up search on the 14th November 2025. Searches were performed through MEDLINE *via* PubMed, Web of Science, and SPORTDiscus *via* EBSCOhost. A population, intervention, comparison and outcome (PICO) strategy was used to build search criteria for electronic databases (Supplementary file 1). The PICO consisted of the phrases "blackcurrant substrate utilisation exercise", "blackcurrant substrate utilisation", "blackcurrant fat oxidation exercise", "blackcurrant fat oxidation", "blackcurrant substrate oxidation", "blackcurrant carbohydrate oxidation exercise", and "blackcurrant physiological response exercise". PubMed was used for the most extensive search with the search strings used for other databases adapted using Polyglot Search Translator Tool (https://sr-accelerator.com/#/polyglot) (Clark et al. 2020). The search strings utilized are provided in Supplementary File 1. Restrictions were applied to the publication types, with conference abstracts, theses, articles in press and books or book chapters were excluded from the search. To be included, studies had to be published in English.

Eligibility criteria

To be included, studies had to adhere to the following criteria: Type of studies: randomized or non-randomized controlled trial where the effect of blackcurrant supplementation on fat and carbohydrate oxidation rate during exercise was examined. Studies undertaking secondary analyses or meta-analyses were excluded. Type of participants: participants required to be physically active, non-injured, and 18–65 years of age. Type of interventions: the intervention had to include blackcurrant supplementation with the studies not limited to the duration of the intervention (i.e. acute, or chronic), the dosage, or the type of blackcurrant given (i.e. food, spray dried powder, freeze dried powder, extract). Type of comparisons: placebo or control condition or no supplementation. Type of outcome measured: substrate utilization during exercise and reported as absolute oxidation rates (i.e. $g \cdot min^{-1}$). There were no limitations on the method used for measuring substrate utilization during exercise.

Study selection

To remove duplicate references, an online tool was used first (https://www.sr-accelerator.com/#/deduplicator), followed by manual removal using the Mendeley reference manager (Mendeley 2.93.0). Two authors (MC and JB) independently reviewed titles and abstracts for initial eligibility using an online tool (https://www.sr-accelerator.com/#/disputatron).

Any disagreements were all resolved through discussion and consultation of a third reviewer (MW) was not required.

Study coding and data extraction

All data extraction was made independently by two authors (MC and JB). From the included studies, the following data were extracted and coded: (1) authors, year of publication, (2) the number of participants in the study and characteristics such as sex, age, body mass, height, and the mean carbohydrate and fat oxidation rate values (i.e. g·min^{-1}) following blackcurrant or placebo/control were extracted and collected in a single Excel spreadsheet. In addition, (3) study design, exercise protocol and the blackcurrant anthocyanin dose and duration. Where available, P values are also presented to indicate differences in fat and carbohydrate oxidation between the placebo or control conditions. When data were presented in figures, corresponding authors were contacted by email for the data, with all those contacted sharing data. Any discrepancies were reviewed and agreed upon by all assessors after discussion. Participants within the studies were also categorized according to their performance caliber (McKay et al. 2022).

Methodological quality and risk of bias

Two researchers (MC and JB) independently assessed the methodological quality of the studies using a modified version of risk of bias 2 (RoB 2) Cochrane Bias Assessment Tool. In case of disagreement between the scores provided, the primary author (MC) made the final decision.

Statistical analysis

Data was analyzed using SPSS (version 29.0.1.0). The inverse variance statistical method was chosen to generate the effect of blackcurrant on exercise-induced carbohydrate and fat oxidation. The meta-analysis was undertaken using the random-effects model because Higgins score was below 60% for both analyses on fat and carbohydrate oxidation. Some protocols had multiple comparisons of blackcurrant, such as different intensities (Cook et al. 2015), doses (Cook et al. 2017), durations of intake (Şahin et al. 2022; Şahin et al. 2021) or doses and durations of intake (Montanari et al. 2020). To allow comparisons and reduce bias, data were combined using the formulae provided within the Cochrane handbook. The I^2 values were also interpreted using the guidelines in the Cochrane Handbook for systematic reviews of interventions (Higgins et al. 2022), with 0-40% might not be important; 30-60% may represent moderate heterogeneity; 50% to 90%: may represent substantial heterogeneity and 75% to 100%: considerable heterogeneity.

Results

The database search returned 263 articles, of which 159 were removed due to duplication. Another 83 articles were then removed based upon the content within the title ($n = 70$)

or the abstract ($n = 13$), with the flowchart shown in Figure 1. The full text of 21 articles was retrieved and assessed, of which 15 articles were included in the review (Table 1).

All the studies reviewed used the same nutritional blackcurrant supplement (New Zealand blackcurrant extract CurraNZ™) and gave the last dose of supplement or placebo 2-h before the laboratory visit. The exercise modalities were either cycling (six studies) or treadmill walking and running (nine studies). Eight of the studies demonstrated that blackcurrant extract altered substrate metabolism during exercise, while the remaining seven studies did not show an effect.

The dose of blackcurrant anthocyanins was most commonly 210 mg·day^{-1} used by ten of the studies. One study compared three different doses of 105, 210 and 315 mg·day^{-1} (Cook et al. 2017), while another study only compared two doses of 105 and 210 mg·day^{-1} (Montanari et al. 2020). Two studies used a dose of 105 mg·day^{-1}, while one study used a single intake with a dose of 315 mg (Moss et al. 2023). Fourteen studies demonstrated some concerns for bias, with one study demonstrating a high risk (Figure 2).

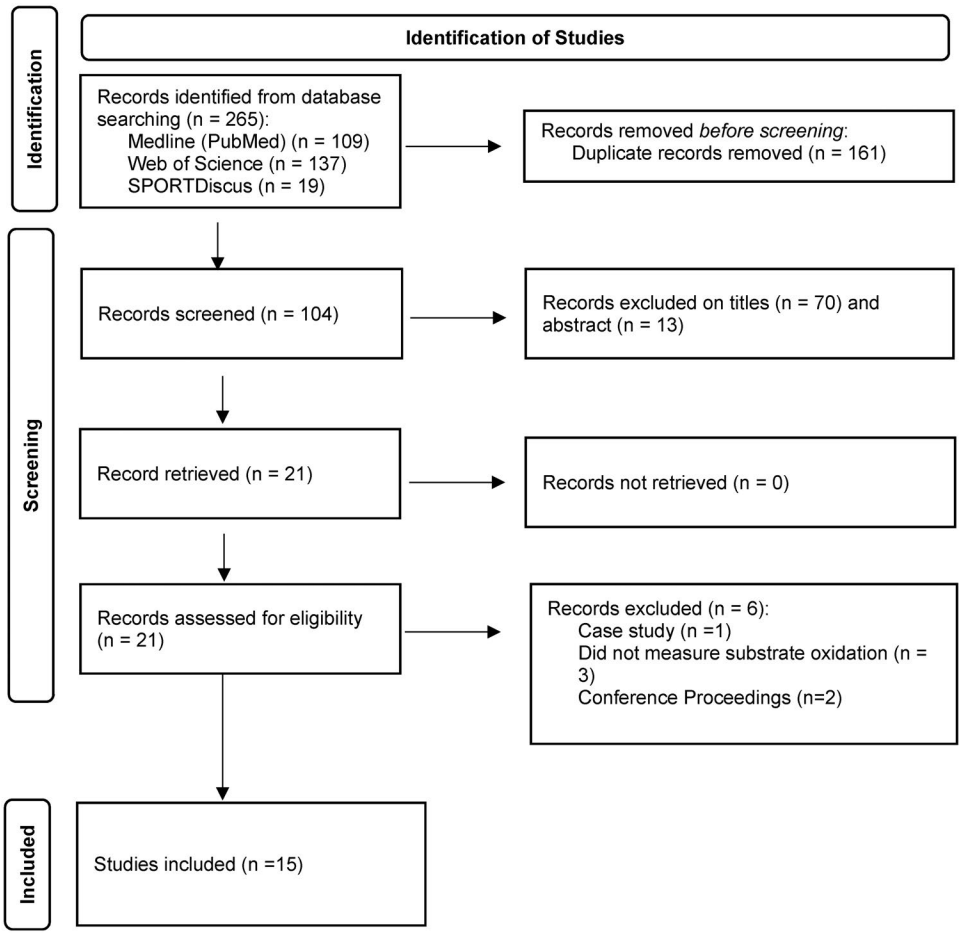

Figure 1. PRISMA Flow chart for the systematic identification of studies included in the review and meta-analysis.

Table 1. Studies included in the review.

Study	Fat oxidation rate (g·min^{-1})	Carbohydrate oxidation rate (g·min^{-1})	*n*; participants; performance classification design;	BC anthocyanin dose	Final dose	Protocol
Cook et al. (2015)	[a]Placebo: 0.26 ± 0.10 NZBC: 0.29 ± 0.09 (p = 0.077) [b]Placebo:0.33 ± 0.14 NZBC: 0.38 ± 0.09 (p = 0.102) [c]Placebo: 0.37 ± 0.15* (p = 0.044) NZBC: 0.44 ± 0.12 Combined mean and SD n42 Placebo: 0.32 ± 0.14 NZBC: 0.37 ± 0.12	[a]Placebo: 1.60 ± 0.39 NZBC: 1.52 ± 0.40 (p > 0.05) [b]Placebo: 1.85 ± 0.43 NZBC: 1.80 ± 0.43 (p > 0.05) [c]Placebo: 2.36 ± 0.54 NZBC: 2.23 ± 0.48 (p > 0.05) Combined mean and SD n42 Placebo: 1.94 ± 0.55 NZBC: 1.85 ± 0.52	14; males; tier 2; randomized double-blind crossover	105 mg·day^{-1} BC anthocyanins for 7-days	2 h before test	[a]10 mins cycling at 45% VO_{2max} [b]10 mins cycling at 55% VO_{2max} [c]10 mins cycling at 65% VO_{2max}
Cook et al. (2017)	Control: 0.63 ± 0.20 [a]NZBC: 0.60 ± 0.16 (p = 0.124) [b]NZBC: 0.74 ± 0.18 (p < 0.05) [c]NZBC: 0.74 ± 0.13 (p < 0.05) Combined mean and SD *n*45 NZBC: 0.69 ± 0.19	Control: 1.78 ± 0.48 [a]NZBC: 1.65 ± 0.45 (p > 0.05) [b]NZBC: 1.56 ± 0.41 (p > 0.05) [c]NZBC: 1.56 ± 0.46 (p > 0.05) Combined mean and SD *n*45 NZBC: 1.59 ± 0.43	15; males; tier 2; randomized counterbalanced Latin-square	[a]105, [b]210, [c]315 mg·day^{-1} BC anthocyanins for 7-days	2 h before test	120 mins cycling at 65% VO_{2max}
Strauss et al. (2018)	Placebo: 0.63 ± 0.20 NZBC: 0.74 ± 0.13 (p = 0.047)	Placebo: 1.30 ± 0.36 NZBC: 1.15 ± 0.26 (p = 0.064)	16; females; tier 1, randomized double-blind crossover	210 mg·day^{-1} BC anthocyanins for 7-days	2 h before test	120 mins cycling at 65% VO_{2max}
Willems et al. (2018)	Placebo: 0.18 ± 0.13 NZBC: 0.19 ± 0.10 (p = 0.40)	Placebo: 1.21 ± 0.37 NZBC: 1.16 ± 0.28 (p = 0.26)	17; male; tier 0; randomized double-blind crossover	210 mg·day^{-1} BC anthocyanins for 7-days	2 h before test	30-mins treadmill walking at 5 MET
Willems et al. (2019)	[a]Placebo: 0.21 ± 0.11 NZBC: 0.18 ± 0.10 (p > 0.05) [b]Placebo: 0.21 ± 0.09 NZBC: 0.24 ± 0.12 (p > 0.05) [c]Placebo: 0.24 ± 0.12 NZBC: 0.20 ± 0.16 (p > 0.05) Combined mean and SD *n*33 Placebo: 0.22 ± 0.11 NZBC: 0.21 ± 0.13	[a]Placebo: 1.47 ± 0.36 NZBC: 1.55 ± 0.19 (p > 0.05) [b]Placebo: 1.90 ± 0.34 NZBC: 2.00 ± 0.27 (p > 0.05) [c]Placebo: 2.34 ± 0.42 NZBC: 2.48 ± 0.35 (p > 0.05) Combined mean and SD *n*33 Placebo: 1.90 ± 0.51 NZBC: 2.01 ± 0.47	11; male; tier 1; randomized double-blind crossover	210 mg·day^{-1} BC anthocyanins for 7-days	2 h before test	[a]10-mins cycling at 45% VO_{2max} at normobaric hypoxia (~2,500 m, 15%O_2) [b]10-mins cycling at 55% VO_{2max} at normobaric hypoxia (~2,500 m, 15%O_2) [c]10-mins cycling at 65% VO_{2max} at normobaric hypoxia (~2,500 m, 15%O_2)
Hiles et al. (2020)	Placebo: 0.53 ± 0.05 NZBC: 0.63 ± 0.06 (p = 0.008)	Placebo: 2.24 ± 0.05 NZBC: 2.00 ± 0.07 (p = 0.0136)	18; 12 male, 6 female; tier 0; randomized double-blind crossover	210 mg·day^{-1} BC anthocyanins for 7-days	Not reported	60-mins treadmill running at 65% VO_{2max} in hot ambient temperature (34 °C, 45% RH).

(*Continued*)

Table 1. Continued.

Study	Fat oxidation rate (g·min^{-1})	Carbohydrate oxidation rate (g·min^{-1})	*n*; participants; performance classification design;	BC anthocyanin dose	Final dose	Protocol
Şahin et al. (2022)	[a]Control: 0.36 ± 0.11 NZBC: 0.41 ± 0.13 ($p < 0.05$) [b]Control: 0.36 ± 0.11 NZBC: 0.37 ± 0.10 ($p > 0.05$) Combined mean and SD n32 Control: 0.36 ± 0.11 NZBC: 0.39 ± 0.16	[a]Control: 0.95 ± 0.40 NZBC: 0.86 ± 0.33 ($p < 0.05$) [b]Control: 0.95 ± 0.40 NZBC: 0.95 ± 0.34 ($p > 0.05$) Combined mean and SD n32 Control: 0.95 ± 0.40 NZBC: 0.91 ± 0.33	16; male; tier 0; randomized crossover	[a]210 mg·day^{-1} BC anthocyanins for 14-days continuously [b]210 mg·day^{-1} BC anthocyanins for 14-days intermittently	2 h before test	30-mins treadmill walking at 4 (n3) or 5 (n13) METS 5.7 ± 0.7 km·hr^{-1}
Şahin et al. (2021)	[a]Control: 0.36 ± 0.12 NZBC: 0.39 ± 0.13 ($p < 0.05$) [b]Control: 0.36 ± 0.12 NZBC: 0.41 ± 0.13 ($p < 0.05$) Combined mean and SD *n*32 Control: 0.36 ± 0.19 NZBC: 0.40 ± 0.13	[a]Control: 0.95 ± 0.40 NZBC: 0.91 ± 0.40 ($p > 0.05$) [b]Control: 0.95 ± 0.40 NZBC: 0.86 ± 0.33 ($p < 0.05$) Combined mean and SD *n*32 Control: 0.95 ± 0.40 NZBC: 0.89 ± 0.36	16; male; tier 0; randomized crossover	[a]210 mg·day^{-1} BC anthocyanins for 7-days continuously [b]210 mg·day^{-1} BC anthocyanins for 14-days continuously	2 h before test	30-mins treadmill walking at 4 (n3) or 5 (n13) METS 5.7 ± 0.7 km·hr^{-1}
Shan and Cook (2023)	Placebo: 0.17 ± 0.11 NZBC: 0.24 ± 0.11 ($p = 0.005$)	Placebo: 1.50 ± 0.48 NZBC: 1.39 ± 0.42 ($p = 0.027$)	15 (n14 reported due to signal loss); 10 male, 4 female; tier 0; randomized double-blind crossover	210 mg·day^{-1} BC anthocyanins for 7-days	2 h before test	60-mins treadmill walking/ running at 50% VO_{2max}
Montanari et al. (2020)	[a]Placebo: 0.41 ± 0.18 [a1]NZBC: 0.34 ± 0.15 ($p > 0.05$) [a2]NZBC: 0.40 ± 0.20 ($p > 0.05$) [b]Placebo: 0.44 ± 0.17 [b1]NZBC: 0.36 ± 0.18 ($p > 0.05$) [b2]NZBC: 0.37 ± 0.19 ($p > 0.05$) [c]Placebo: 0.38 ± 0.17 [c1]NZBC: 0.37 ± 0.18 ($p > 0.05$) [c2]NZBC: 0.39 ± 0.16 ($p > 0.05$) Combined mean and SD Placebo: 0.41 ± 0.17 *n*36 NZBC: 0.37 ± 0.17 *n*72.	[a]Placebo: 2.21 ± 0.41 [a1]NZBC: 2.38 ± 0.56 ($p > 0.05$) [a2]NZBC: 2.22 ± 0.54 ($p > 0.05$) [b]Placebo: 2.13 ± 0.45 [b1]NZBC: 2.28 ± 0.58 ($p > 0.05$) [b2]NZBC: 2.18 ± 0.71 ($p > 0.05$) [c]Placebo: 2.27 ± 0.53 [c1]NZBC: 2.34 ± 0.64 ($p > 0.05$) [c2]NZBC: 2.26 ± 0.51 ($p > 0.05$) Combined mean and SD Placebo: 2.27 ± 0.46 *n*36 NZBC: 2.23 ± 0.60 *n*72.	13 (n12 reported) male; tier 2; randomized double-blind crossover	[a1]105 mg·day^{-1} BC anthocyanins for 1-day [a2]210 mg·day^{-1} BC anthocyanins for 1-day [b1]105 mg·day^{-1}BC anthocyanins for 4-days [b2]210 mg·day^{-1} BC anthocyanins for 4-days [c1]105 mg·day^{-1} BC anthocyanins for 7-days [c2]210 mg·day^{-1} BC anthocyanins for 7-days		10-minutes cycling at 65% VO_{2max}
Willems et al. (2022)	Placebo: 0.24 ± 0.09 NZBC: 0.29 ± 0.08 ($p = 0.005$)	Placebo: 0.71 ± 0.31 NZBC: 0.57 ± 0.18 ($p = 0.03$)	12; female; tier 1, randomized double-blind crossover	210 mg·day^{-1} BC anthocyanins for 7-days	2 h before test	30 min treadmill walk at 4.7 ± 0.4 METs

(*Continued*)

Table 1. Continued.

Study	Fat oxidation rate ($g \cdot min^{-1}$)	Carbohydrate oxidation rate ($g \cdot min^{-1}$)	*n*; participants; performance classification design;	BC anthocyanin dose	Final dose	Protocol
Pastellidou et al. (2021)	Placebo: 0.59 ± 0.26 NZBC: 0.56 ± 0.44 ($p > 0.05$)	Placebo: 2.26 ± 0.61 NZBC: 2.15 ± 0.41 ($p > 0.05$)	15; male; tier 1, randomized double-blind crossover	105 mg.day^{-1} BC anthocyanins for 8-days.	2-h before	Treadmill exercise at lactate threshold
Moss et al. (2023).	Placebo: 0.39 ± 0.27 NZBC: 0.40 ± 0.20 ($p > 0.05$)	Placebo: 3.12 ± 0.89 NZBC: 2.98 ± 0.56 ($p > 0.05$)	16 male: tier 2; randomized double-blind crossover	315 mg of BC anthocyanin for one intake	2-h before	10 min treadmill running at lactate threshold
Cook et al. (2025)	Placebo: 0.21 ± 0.12 NZBC: 0.27 ± 0.11 ($p < 0.001$)	Placebo: 1.43 ± 0.49 NZBC: 1.32 ± 0.44 ($p = 0.002$)	22, 11 males and 11 females; tier 0; randomized double-blind crossover	210 mg·day^{-1} BC anthocyanins for 7-days	2 h before test	60 mins treadmill walking/ running at 50% VO_{2max}
Jones et al. (2025)	Placebo: 0.29 ± 0.12 NZBC: 0.35 ± 0.10 ($p < 0.001$)	Placebo: 2.38 ± 0.51 NZBC: 2.23 ± 0.47 ($p = 0.097$)	10 males; tier 1, randomized, double blind cross-over	210 mg·day^{-1} BC anthocyanins for 7-days	2 h before test	120 mins cycling at 65% VO_{2max}

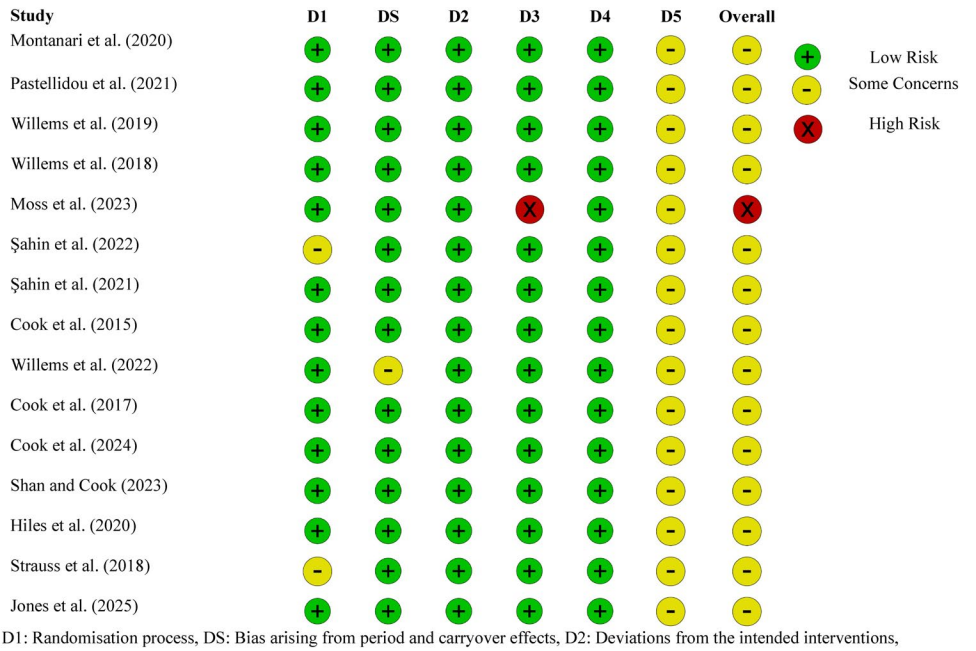

Figure 2. Risk of bias assessment from the cochrane risk-of-bias tool for randomized trials.

Participants

Of the studies included in this analysis, there were 226 participants [males 192 (85%), females 34 (15%)], with 96 participants stated to be trained (~42%) and 130 (~58%) untrained or recreationally active. When categorized into performance status, four studies had participants from tier two (Cook et al. 2015; 2017; Montanari et al. 2020; Moss et al. 2023), five studies had participants from tier one (Strauss et al. 2018; Willems et al. 2019; Pastellidou et al. 2021; Willems et al. 2022; Jones et al. 2025), with the remaining six studies using participants from performance tier zero (Willems et al. 2018; Hiles et al. 2020; Şahin et al. 2021; Şahin et al. Şahin et al. 2022; Shan and Cook 2023; Cook et al. 2025).

Meta-analysis

Fat oxidation from blackcurrant during exercise was higher (0.042 g·min^{-1}; 95%CI: 0.017, 0.068 g.min^{-1}, $p < 0.001$) (Figure 3) and carbohydrate oxidation was lower (−0.099 g·min^{-1}; 95%CI: −0.176, −0.022 g.min^{-1}, $p = 0.012$) (Figure 4). For fat oxidation, the heterogeneity among the studies was 39.5%, while for carbohydrate oxidation it was 50.1%.

Discussion

The present study presents a systematic review and meta-analysis of studies on the effect of intake of anthocyanin-rich blackcurrant extract on the substrate utilization responses during exercise. The main findings from this meta-analysis are that during

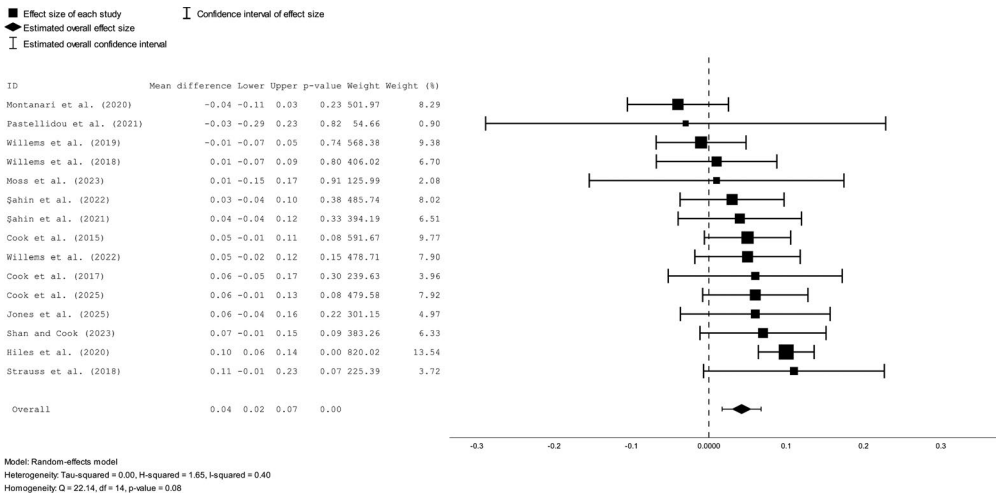

Figure 3. Forest Plot with 95% confidence interval for effect of blackcurrant on fat oxidation during exercise.

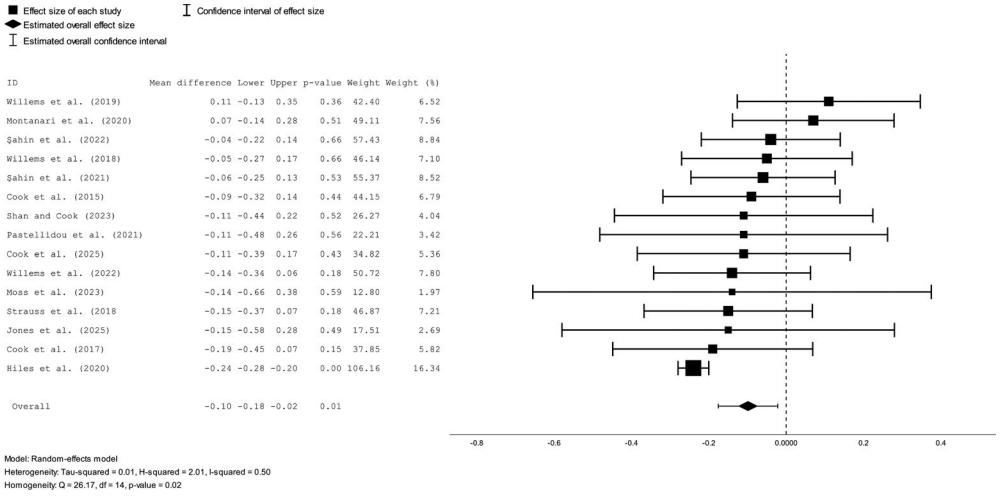

Figure 4. Forest Plot with 95% confidence interval for effect of blackcurrant on carbohydrate oxidation during exercise.

exercise, blackcurrant extract supplementation increases fat oxidation by 0.042 g·min^{-1} (95%CI: 0.017, 0.068 g.min^{-1}) and decreases carbohydrate oxidation by 0.099 g·min^{-1} (95%CI: −0.176, −0.022 g·min^{-1}).

This meta-analysis gives a range of expected responses for changes in fat and carbohydrate oxidation responses. However, it is important to recognize that these changes did not occur in every study, with 8 of 15 studies showing no change in substrate oxidation. These expected responses have also been calculated from group mean changes, and there are individual responses which are not clear from this type of analysis. Recent analyses indicate that changes in fat oxidation in response to blackcurrant supplementation are correlated with body fat percentage in women, but not

in men (Cook et al. 2025). Additionally, individuals exhibiting a higher respiratory exchange ratio (RER; indicative of greater carbohydrate utilization) during exercise under placebo/control conditions appear to be higher responders to blackcurrant supplementation (Willems and Cook 2025). Therefore, the results of the present study should be interpreted alongside these observations. Lastly, study methods might explain some of the studies demonstrating no change. For example, Willems et al. (2019) observed no change, but was examining responses in hypoxia (~2,500 m, 15%O2), conditions that are known to increases carbohydrate oxidation, which may have been too great a stimulus than blackcurrant could overcome.

Future work is needed to identify the mechanisms for the alteration of substrate utilization by intake of blackcurrant supplementation. It is possible that mechanisms relate to increased lipolysis (Strauss et al. 2018), alterations in blood flow (Cook et al. 2017; 2023), greater usage of intramuscular triglycerides from type I fibers (Jones et al. 2025) or genes involved in energy expenditure (Benn et al. 2014). Furthermore, while the fat oxidation changes observed in this meta-analysis are modest, it would equate to approximately 5 grams of extra fat oxidation in 120-minutes of exercise. However, it is comparable to the change in total fat oxidized during 120-minutes of cycling at 65%VO_{2max} in trained cyclists (Blackcurrant: 42 ± 9 vs. Placebo: 34 ± 14 g) (Jones et al. 2025). The implications of this on endurance performance, or longer-term body composition effects are not known and need to be investigated.

Different fruits and berries have a unique profile of anthocyanins (Lee et al. 2015) and it needs to be determined if similar substrate utilization alterations during exercise can be obtained from berries and fruits with different anthocyanin profiles. Although blackcurrant contains 15 anthocyanins, it primarily has a high content of delphinidin and cyanidin (Slimestad and Solheim 2002). The main anthocyanins in blueberries are malvidin glycosides (Yang et al. 2022), and has also been examined for alterations in substrate utilization. For example, in a two-week intervention, Pilolla et al. (2023) observed that supplementation with 12.5 g freeze-dried blueberry powder in 125 mL water, consumed twice daily (providing 375 mg·day^{-1} anthocyanins), increased fat oxidation by up to 43% during 40-minutes of cycling at 65% VO_{2peak}. However, this was supplemented alongside a low polyphenol washout diet, whereas all the studies within the present analysis did not have a low polyphenol washout diet applied, therefore maintain higher ecological validity.

While a bias assessment was completed (Figure 2), it needs to be interpreted against the measurement examined in these studies. Substrate oxidation measured during exercise cannot be affected by bias of the data analyzers. However, participants could alter behavior before the experimental measurements, such as exercise, caffeine intake or altered dietary intake. The studies reviewed in this analysis mostly had controls and requirements on participants before experimental measurements, but this was self-reported by participants and potentially exposes the researchers to participants reporting of desired behaviors (i.e. no consumption of caffeine or exercising the day before measurements). Of note, findings from the bias assessment suggest that studies generally lacked adequate description of randomization processes (domain 1) and often did not register or prespecify data analysis plans before unblinded data were available (domain 5). While not examined within a bias assessment, it must also be noted that there is some publication clustering as a substantial proportion of studies included in this analysis involve overlapping research groups and laboratories.

Limitations

There are several limitations to this review that should be considered when interpreting the results. The main limitation of this systematic review is that all the studies that met the inclusion criteria used the same anthocyanin rich blackcurrant extract and therefore, there can be no comparisons to consumption of blackcurrant anthocyanins in other formats (i.e. food, spray dried, freeze dried). An advantage of using an extract over blackcurrant in natural form is that participants can consume a known and consistent dose of blackcurrant anthocyanins that is not dependent upon seasonal availability and/or synergy with non-anthocyanin components in blackcurrant powder. Nevertheless, the extent to which these results can be generalized to other blackcurrant supplements or to blackcurrant consumed in its natural form is unclear.

Another limitation is that all studies recruited healthy participants, either trained or untrained, with participants categorized as sedentary, recreationally active, or trained (Table 1), limiting applicability to other populations. It would be expected that participants who are highly endurance trained, competing at elite international levels (tier 4 and 5 McKay et al. 2022) would have greater adaptations for fat oxidation, therefore, the effects of blackcurrant anthocyanins on fat oxidation and how this could influence competitive performance situations in these groups are not known. However, there have been some case studies examining effects of blackcurrant extract supplementation and fat oxidation. For example, in an ultra-endurance runner during a 2-h run at 58% $\dot{V}O_{2max}$ following 7-days of 210 mg·day^{-1} of blackcurrant anthocyanins, there was a 23% increase in fat oxidation (control: 0.39 ± 0.08 vs. blackcurrant: 0.48 ± 0.12 g·min^{-1}) (Willems and Briggs 2022). Furthermore, during a 4-h indoor cycle at 165 W with carbohydrate and caffeine consumption of an experienced ironman triathlete, following an intake of 420 mg blackcurrant anthocyanins 2-h before the cycling, there was a possible increase in fat oxidation (placebo: 0.50 ± 0.06 vs blackcurrant 0.56 ± 0.05 g·min^{-1} (Willems et al. 2024). Additionally, effects in sedentary populations, people with disability, older adults or with metabolic disease are not known and should be examined. The effectiveness of blackcurrant extract supplementation for promoting fat loss in individuals with metabolic disease, overweight, or obesity is currently unknown. Of note, Willems et al. (2023) demonstrated a 14-day intake of 210 mg·day^{-1} anthocyanins from blackcurrant extract to increase resting fat oxidation (baseline: 0.079 ± 0.03, vs. blackcurrant 0.088 ± 0.043 g·min^{-1}) in healthy active men, therefore viewed alongside the findings of the present investigation indicates a strong potential for benefit.

Lastly, none of the studies included in this review have examined whether blackcurrant-induced alterations in substrate utilization translate into improvements in competitive endurance performance. Theoretically, an increase in fat oxidation following blackcurrant supplementation may contribute to glycogen sparing during prolonged endurance exercise and, in turn, enhance performance.

Jones et al. (2025) were the first to provide mechanistic insight into these effects using vastus lateralis muscle biopsies collected pre-exercise and at 30 and 120 min during 120 min of cycling at 65% $\dot{V}O_{2max}$ in trained male cyclists following seven days of blackcurrant anthocyanin supplementation (210 mg·day^{-1}). The authors observed a 24% increase in whole-body fat oxidation (p = 0.025) in the blackcurrant condition. Despite a greater rate of muscle glycogen utilization during exercise following blackcurrant

supplementation (blackcurrant: 3.19 ± 1.21 vs. placebo: 1.80 ± 0.70 mmol·kg^{-1}·min^{-1}), end-exercise muscle glycogen concentrations did not differ between conditions.

This finding was explained by higher pre-exercise muscle glycogen concentrations in the blackcurrant condition (NZBC: 493 ± 85 vs. placebo: 355 ± 65 mmol·kg^{-1} dry weight; p = 0.007), resulting in a greater net glycogen breakdown during exercise (NZBC: 383 ± 145 vs. placebo: 216 ± 84 mmol·kg^{-1} dry weight). These glycogen responses were accompanied by greater utilization of intramuscular triglycerides within type I muscle fibers following blackcurrant anthocyanin supplementation, providing mechanistic insight into the repeatedly observed increases in fat oxidation associated with blackcurrant supplementation.

Conclusions

Blackcurrant extract increases fat oxidation and decreases carbohydrate oxidation during exercise. The magnitude of change observed from the meta-analysis was an increase in fat oxidation of 0.042 g·min^{-1} and a decrease in carbohydrate oxidation of 0.099 g·min^{-1}. The systematic review identified fifteen studies that met the inclusion criteria, however, of these studies, only eight demonstrated a change in substrate utilization during exercise.

Author contributions

CRediT: **Matthew D. Cook**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft; **James J. Bateman**: Data curation, Investigation, Writing – review & editing; **Mark E.T. Willems**: Data curation, Supervision, Writing – original draft.

Ethical statement

As this is a systematic review, ethics of working with human participants is not a factor. The study was approved by the University of Worcester Health and Science Research Ethics Panel (ANHS23240025) and all studies included in the analysis were all ethically approved by their institutional ethics committees.

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Data availability statement

Data described in the manuscript, will be made available upon request to the corresponding author

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Appendix A. Supplementary information

Search strings for databases.