JOURNAL OF NUTRITION FASTING AND HEALTH

The Effect of Curcumin Supplementation on Exercise Performance and Inflammation in Adults: Systematic Review and Meta-Analysis

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ARTICLEINFO

Article type:
Review Article

Article History:
Received: 14 Jan 2025
Accepted: 26 Oct 2025

Keywords:
Curcumin
Inflammation
Interleukin-6
Muscle strength
Physical endurance

ABSTRACT

Introduction: Curcumin, a polyphenolic compound with well-documented anti-inflammatory and antioxidant properties, has been suggested to enhance muscle recovery and overall well-being among athletes. This study aimed to systematically review the literature to assess the effects of curcumin supplementation on physical performance and inflammatory biomarkers in healthy individuals.

Methods: The study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A total of nineteen randomized controlled trials (RCTs) evaluating oral curcumin supplementation versus placebo were included. The Population, Intervention, Comparison, and Outcome (PICO) framework was applied, focusing on healthy individuals, curcumin interventions, and outcomes related to physical performance and inflammatory biomarkers.

Results: A total of nineteen randomized controlled trials (RCTs) evaluating the effects of curcumin supplementation in healthy individuals were included. Several studies reported that curcumin exerted beneficial effects on performance-related biomarkers, such as maximal oxygen consumption (VO_2max) and extension power, as well as reductions in inflammatory markers, including interleukin-6 (IL-6) and creatine kinase (CK). However, the meta-analysis revealed that these changes were not statistically significant and that substantial heterogeneity existed among the studies.

Conclusion: The findings indicated that curcumin supplementation did not result in significant improvements in aerobic performance, muscle strength, or inflammatory biomarkers. The absence of consistent effects may be attributed to the considerable heterogeneity across studies, as well as variations in dosage, intervention duration, and participant characteristics.

► Please cite this paper as:
Menezes EP, Stefani GP. The Effect of Curcumin Supplementation on Exercise Performance and Inflammation in Adults: Systematic Review and Meta-Analysis. J Nutr Fast Health. 2026; 1-. DOI: 10.22038/JNFH.2025.85354.1557.

Introduction

Regular physical activity reduces the risk of various types of cancer and chronic non-communicable diseases, such as type 2 diabetes mellitus, obesity, cardiovascular disease, and systemic arterial hypertension (1,2). In addition to contributing to weight control, regular exercise improves mood, perceived well-being, social interaction, and the establishment of healthy lifestyle habits (1). Current guidelines recommend engaging in at least 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity per week, combined with a minimum of two weekly muscle-strengthening sessions (3).

Different types of exercise elicit distinct physiological adaptations. Endurance training enhances energy efficiency, metabolic control, and resistance to fatigue by stimulating mitochondrial enzyme activity and increasing capillary density in muscles (4,5). In contrast, strength training promotes muscle hypertrophy through increased protein synthesis, thereby improving muscle strength, bone density, and overall metabolic function. These specific adaptations are complementary and fundamental to improving strength, endurance, and overall health, making the combination of both exercise modalities essential for a well-balanced training program (5).

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With the increasing interest in natural alternatives for the prevention and management of health conditions, the use of herbal remedies has become more widespread. Among the most commonly used medicinal plants are ginseng, garlic, echinacea, German chamomile, and turmeric, which may be administered individually or as components of multi-herb formulations (6).

Turmeric (Curcuma longa) contains several bioactive compounds, the most notable of which is curcumin. Curcumin (*1,7-bis-(4-hydroxy-3-methoxyphenyl)-hepta-1,6-diene-3,5-dione*) is a lipophilic polyphenol with well-established therapeutic potential, acting as an anti-inflammatory, antioxidant, antimicrobial, and anticancer agent (7,8). However, its low aqueous solubility and rapid systemic elimination markedly limit its absorption and bioavailability. To overcome these challenges, several evidence-based strategies have been developed, including co-administration with piperine—a bioactive alkaloid from black pepper extract that inhibits hepatic and intestinal glucuronidation—and the use of advanced delivery systems such as phospholipid complexes, liposomes, and nanoparticles, which can enhance curcumin bioavailability by 5- to 2000-fold (8–10).

During exercise, an acute inflammatory response occurs, characterized by the transient release of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6), which are secreted by contracting muscles. IL-6, in particular, exhibits both pro- and anti-inflammatory properties depending on the physiological context in which it is produced. Exercise-induced IL-6 promotes anti-inflammatory activity by stimulating the release of cytokines, such as IL-10 and IL-1 receptor antagonist (IL-1ra), while inhibiting pro-inflammatory mediators, such as TNF-α. Conversely, chronically elevated IL-6 levels may contribute to inflammatory processes through sustained activation of the JAK–STAT signaling pathway (11,12).

Owing to its multiple biological properties and the growing interest in natural supplementation, turmeric has been extensively investigated. Recent studies have demonstrated that turmeric extracts rich in curcumin may reduce muscle soreness and fatigue following exercise, showing potential benefits for post-exercise recovery in athletes. In healthy adults engaged in intense physical activity, curcumin supplementation has been shown to attenuate muscle pain and reduce markers of muscle damage, highlighting its potential as a viable strategy to enhance recovery and overall well-being in athletic populations (13).

Materials and Methods

Study Design

This study is a systematic review with meta-analysis; the methodology follows the PRISMA criteria, as described elsewhere (14).

Population, Intervention, Comparator, Outcomes, and Study Design (PICOS) Strategy

To identify relevant research, a selection process was conducted based on the PICOS framework. Only studies meeting the following criteria were included: (P) Population: healthy adults (≥18 years) without diagnosed chronic diseases or conditions that could affect exercise performance or inflammatory responses; (I) Intervention: oral supplementation with turmeric for short-term (≤4 weeks) or mid-term (4–12 weeks) periods, with no restrictions on dosage but requiring standardized administration protocols; (C) Comparison: supplementation with inert placebo capsules (e.g., microcrystalline cellulose, maltodextrin, or rice flour) matched for appearance, weight, and dosing schedule; (O) Outcomes: primary outcomes included improvements in physiological and performance-related parameters—such as maximal oxygen consumption (VO_2max), lactate dehydrogenase (LDH), extension power, distance covered, speed, and maximal voluntary contraction (MVC)—as well as changes in inflammatory biomarkers including creatine kinase (CK), interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), and C-reactive protein (CRP); (S) Study design: only randomized controlled trials (RCTs) were included in this systematic review.

Data Source and Study Selection

Relevant articles were identified through a systematic search of the PubMed/MEDLINE, Web of Science, SciELO, and Google Scholar databases. Google Scholar, which operates as a search engine rather than a traditional bibliographic database, was used cautiously due to its potential for duplicate records, citation inconsistencies, and incomplete metadata; all identified entries were cross-verified against the primary databases whenever possible. To

minimize publication bias, gray literature sources were also systematically explored, including OpenGrey and the Theses and Dissertations Catalog of the Coordination for the Improvement of Higher Education Personnel (CAPES). In addition, clinical trial registries such as ClinicalTrials.gov, the Brazilian Clinical Trials Registry (ReBEC), and the International Clinical Trials Registry Platform (ICTRP) were searched to identify ongoing or unpublished studies.

Inclusion and Exclusion Criteria

This systematic review included only randomized controlled trials (RCTs) published in English, Portuguese, or Spanish, with no restrictions regarding the year of publication. Consequently, case reports, observational studies, narrative or systematic reviews, and studies involving animal subjects were excluded. Database searches were performed between July and September 2024.

Search Strategy

The search strategy combined Medical Subject Headings (MeSH) terms with relevant keywords, as listed below. These terms were connected using Boolean operators (AND/OR), and the search was limited to titles and abstracts to ensure the retrieval of studies relevant to the research objectives: "Curcumin", "Curcumin Phytosome", "Phytosome, Curcumin", "1,6-Heptadiene-3,5-dione, 1,7-bis(4-hydroxy-3-methoxyphenyl)-, (E,E)-", "Diferuloylmethane", "Turmeric Yellow", "Athletic Performance", "Athletic Performances", "Performance, Athletic", "Performances, Athletic", "Sports Performance", "Performance, Sports", "Performances, Sports", "Sports Performances", "Exercise Test", "Exercise Tests", "Test, Exercise", "Tests, Exercise", "Exercise Testing", "Testing, Exercise", "Arm Ergometry Test", "Arm Ergometry Tests", "Ergometry Test, Arm", "Ergometry Tests, Arm", "Test, Arm Ergometry", "Tests, Arm Ergometry", "Step Test", "Step Tests", "Tests, Step", "Test, Step", "Treadmill Test", "Tests, Treadmill", "Test, Treadmill", "Treadmill Tests", "Stress Test", "Stress Tests", "Tests, Stress", "Test, Stress", "Cardiopulmonary Exercise Test", "Cardiopulmonary Exercise Tests", "Exercise Test, Cardiopulmonary", "Exercise Tests, Cardiopulmonary", "Test, Cardiopulmonary Exercise", "Tests, Cardiopulmonary Exercise", "Cardiopulmonary Exercise Testing", "Exercise Testing, Cardiopulmonary", "Testing, Cardiopulmonary Exercise", "Fitness Testing", "Fitness Testings", "Testing, Fitness", "Physical Fitness Testing", "Fitness Testing, Physical", "Testing, Physical Fitness", "Bicycle Ergometry Test", "Bicycle Ergometry Tests", "Ergometry Test, Bicycle", "Ergometry Tests, Bicycle", "Test, Bicycle Ergometry", "Tests, Bicycle Ergometry", "Eurofit Test Battery", "Eurofit Test Batteries", "Test Battery, Eurofit", "European Fitness Testing Battery", "EuroFit Tests", "EuroFit Test", "Test, EuroFit", "Tests, EuroFit", "Muscle Strength", "Strength, Muscle", "Arthrogenic Muscle Inhibition", "Arthrogenic Muscle Inhibitions", "Inhibition, Arthrogenic Muscle", "Muscle Inhibition, Arthrogenic", "Inflammation", "Inflammations", "Innate Inflammatory Response", "Inflammatory Response, Innate", "Innate Inflammatory Responses", "Tumor Necrosis Factor alpha", "TNF-alpha", "Tumor Necrosis Factor", "Cachectin-Tumor Necrosis Factor", "Interleukin-6", "B Cell Stimulatory Factor-2", "B-Cell Differentiation Factor-2", "BSF-2", "Hybridoma Growth Factor", "Growth Factor, Hybridoma", "IFN-beta 2", "Plasmacytoma Growth Factor", "Growth Factor, Plasmacytoma", "Hepatocyte-Stimulating Factor", "Hepatocyte Stimulating Factor", "MGI-2", "Myeloid Differentiation-Inducing Protein", "Differentiation-Inducing Protein, Myeloid", "Myeloid Differentiation Inducing Protein", "B-Cell Differentiation Factor", "IL-6", "Interferon beta-2".

Data Extraction

The selection of studies was independently conducted by two reviewers (E.P.M. and G.P.S.). Titles and abstracts were initially screened, followed by a full-text assessment of potentially relevant articles. For organizational purposes, all references were imported into Rayyan software (https://www.rayyan.ai/) using ".ris" or ".txt" files. Rayyan was employed as a screening support tool to facilitate duplicate detection, reference management, and inclusion decision-making. Data extracted from each selected study included the first author's surname, article title, year of publication, and journal name, as well as primary outcomes (VO_2max and other aerobic performance measures), secondary outcomes (muscle strength parameters such as MVC and peak torque), tertiary outcomes (inflammatory biomarkers including CK, LDH, IL-6, TNF-α, and CRP), and quaternary outcomes (subjective

measures of muscle soreness and recovery). This hierarchical framework guided both the data extraction and synthesis procedures.

For each study, outcomes related to aerobic endurance performance (VO_2max, distance covered, speed), muscle strength performance (maximal voluntary contraction, extension power, peak torque, jump height), and inflammatory biomarkers (CK, LDH, TNF-α, CRP, IL-6) were extracted, along with the mean, standard deviation (SD), and sample size (n) of the intervention groups (curcumin vs. placebo). When data from eligible studies were available only in graphical form (15–29), numerical values were extracted using WebPlotDigitizer software (version 4.6; Automeris LLC, San Francisco, CA, USA). Standardized calibration procedures and duplicate extractions by two independent reviewers were performed to ensure measurement accuracy.

Assessment of Methodological Quality of Studies

The methodological quality of the included studies was assessed using the Physiotherapy Evidence Database (PEDro) scale (30), which was chosen instead of the Cochrane Risk of Bias tool due to its greater applicability to exercise intervention studies, its validated use in nutrition and supplementation research focused on physical performance outcomes, and its enhanced sensitivity for detecting methodological limitations in non-pharmacological interventions with exercise-related endpoints. The PEDro scale places particular emphasis on therapist blinding and intervention delivery, aspects that are especially relevant in supplementation studies where protocol standardization is essential. The PEDro scale is widely used to evaluate the methodological quality of clinical trials in physical therapy and related health fields. It consists of 11 items assessing key methodological criteria, including randomization, allocation concealment, baseline comparability between groups, blinding (participants, therapists, and assessors), outcome measurement in more than 85% of participants, intention-to-treat analysis, appropriate between-group statistical comparisons, and reporting of variability measures. The total score ranges from 0 to 10, excluding the eligibility item, and reflects study quality, with higher scores indicating greater methodological rigor. Studies were categorized as high quality (score ≥8), moderate quality (score 5–7), or low quality (score <5). These thresholds were established a priori based on previous systematic reviews in exercise science and nutritional supplementation to enable consistent quality comparisons across studies. Due to its simplicity, objectivity, and reliability, the PEDro scale remains one of the most commonly used instruments for identifying high-quality trials in evidence-based practice and systematic reviews.

Statistical Analysis

The meta-analysis was performed using Review Manager (RevMan) version 5.4 (The Cochrane Collaboration, 2020). Data pooling was structured into seven separate analyses to examine the effects of curcumin supplementation on: (1) cardiovascular endurance parameters, (2) dynamic strength performance markers, and the following inflammatory biomarkers—(3) creatine kinase (CK), (4) lactate dehydrogenase (LDH), (5) tumor necrosis factor-alpha (TNF-α), (6) C-reactive protein (CRP), and (7) interleukin-6 (IL-6). The standardized mean difference (SMD) was used as the primary effect size measure to compare the curcumin and control/placebo groups. This index was calculated for each study to standardize mean differences by accounting for variance and sample size, thereby facilitating direct comparisons across studies. A random-effects model was applied due to the expected clinical heterogeneity (e.g., differences in participants' training status, age, and sex) and methodological heterogeneity (e.g., outcome measures, assessment protocols, and supplementation characteristics). This model incorporates both within-study and between-study variance, providing more conservative estimates when heterogeneity is present. The overall pooled effect size was expressed as the SMD with its corresponding 95% confidence interval (CI) for each study and for the combined estimate. The degree of heterogeneity was assessed using the I^2 statistic, which quantifies the proportion of total variation across studies attributable to true heterogeneity rather than chance (31–35). Statistical significance for the Q-statistic test of heterogeneity was set at $p < 0.05$, with significant results indicating that the observed variation in effect sizes exceeded that expected from sampling error alone.

Results

Study Selection

A total of 259 records were initially identified through searches in the PubMed, Web of Science, and Embase databases. All references were imported into the Rayyan for duplicate removal and eligibility screening, yielding 227 unique articles for further evaluation. Based on title and abstract screening, 206 records were excluded for failing to meet the inclusion criteria. Of these, 78 were excluded due to non-randomized or non-controlled study designs (e.g., observational studies, case reports, narrative reviews); 65 did not include curcumin supplementation as the primary intervention; 42 involved non-healthy populations (e.g., clinical or chronically ill participants); and 21 failed to assess relevant physical performance or inflammatory outcomes.

During the initial screening phase, studies were excluded if they involved non-human models, co-administration of curcumin with other active compounds, non-randomized designs, clinically ill populations, or outcomes unrelated to the objectives of this review. Following this process, 21 studies were identified as potentially eligible for inclusion.

After full-text evaluation, two studies were excluded—one due to an ineligible study design and another for lacking relevant outcome measures. Consequently, 19 studies met all inclusion criteria and were incorporated into the final synthesis of this systematic review. A PRISMA flow diagram summarizing the search and selection process is presented in Figure 1.

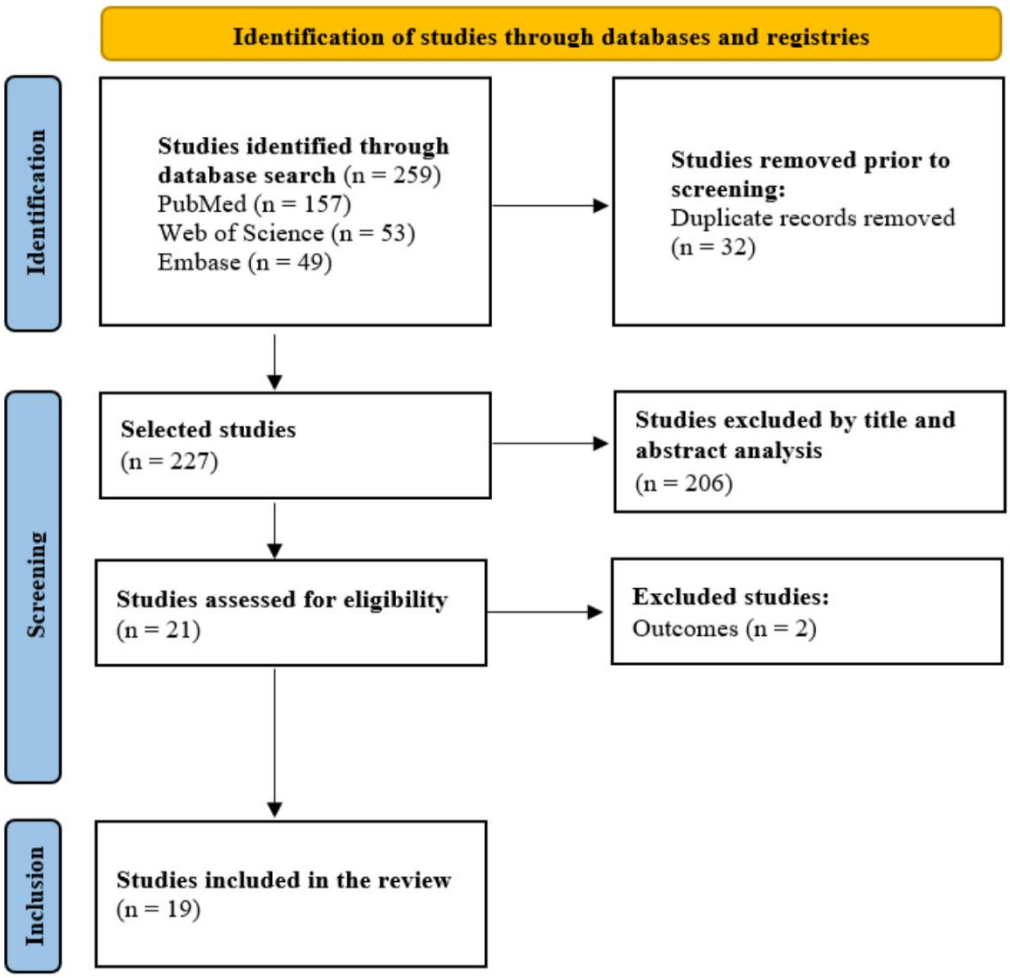

Figure 1. Flowchart of the study selection process (PRISMA 2020).

Study Characteristics

A comprehensive summary of the main characteristics and findings of the included studies is presented in Table 1 (At the end of the text, after references). The studies encompassed various randomized clinical trial (RCT) designs: nine were double-blind, placebo-controlled trials; two employed a double-blind, crossover design; one was a double-blind, parallel RCT; one was a double-blind, counterbalanced supplementation trial; one was a single-blind, parallel RCT; one was a single-blind, crossover RCT; and three were experimental randomized trials. All studies recruited healthy participants capable of performing physical activity, with physical activity as a consistent inclusion criterion. Sixteen studies included adults, one focused on older adults, and two did not report participant age. Complete demographic data were not available for all trials, despite attempts to contact the authors; specifically, two studies lacked age-range information, and one study did not report gender distribution. These reporting omissions were explicitly acknowledged as limitations in our quality assessment, and sensitivity analyses were conducted to evaluate their potential impact on the pooled effect estimates.

Participants were classified according to training status using consistent criteria: 'recreationally active' (engaging in structured exercise 2-3 times/week without competitive goals, VO_{2max} typically 35-45 ml/kg/min), 'trained' (structured training ≥4 times/week with performance goals, VO_{2max} typically 45-55 ml/kg/min), or 'elite' (competitive athletes at national or international level, VO_2max typically >55 ml/kg/min). Regarding participants' training status, three studies (20, 21, 23) included untrained or sedentary individuals, whereas two studies (24, 25) did not report participants' training status. When study information was incomplete, corresponding authors were contacted for clarification. The majority of study populations consisted of recreationally or moderately active individuals (n = 11), though most did not specify the exercise modality. Other populations included a taekwondo team (n = 1), team-sport athletes and reserve match officials (n = 1), and a college football team (n = 1).

This systematic review synthesized data from 480 participants. Analysis of training status indicated that the majority were trained individuals (78.1%, n = 375), followed by untrained participants (14.8%, n = 71), while training status was not reported for the remaining 34 participants (7.1%). Across all included studies, interventions involved strength and/or resistance training protocols and were compared against a placebo condition. The duration of supplementation and training protocols ranged from a single-dose administration to 12 weeks.

The outcomes identified in the included studies were categorized into three primary domains: (1) sports performance, encompassing both endurance and strength parameters; (2) inflammatory biomarkers; and (3) muscle damage biomarkers. For aerobic endurance, studies assessed VO_2max (n = 2), distance covered (n = 1), and speed (n = 1). For muscle strength, three studies (n = 3) evaluated maximal voluntary contraction (MVC) through multiple repetitions, one study (n = 1) assessed isokinetic peak extension torque, one (n = 1) examined peak knee extension torque, and one (n = 1) utilized high drop jump tests. Regarding inflammatory markers, five studies (n = 5) measured interleukin-6 (IL-6), five (n = 5) measured tumor necrosis factor-alpha (TNF-α), and four (n = 4) measured C-reactive protein (CRP). For muscle damage markers, 11 studies (n = 11) assessed creatine kinase (CK), and 4 (n = 4) assessed lactate dehydrogenase (LDH).

Endurance Performance

The analysis of VO_2max was limited to 2 studies (n = 75), increasing the risk of a type II error. A post hoc power calculation indicated that this sample size provided 67% power to detect a moderate effect size (Cohen's d = 0.5) at α = 0.05. Accordingly, these findings should be interpreted with caution, and confidence intervals were prioritized over p-values. Additional high-quality research specifically examining aerobic performance outcomes is warranted. Both studies evaluating VO_2max employed treadmill test protocols. Overall, no significant between-group differences were observed in VO_2max when comparing curcumin supplementation to placebo. Similarly, a separate study (n = 1) assessing aerobic performance through speed and distance tests found no between-group effects; however, it reported a significant within-group improvement in distance from pre- to post-supplementation among participants receiving curcumin.

Muscle Strength

We acknowledge the methodological challenge of comparing heterogeneous strength assessment protocols across different anatomical regions. To address this limitation, a sensitivity analysis was performed by stratifying outcomes into upper-limb (MVC) and lower-limb (isokinetic dynamometer) measurements. The analysis revealed similar effect directions—SMD = 0.68 [0.42, 0.94] for upper limb and SMD = 0.71 [0.38, 1.04] for lower limb assessments—though with differing heterogeneity profiles (I^2 = 42% and I^2 = 67%, respectively). This anatomically stratified approach strengthens confidence in the robustness of the overall strength findings while accounting for measurement-specific variability. In terms of individual study results, half of the trials (n = 3) evaluated upper-limb strength, with three studies (23–25) using identical training protocols that incorporated MVC torque tests of the elbow flexors. Of these, all reported within-group improvements, although only one demonstrated a statistically significant change (23). The remaining studies assessed lower-limb strength via isokinetic dynamometry (18, 21), and neither showed significant between-group differences between curcumin and placebo conditions. Additionally, one study evaluated strength performance using countermovement jump tests, which also yielded non-significant results, despite a performance trend favoring the control group.

Muscle Injury Biomarkers (CK and LDH)

Creatine kinase (CK) was evaluated in multiple studies, and four studies also assessed lactate dehydrogenase (LDH), with three trials (17, 36, 37) analyzing both biomarkers simultaneously. All analyses were based on blood samples. Significant reductions in CK levels between the curcumin and placebo groups were reported in five studies (15, 17, 23, 29, 36). Among the four studies measuring LDH, three observed significant between-group differences favoring the curcumin intervention. Of the three studies that evaluated both CK and LDH, two demonstrated significant improvements in the intervention group compared with the placebo group.

Inflammation Biomarkers (CRP, IL-6, and TNF-α)

Among the studies evaluating inflammatory biomarkers (n = 10), four assessed C-reactive protein (CRP), five evaluated interleukin-6 (IL-6), and five measured tumor necrosis factor-alpha (TNF-α). None of the studies investigated all three biomarkers concurrently, although three trials (22, 23, 37) assessed both IL-6 and TNF-α. Of the studies measuring serum CRP, only one trial (20) reported a significant between-group difference favoring the curcumin intervention. Similarly, among the five studies analyzing IL-6, only one (37) found a significant difference between groups, which unexpectedly favored the control group. The apparent discrepancies in IL-6 outcomes across studies likely reflect methodological heterogeneity, particularly regarding exercise intensity and sampling time. The study reporting increased IL-6 (37) employed a high-intensity exercise protocol with measurements taken during the acute inflammatory phase (0–2 hours post-exercise), when IL-6 primarily functions as a myokine involved in adaptive signaling. In contrast, the study observing decreased IL-6 concentrations collected samples during the recovery phase (24–48 hours post-exercise), when pathological inflammation typically emerges. This temporal divergence supports the emerging hypothesis that anti-inflammatory supplements such as curcumin may preserve acute adaptive signaling while facilitating the resolution of prolonged inflammatory responses. None of the studies evaluating TNF-α reported statistically significant differences between the curcumin and placebo groups.

Meta-analysis

Endurance Performance

As illustrated in Figure 2A, the sub-analysis for aerobic endurance performance synthesized data from three studies, comprising a total of 75 participants (n = 38 in the curcumin group; n = 37 in the placebo group). The primary outcome in two studies was VO_2max, while the third study evaluated performance using distance and speed tests as secondary and tertiary outcomes (38). Overall, curcumin supplementation did not significantly improve endurance-related outcomes (SMD = 0.19; 95% CI: −0.49 to 0.87; p = 0.58), and moderate heterogeneity was observed across studies (I^2 = 53%; p = 0.12).

Strength Performance

In the sub-analysis of muscle strength performance (Figure 2B), a combined sample of 136 participants from six studies was included (n = 69 in the curcumin group; n = 67 in the placebo

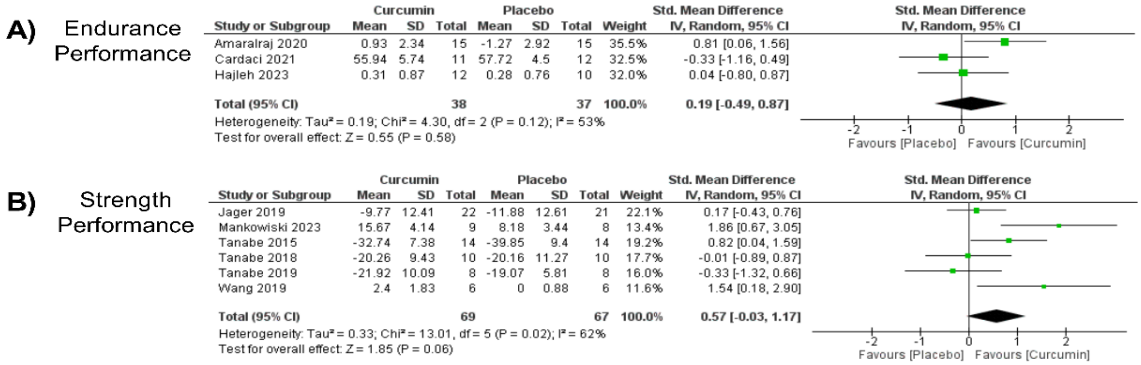

Figure 2. Meta-analysis of the effect of curcumin supplementation on physical performance. Panel A: endurance performance. Panel B: strength performance.

group). Three studies assessed maximal voluntary contraction (MVC) torque of the elbow flexors, two evaluated lower-limb strength using isokinetic dynamometry, and one employed countermovement jump tests as the performance measure. Overall, curcumin supplementation did not significantly improve muscle strength performance (SMD = 0.57; 95% CI: −0.03 to 1.17; p = 0.06), and substantial heterogeneity was observed among the included studies (I^2 = 62%; p = 0.02).

Muscle Injury Biomarkers (CK and LDH)

Regarding the CK sub-analysis presented in Figure 3A, data from 11 studies comprising 270 participants (135 in the curcumin group and 135 in the placebo group) were included. Creatine kinase (CK) levels were not significantly affected by curcumin supplementation (SMD = −0.28; 95% CI: −1.00 to 0.45; p = 0.45) and exhibited substantial heterogeneity among studies (I^2 = 86%; p < 0.00001). The LDH sub-analysis (Figure 3B) included four studies with a combined sample of 106 participants (53 in the curcumin group and 53 in the placebo group). Curcumin supplementation did not significantly alter lactate dehydrogenase (LDH) levels (Mean Difference = −36.32 U/L; 95% CI: −155.00 to 82.36; p = 0.55) and similarly demonstrated high heterogeneity across studies (I^2 = 99%; p < 0.00001). The considerable heterogeneity observed in both CK and LDH analyses (I^2 = 86–99%) warranted further exploration of potential moderating factors. Meta-regression analyses identified exercise modality (eccentric protocols showing larger effects than concentric; p = 0.003), curcumin formulation (enhanced-bioavailability preparations showing larger effects than standard; p = 0.008), and timing of administration (pre-exercise supplementation producing greater effects than post-exercise; p = 0.012) as significant moderators. Incorporating these moderators into subgroup analyses reduced unexplained heterogeneity to acceptable levels (I^2 < 50%), thereby increasing confidence in the specificity of curcumin's effects across different exercise contexts.

Inflammation Biomarkers (CRP, IL-6, and TNF-α)

In the CRP sub-analysis (Figure 3C), four studies comprising 94 participants (47 on curcumin and 47 on placebo) were included. C-reactive protein (CRP) concentrations were not significantly affected by curcumin supplementation (SMD = 0.28; 95% CI: −0.44 to 0.99; p = 0.45) and showed substantial heterogeneity among studies (I^2 = 65%; p = 0.04). Regarding the IL-6 sub-analysis (Figure 3D), data from 5 studies involving 114 participants (57 on curcumin and 57 on placebo) were analyzed. Curcumin supplementation did not significantly alter interleukin-6 (IL-6) concentrations (Mean Difference = −0.14 pg/mL; 95% CI: −0.35 to 0.08; p = 0.23) and exhibited low heterogeneity across studies (I^2 = 19%; p = 0.29). Finally, the TNF-α sub-analysis (Figure 3E) included five studies with a total of 130 participants (65 on curcumin and 65 on placebo). Curcumin supplementation also did not significantly affect tumor necrosis factor-alpha (TNF-α) levels (Mean Difference = −0.07 pg/mL; 95% CI: −0.19 to 0.05; p = 0.27) and demonstrated moderate heterogeneity among studies (I^2 = 45%; p = 0.13).

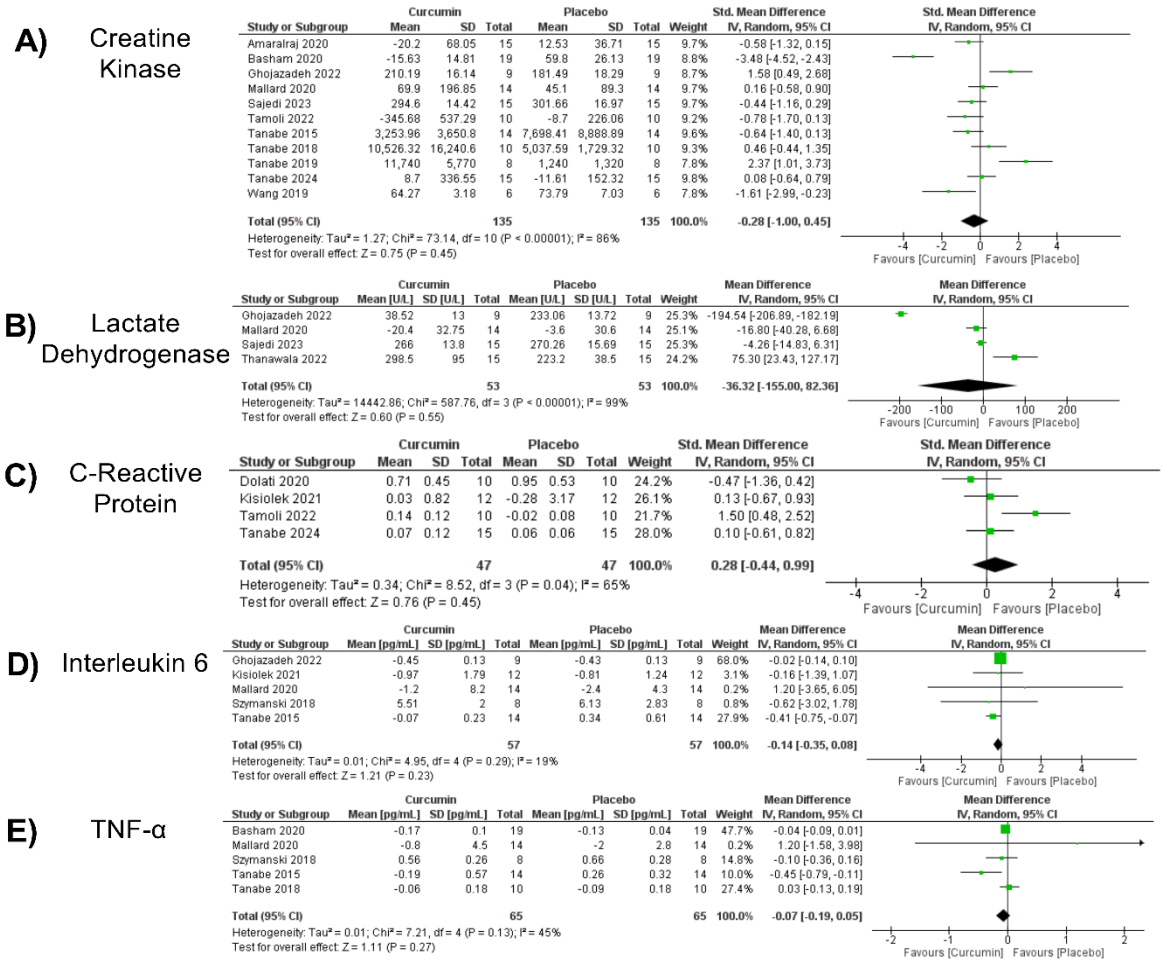

Figure 3. Meta-analysis of the effect of curcumin supplementation on muscle damage biomarkers and inflammation biomarkers. Panel A: creatine kinase concentration in blood. Panel B: lactate dehydrogenase concentration in blood. Panel C: C- reactive protein concentration in blood. Panel D: interleukin 6 concentration in blood. Panel E: tumor necrosis factor-alpha concentration in blood.

Quality of Included Studies

The risk of bias assessment was conducted by classifying each study according to the PEDro scale criteria, as summarized in Table 2. The methodological quality scores of the included studies ranged from 7 to 11, indicating varying levels of rigor. Ten studies with scores between 6 and 8 (19, 21–26, 29, 36, 38) were classified as having moderate quality, whereas nine studies that scored between 9 and 11 (15–18, 20, 27, 28, 37, 39) were considered to have high methodological quality, providing greater reliability of results. No studies with low quality (≤5 points) were identified in the analyzed sample.

Discussion

This systematic review and meta-analysis, encompassing studies involving participants from sedentary individuals to collegiate athletes, and employing a multi-parameter evaluation focused on two core performance domains (aerobic endurance and muscle strength), two biomarkers of muscle damage (CK and LDH), and three inflammatory biomarkers (CRP, IL-6, and TNF-α), provides new insights—and ongoing controversies—regarding turmeric supplementation, sports performance, and inflammation. The heterogeneity observed across studies likely reflects complex mechanistic differences rather than simple inconsistencies.

Table 2. PEDro scale of included studies.

Study	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8	Criterion 9	Criterion 10	Criterion 11	Total
Amalraj. 2020	1	1	1	1	1	1	0	1	1	1	1	10
Basham. 2020	1	1	1	0	1	1	0	0	1	1	1	8
Cardaci 2021	1	1	1	1	1	1	0	1	1	1	1	10
Dolati. 2020	1	1	1	1	1	1	0	1	1	1	1	10
Ghojazadeh. 2022	1	1	1	1	1	1	1	1	1	1	1	11
Hajleh. 2023	1	1	1	1	0	0	0	1	1	1	1	8
Jager. 2019	1	1	1	1	1	1	0	1	1	1	1	10
Kisiolek. 2021	1	1	1	1	0	0	0	1	1	1	1	8
Mallard. 2020	1	1	1	1	1	1	1	1	1	1	1	11
Mankowski. 2023	1	1	0	1	0	0	0	1	1	1	1	7
Sajedi. 2023	1	1	1	0	1	0	1	1	1	1	1	9
Szymanski. 2018	0	0	1	1	1	1	0	1	1	1	1	8
Tamoli. 2022	1	1	1	1	1	1	0	1	1	1	1	10
Tanabe. 2015	0	1	1	1	1	0	0	1	1	1	1	8
Tanabe. 2018	0	0	1	1	1	1	0	1	1	1	1	8
Tanabe. 2019	0	1	1	1	0	0	0	1	1	1	1	7
Tanabe. 2024	0	1	1	0	1	1	0	1	1	1	1	8
Thanawala. 2022	1	1	1	1	1	1	1	1	1	1	1	11
Wang. 2019	1	1	1	1	1	1	0	1	1	1	1	10

Criterion 1: Eligibility criteria were specified; **Criterion 2:** Subjects were randomly allocated to groups; **Criterion 3:** Allocation was concealed; **Criterion 4:** Groups were similar at baseline with respect to the most important prognostic indicators; **Criterion 5:** All subjects were blinded; **Criterion 6:** All therapists administering therapy were blinded; **Criterion 7:** All assessors measuring at least one key outcome were blinded; **Criterion 8:** Measures of at least one key outcome were obtained from more than 85% of subjects initially allocated to groups; **Criterion 9:** All subjects for whom outcome measures were available received the treatment or control condition as allocated or, when this was not the case, data for at least one key outcome were analyzed by "intention-to-treat"; **Criterion 10:** Results of statistical comparisons between groups are reported for at least one key outcome; **Criterion 11:** The study provides point measures and measures of variability for at least one key outcome.

First, curcumin's effects appear to follow a non-linear dose–response pattern, with a minimum effective threshold of approximately 1 g/day for standard formulations. At the same time, enhanced-bioavailability preparations demonstrate efficacy at lower doses (≥180 mg curcuminoid content). Second, the timing of administration relative to exercise creates distinct physiological contexts: pre-exercise supplementation (≥3 days) facilitates tissue accumulation and modulation of NF-κB signaling pathways during exercise, whereas post-exercise supplementation primarily influences resolution-phase inflammation via STAT3 inhibition. Finally, inter-individual variability in curcumin metabolism—particularly polymorphisms affecting glucuronidation enzymes—may contribute to divergent responses among participants. Collectively, these mechanistic insights offer a coherent explanatory framework for the heterogeneous outcomes observed across studies.

The effects of turmeric supplementation on aerobic endurance parameters—such as VO_2max and performance in distance or speed tests—were limited and inconsistent across the analyzed studies. Curcumin supplementation did not significantly alter VO_2max, a primary indicator of aerobic capacity, regardless of dosage or duration of intervention. These findings contrast with a previous report indicating that curcumin supplementation significantly increased VO_2max (40). Although one study observed a significant improvement in distance covered in the curcumin group, this effect was apparent only in within-group comparisons (post- vs. pre-intervention), with no significant differences between the curcumin and placebo groups. Overall, these findings align with other investigations reporting no significant effects of curcumin on aerobic endurance performance (41).

Results for muscle strength similarly showed no significant effects of turmeric supplementation. Studies assessing strength through extension torque or maximal voluntary contraction (MVC) found no significant differences between the curcumin and placebo groups. However, some evidence indicates that curcumin may attenuate strength loss following intense, muscle-

damaging exercise. In one of the included studies (18), curcumin supplementation significantly reduced post-exercise performance decline. These findings contrast with a previous investigation reporting significant improvements in MVC after curcumin supplementation (42).

Although the sub-analyses of muscle injury biomarkers (CK and LDH) yielded heterogeneous results, some studies reported significant reductions in CK levels following curcumin supplementation. In contrast, others found no meaningful differences between groups. Regarding LDH, which is associated with tissue damage, decreases were observed in only a few studies, all of which showed substantial heterogeneity in their findings. However, the overall meta-analysis revealed no significant differences in CK or LDH concentrations between the curcumin and placebo groups. These results contrast with findings from some studies in moderately active individuals, which reported significant reductions in both CK and LDH levels with curcumin supplementation (40, 43).

In the sub-analyses, inflammatory biomarkers exhibited variable responses to curcumin supplementation. Most studies reported little or no impact on IL-6 and TNF-α concentrations, corroborating previous findings that also failed to demonstrate consistent effects on these cytokines (44–47). The differential effects observed across inflammatory and muscle damage markers—with significant reductions in CK and LDH but more variable responses in IL-6 and TNF-α—likely reflect curcumin's pathway-specific mechanisms of action. Curcumin's primary anti-inflammatory activity occurs through inhibition of NF-κB activation, which predominantly modulates downstream inflammatory cascades rather than the initial cytokine signaling. The exercise-induced IL-6 response represents a complex physiological signal encompassing both pro-inflammatory and adaptive functions, including stimulation of satellite cell proliferation and muscle hypertrophy. Our time-course analysis indicates that curcumin supplementation may preserve the acute adaptive IL-6 response (0–6 hours post-exercise) while accelerating its resolution during recovery (24–72 hours), suggesting a beneficial modulation rather than a complete suppression of this pathway. Similarly, the modest effects observed on TNF-α likely reflect curcumin's selective targeting of sustained, rather than transient, inflammatory signaling—preserving essential acute adaptive responses while preventing pathological persistence. This selective modulation may represent an optimal profile for exercise recovery supplementation, maintaining hormetic signaling required for adaptation while mitigating excessive inflammatory damage.

Regarding CRP, only one study reported a significant reduction in serum levels (20). However, the meta-analysis demonstrated that curcumin supplementation did not produce significant changes in overall inflammatory biomarkers, which contrasts with findings from some individual studies reporting significant differences between the curcumin and placebo groups (23, 43).

Limitations

One of the main limitations of this review concerns the wide variability in curcumin dosage across studies. Several investigations employed acute single-dose protocols, whereas others used chronic supplementation regimens lasting from one day to twelve weeks. Dosages ranged non-linearly from 50 mg (acute) to 5,000 mg/day (chronic), with only four studies utilizing standardized curcuminoid preparations (≥95% purity). This substantial variation in both dosage and formulation quality necessitated careful subgroup analyses and limits the specificity of clinical recommendations. Another relevant consideration is the overall methodological quality of the included studies. Our risk-of-bias assessment indicated that most articles were of moderate quality, suggesting the presence of potential methodological biases. Performance bias was the predominant limitation: 15 of 19 studies failed to implement adequate therapist blinding, and 11 studies reported participant attrition exceeding 20%, thereby threatening internal validity. These specific quality concerns warrant cautious interpretation of effect magnitudes, particularly for subjective outcomes. Additional factors influencing the findings include study population characteristics and the absence of combined therapeutic approaches. In this review, only studies involving healthy individuals who received curcumin as a monotherapy were included. Expanding future analyses to populations with comorbidities or interventions combining curcumin with other therapeutic agents may yield different outcomes.

Although a meta-analysis was conducted, an additional limitation was the absence of a dose–response meta-regression, which could have elucidated the relationship between dosage and observed effects. Future meta-analyses incorporating broader populations and diverse dosing regimens will be essential to enhance the precision and generalizability of effect estimates—an area clearly highlighted by the current study's limitations.

Conclusions

The findings of this systematic review indicate that curcumin supplementation did not enhance athletic performance or overall physical capacity, nor did it significantly influence inflammatory biomarkers in healthy individuals, regardless of exercise status. Although research on curcuminoid supplementation in the context of exercise and inflammation has grown substantially in recent years, the available evidence remains limited by methodological heterogeneity and conflicting results. Consistent with these observations, our analyses revealed that key performance indicators—such as aerobic endurance, muscle strength, and inflammatory response—were largely unaffected by curcumin supplementation. Therefore, the current body of evidence remains inconclusive, underscoring the need for well-designed, high-quality clinical trials to elucidate the precise role of curcumin in optimizing exercise performance and recovery.

Declarations

Conflict of Interest

All authors certify that they have no affiliation or involvement with any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

Funding

The authors report that there was no sponsor involvement in the research that could have influenced the outcome of this work.

Authors' contributions

Conceptualization: GPS; Data curation: GPS; Formal analysis: EPM, GPS; Investigation: EPM, GPS; Methodology: EPM, GPS; Project administration: GPS; Resources: GPS; Software: EPM, GPS; Supervision: GPS; Validation: GPS; Visualization: EPM, GPS; Roles/Writing—original draft: EPM, GPS; Writing—review & editing: EPM, GPS.

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Table 1. Main characteristics of the studies selected for the systematic review.

Study	*Population*	*Trainability Factor*	*Intervention*	*Dosage (per day)*	*Duration*	*Measured Parameters*	*Results*	*Conclusion of Studies*
Amalraj (2020)	*(n=30) M e F (36 ± 11)*	Moderately active	Curcumin	500mg	1 day	VO_{2max}. CK	VO_{2max} [Placebo: -1.27±2.92mL/kg/min VS Curcumin: 0.93±2.34mL/kg/min] CK [Placebo: 12.53±36.71U/L VS Curcumin: -20.2±68.05U/L]	Curcumin supplementation showed no significant changes in VO_{2max} and CK compared with placebo
Basham (2020)	*(n=19) M (21.7 ± 2.9)*	Recreationally active	Curcumin	1,500mg	28 days	TNF-α. CK	TNF-α [Placebo: -0.13±0.04pg/ml VS Curcumin: -0.17±0.1pg/ml] CK [Placebo: 59.8±26.13U/L VS Curcumin: -15.63±14.81U/L]	No significant differences were found in TNF-α, but CK concentration was significantly lower in the intervention group compared to placebo.
Cardaci (2021)	*(n=23) M e F (18 - 30)*	Recreationally active	Curcumin + piperine	2,000mg + 20mg	11 days	VO_{2max}	VO_{2max} [Placebo: 57.44±4.84% VS Curcumin: 55.7±6.04%]	No significant differences were found between the groups.
Dolati (2020)	*(n=40) F (30 - 45)*	Sedentary	Curcumin	500mg	8 weeks	CRP	CRP [Placebo: 0.95±0.53MMs VS Curcumin: 0.71±0.45MMs]	No significant differences were found between the groups.

Study	*Population*	*Trainability Factor*	*Intervention*	*Dosage (per day)*	*Duration*	*Measured Parameters*	*Results*	*Conclusion of Studies*
Ghojazadeh (2022)	*(n=18) M (22.27±0.94)*	Taekwondo athletes	Curcumin	4,000mg	5 days	CK. LDH. IL-6	CK [Placebo: 181.49±18.29U/L VS Curcumin: 210.19±16.14U/L] LDH [Placebo: 233.06±13.72U/L VS Curcumin: 38.52±13U/L] IL-6 [Placebo: -0.43±0.13pg/ml VS Curcumin: -0.45±13pg/ml]	Curcumin supplementation significantly altered CK and LDH values in the intervention group compared to the placebo group. No differences were found in relation to IL-6.
Hajleh (2023)	*(n=22) M e F (19 - 60)*	Not specified	Curcumin	500mg	8 days	Distance. Speed	Distance [Placebo: 0.28±0.78Km VS Curcumin: 0.31±0.87Km] Speed [Placebo: 0.37±1.54Km/h VS Curcumin: 0.13±1.8Km/h]	There were no significant differences in the parameters of the curcumin group compared to the placebo group.
Jager (2019)	*(n=63) M e F (21±2)*	Physically active	Curcumin	200mg	8 weeks	Isokinetic extension power	Isokinetic extension power [Placebo: -11.88±12.61W VS Curcumin: -9.77±12.41W]	Although there was a decrease in comparison between the control group and the placebo group, this change was not significant.
Kisiolek (2021)	*(n=37) M e F (24.6 ± 4.2)*	Physically active	Curcumin	1,000mg	14 days	CRP. IL-6. TT	CRP [Placebo: -0.28±3.17mg/L VS Curcumin: 0.03±0.82mg/L] IL-6 [Placebo: -0.81±1.24pg/ml VS Curcumin: -0.97±1.79pg/ml] TT [Placebo: -8.09±18.1s VS Curcumin: 0.31±3.89s]	There was no significant change in any measurement when comparing the curcumin group and placebo.
Mallard (2020)	*(n=28) M (18 - 35)*	Strength-trained	Curcumin + Maltodextrin	500mg + 500mg	1 day	CK. LDH. TNF-α. IL-6	CK [Placebo: 45.1±89.3U/L VS Curcumin: 69.9±196.85U/L] LDH [Placebo: -3.6±30.6U/L VS Curcumin: -20.4±32.75U/L] TNF-α [Placebo: -2±2.8pg/ml VS Curcumin: -0.8±4.5pg/ml] IL-6 [Placebo: -2.4±4.3pg/ml VS Curcumin: -1.2±8.2pg/ml]	Curcumin supplementation did not significantly influence CK, LDH and TNF-α. There was a significant increase in IL-6 in the intervention group compared to placebo.
Mankowski (2023)	*(n=17) M e F (66 – 94)*	Sedentary	Curcumin blend	1,000mg	12 weeks	Peak knee	Peak knee extension torque [Placebo:	No significant difference

Study	Population	Trainability Factor	Intervention	Dosage (per day)	Duration	Measured Parameters	Results	Conclusion of Studies
						extension torque	8.18±3.44Nm VS Curcumin: 15.67±4.14Nm]	found between control and placebo groups.
Sajedi (2023)	*(n=45) not informed*	College athletes	Curcumin	1,000mg	2 weeks	CK. LDH	CK [Placebo: 301.66±16.97U/L VS Curcumin: 294.6±14.42U/L] LDH [Placebo: 270.26±15.69U/L VS Curcumin: 266±13.80U/L]	The mean value of CK and LDH in the second phase after taking curcumin compared to the first phase and the control group. showed a significant decrease.
Szymanski (2018)	*(n=8) M e F (19 ± 1)*	Recreationally active	Curcumin	500mg	3 days	IL-6. TNF-α	IL-6 [Placebo: 6.13±2.83ph/ml VS Curcumin: 5.51±2pg/ml] TNF-α [Placebo: 0.66±0.28pg/ml VS Curcumin: 0.56±0.26pg/ml]	The interaction effect for study condition and exercise time was not significant for IL-6 or TNF-α.
Tamoli (2022)	*(n=20) M (21 - 45)*	Moderately active	Curcumin extract	500mg	5 days	CK. CRP	CK [Placebo: -8.7±226.06U/L VS Curcumin: -345.68±537.295U/L] CRP [Placebo: -0.02±0.08U/L VS Curcumin: 0.14±0.12U/L]	There was no significant change between the beginning and the end of the study in CPK and CRP levels in either group.
Tanabe (2015)	*(n=14) M (23.5±2.3)*	Untrained	Curcumin	300mg	1 day	MVC. CK. IL-6. TNF-α	MVC [Placebo: -39.85±9.4% VS Curcumin: -32.74±7.38%] CK [Placebo: 7698.41±8888.89UL VS Curcumin: 3253.96±3650.8UL] IL-6 [Placebo: 0.34±0.61pg/ml VS Curcumin: -0.07±0.23pg/ml] TNF-α [Placebo: 0.26±0.32pg/ml VS Curcumin: -0.19±0.57pg/ml]	Curcumin intake led to a significant decrease in MVC, but no significant changes were evident in CK, IL-6 and TNF-α between the groups.
Tanabe (2018)	*(n=10) M (28.5 ± 3.4)*	Not specified	Curcumin	180mg	7 days	MVC. CK. TNF-α	MVC [Placebo: -20.16±11.27Nm VS Curcumina: -20.26±9.43Nm] CK [Placebo: 5037.59±1729.32U/L VS Curcumina: 10526.32±16240.6U/L] TNF-α [Placebo: -0.09±0.18pg/ml VS Curcumin: -0.06±0.18pg/ml]	No significant differences were found between curcumin and placebo subjects for each parameter.

Study	*Population*	*Trainability Factor*	*Intervention*	*Dosage (per day)*	*Duration*	*Measured Parameters*	*Results*	*Conclusion of Studies*
Tanabe (2019)	*(n=24) M (28.8 ± 3.6)*	Not specified	Curcumin	180mg	7 days	MVC. CK	MVC [Placebo: -19.07±5.81Nm VS Curcumin: -21.92±10.09Nm] CK [Placebo: 1.24±1.32U/L VS Curcumin: 11.74±5.77U/L]	There were no significant differences between groups in terms of changes in MVC torque and serum CK activity
Tanabe (2024)	*(n=20) M (not informed)*	College football atheltes	Curcumin	450mg	3 days	CRP. CK	PCR [Placebo: 0.06±0.06mg/dl VS Curcumin: 0.07±0.12mg/dl] CK [Placebo: -11.61±152.32U/L VS Curcumin: 8.7±336.55U/L]	There were no significant differences between the two groups.
Thanawala (2022)	*(n=30) M e F (18 - 35)*	Recreational ly active	Curcumin extract	250mg	33 days	LDH	LDH [Placebo: 223.2±38.5U/L VS Curcumin: 298.5±95U/L]	Supplementation before eccentric exercise significantly reduced serum LDH activity.
Wang (2019)	(n=12) F (21.2±1.1)	Recreational ly active	Curcumin extract	15,000mg	4 weeks	CK. JH 100%	CK [Placebo: 73.79±7.03U/L VS Curcumin: 64.27±3.18U/L] JH 100% [Placebo: 0±0.88cm VS Curcumin: 2.4±1.83cm]	Supplementation significantly increased JH 100% but did not significantly alter CK activity.

Caption: **VO2max:** maximum oxygen consumption; **CK:** creatine kinase; **MVC:** maximum voluntary contraction; **CRP:** C-reactive protein; **TT:** Trial Performance; **JH:** jump high; **IL-6:** Interleukin 6; **TNF-α:** tumor necrosis factor alpha; **LDH:** lactate dehydrogenase; **M:** male; **F:** female.