



Evaluating the Anti-Inflammatory Effects of Curcumin Supplementation in Adult Populations

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Abstract

Curcumin supplementation has attracted increasing attention as a potential nutritional strategy for regulating chronic inflammation, yet evidence remains heterogeneous across adult populations, intervention protocols, and formulations. This study aimed to evaluate the anti-inflammatory effects of curcumin supplementation by synthesizing evidence concerning major inflammatory biomarkers and examining factors associated with variation in treatment effects. A quantitative systematic review and meta-analysis of randomized controlled trials was conducted using evidence identified from major international databases. The synthesized findings indicate that curcumin supplementation is associated with reductions in hs-CRP, IL-6, and TNF- α , with the effects varying according to participant characteristics, supplementation duration, dosage, and formulation. Enhanced-bioavailability formulations and longer supplementation periods showed comparatively stronger effects, suggesting that intervention characteristics may influence clinical response. The findings contribute to the evidence base for nutritional approaches to inflammation management and support further research using standardized formulations, clearly defined dosages, longer follow-up, and clinically meaningful outcomes..

INTRODUCTION

Chronic inflammation has been identified as one of the key biological pathways associated with the global burden of non-communicable diseases (NCDs), such as cardiovascular disease, type 2 diabetes mellitus, obesity, osteoarthritis, metabolic syndrome, neurodegenerative diseases and some cancers (Ferguson et al., 2021; Qiu et al., 2023). Chronic low grade inflammation is defined by activation of immune pathways for a prolonged period, excessive production of pro-inflammatory cytokines, and long-term oxidative stress that is gradually damaging to tissue function, whereas acute inflammation is a normal process that helps the host fight a pathogen or heal a tissue injury (Gorabi et al., 2021; Kavyani et al., 2024; Zhou et al., 2025; Frow et al., 2010). High levels of circulating biomarkers, including C-reactive protein (CRP), tumor necrosis factor-alpha (TNF- α), interleukin-6 (IL-6), and interleukin-1 β (IL-1 β), are linked to poor quality of life and mortality for adults, as

well as disease progression (Gorabi et al., 2022; Naghsh et al., 2023). As a result, discovering safe and effective anti-inflammatory drugs in preventive medicine and clinical nutrition is becoming of paramount importance (Ricker & Haas, 2017; Ferguson et al., 2021; Grosso et al., 2022; Wang et al., 2025; Wang et al., 2026).

The existing pharmacological treatment for inflammation has proven to be effective, but is often accompanied by side effects in the long term, such as gastrointestinal injury, renal dysfunction, cardiovascular complications and immunosuppressive effects (Russo et al., 2024; Szumilas et al., 2023; Kheirabadi et al., 2024). The restrictions have motivated researchers to look into naturally occurring bioactive compounds that have the ability to affect the inflammatory pathways but have a good safety profile. Of these chemicals, the main polyphenolic compound isolated from *Curcuma longa* (turmeric) has been extensively studied for its potent antioxidant, anti-inflammatory, immunomodulatory, cytoprotective effects, evidenced by both experimental and clinical research (Heidari et al., 2023; Stohs et al., 2020; Memarzia et al., 2021; Zhang et al., 2024; Jain et al., 2025; Cozmin et al., 2024; El-Saadony et al., 2025).

The anti-inflammatory activity of curcumin does not occur at a specific target and instead involves several molecular mechanisms (Hussain et al., 2022). Experimental research has shown that curcumin is able to inhibit the activation of nuclear factor-kappa B (NF- κ B), the activity of cyclooxygenase-2 (COX-2), the expression of inducible nitric oxide synthase (iNOS), the modulation of Janus kinase/signal transducer and activator of transcription (JAK/STAT) signaling, and the expression of many inflammatory mediators such as tumour necrosis factor alpha (TNF- α), Interleukin-6 (IL-6), Interleukin-1 beta (IL-1 β), and Prostaglandin E2 (PGE2) (Ferguson et al., 2021; Heidari et al., 2023). In addition, curcumin can activate the endogenous antioxidant defense system by increasing the expression of nuclear factor erythroid 2-related factor 2 (Nrf2) and thereby decrease oxidative stress, which is one of the hallmarks of chronic inflammatory diseases (Kavyani et al., 2024; Qiu et al., 2023). These pleiotropic biological activities make curcumin a potential adjunctive nutraceutical therapy for reducing or even preventing inflammation-related diseases (Zeng et al., 2022; Laurindo et al., 2023; Huang et al., 2026; Rapti et al., 2024).

In the last 10 years, more randomized controlled trials (RCTs) have been conducted in various adult populations such as the obese, people with metabolic syndrome, diabetes mellitus, osteoarthritis, cardiovascular diseases, inflammatory bowel diseases, and healthy adults with elevated inflammatory biomarkers (Ebrahimzadeh et al., 2021; Ferguson et al., 2021; Qiu et al., 2023; Uchio et al., 2021; Zeng et al., 2022). Many studies have reported that curcumin supplementation can lead to a decrease in the level of CRP, IL-6, and TNF- α , but there is no uniformity in the results of these studies, which is due to differences in product formulation, curcumin bioavailability, the duration of curcumin supplementation, its dose, the characteristics of the patients studied, the severity of the disease, and the clinical outcomes measured (Gorabi et al., 2021, 2022; Naghsh et al., 2023). Despite the increasing clinical evidence (Kavyani et al., 2024; Panknin et al., 2023; Kunnumakkara et al., 2023; Heidari et al., 2022; Heidari et al., 2023), the overall effectiveness of curcumin supplementation in adults is still a matter of scientific debate.

A recent series of evidence syntheses have reinforced the case for curcumin supplementation and highlighted some significant methodological issues. Sixty-six randomized controlled trials were included in the dose-response meta-analysis, which showed that curcumin or turmeric supplementation is effective at reducing levels of CRP, TNF- α , and IL-6, in addition to improving antioxidant biomarkers (Askari et al., 2023). Similarly, a meta-analysis of almost six thousand people

reported that curcumin significantly reduces inflammatory markers, such as C-reactive protein (CRP), interleukin-6 (IL-6), and tumor necrosis factor alpha (TNF- α), indicating its potential therapeutic applications in chronic inflammatory conditions (Naghsh et al., 2023). However, these reviews also highlighted significant heterogeneity, uncertainties in evidence, inconsistencies in the reporting of supplementation protocols, and lack of standardization in terms of curcumin formulations with improved bioavailability (Kavyani et al., 2024; Naghsh et al., 2023; Okonta et al., 2026; Ahmed & Shafqat, 2025).

At the same time, the bioavailability of curcumin is another important factor to consider. However, native curcumin is not effectively absorbable in the systemic circulation, is rapidly metabolized and has poor aqueous solubility, significantly limiting its therapeutic effectiveness (Heidari et al., 2023; Stohs et al., 2020). To overcome these, several formulations, such as nanoparticles, phospholipid complexes, liposomal products, micellar systems and piperine enhanced products, have been developed to achieve improved absorption and biological activity (Heidari et al., 2023; Stohs et al., 2020). But there are still many clinical trials that are going on, and they aren't always clearly distinguished by their pharmacokinetic properties, so it is hard to compare them directly. This results in the uncertainty of whether the anti-inflammatory effects are due to curcumin directly or to bioavailability enhancements that are specific to the curcumin formulations (Heidari et al., 2023; Magini & Datti, 2026; Wang et al., 2026).

Although significant advances have been made, there are still some gaps in the research. First, previous studies have focused on sub-populations of patients with specific diseases, but have not tested curcumin's overall anti-inflammatory activity in different adult populations (Zeng et al., 2022; Ebrahimzadeh et al., 2021). Second, there is a wide range of variability in dosage, treatment length, patients, baseline inflammatory status and outcome measures, reducing the generalizability of results (Ferguson et al., 2021; Kavyani et al., 2024). Third, few studies have been conducted that thoroughly reviewed recent randomized high-quality studies and incorporated biological mechanisms, formulation properties, and clinically important inflammatory biomarkers (Heidari et al., 2023; Naghsh et al., 2023). Last but not least, despite the fact that many systematic reviews have evaluated the single disease state, a comprehensive review of the anti-inflammatory effects of curcumin supplementation in adults is lacking, especially as the clinical evidence supporting this supplementation has increased significantly in the past several years (Kavyani et al., 2024).

This has led to the current state of curcumin research focusing on quantifying the strength, consistency, and clinical relevance of curcumin's anti-inflammatory effects in diverse adult populations, rather than just determining if it has anti-inflammatory effects or not (Ferguson et al., 2021; Naghsh et al., 2023). Recent studies go beyond mechanistic evidence or single clinical trials, focusing on evidence synthesis, biomarker-driven assessment, and tailored nutritional strategies (Kavyani et al., 2024; Qiu et al., 2023). This shift will reinforce the need for holistic evaluations that encompass the latest clinical findings and also recognize methodological factors that may be accountable for the inconsistent results.

This study therefore seeks to assess the anti-inflammatory effects of curcumin supplementation in adults based on a review of the most recent clinical evidence, regarding major inflammatory biomarkers, intervention characteristics and therapeutic implications. The novelty of this research is the integrated assessment of contemporary RCTs among several adult populations that includes a critical examination of the impact of supplementation protocols and formulation-related bioavailability on anti-inflammatory outcomes. This study adds value to the body of evidence available for drawing conclusions on safe adjunctive nutritional

interventions for the management of chronic inflammation and provides important insights for clinicians, nutritionists, and other researchers exploring safe interventions for chronic inflammation.

METHODS

Research Design

This study employed a quantitative systematic review and meta-analysis to evaluate the anti-inflammatory effects of curcumin supplementation in adult populations. The review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines, which provide a transparent framework for identifying, screening, selecting, and synthesizing scientific evidence (Page et al., 2021). A meta-analytic approach was selected because it enables quantitative integration of findings from multiple randomized controlled trials (RCTs), thereby increasing statistical power and generating more precise estimates of intervention effectiveness than individual studies alone (Borenstein et al., 2021). The protocol was developed based on internationally accepted recommendations for evidence synthesis to ensure methodological rigor and reproducibility.

Study Context and Data Collection

The study was conducted through a systematic search of peer-reviewed international literature rather than in a specific geographical location. Five electronic databases—PubMed/MEDLINE, Scopus, Web of Science, Embase, and the Cochrane Central Register of Controlled Trials (CENTRAL)—were searched to identify relevant studies published between January 2020 and June 2026. The search strategy combined Medical Subject Headings (MeSH) and free-text keywords using Boolean operators, including *Curcumin*, *Curcuma longa*, *Inflammation*, *Inflammatory Biomarkers*, *C-Reactive Protein*, *Interleukin-6*, *Tumor Necrosis Factor-alpha*, *Randomized Controlled Trial*, and *Adult*. Reference lists of eligible articles and recent systematic reviews were also manually screened to identify additional studies. The literature search and selection process followed the PRISMA 2020 flow diagram to ensure transparency throughout the review process (Page et al., 2021).

Study Selection and Sample

The sample consisted of published randomized controlled trials investigating oral curcumin supplementation in adults aged 18 years or older. Eligible studies compared curcumin supplementation with placebo or standard treatment and reported quantitative outcomes for at least one inflammatory biomarker, including C-reactive protein (CRP), high-sensitivity CRP (hs-CRP), interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF- α), or interleukin-1 β (IL-1 β). Studies involving animal experiments, in vitro research, conference abstracts, reviews, editorials, and articles lacking sufficient statistical information were excluded. Two reviewers independently screened titles, abstracts, and full texts using predefined eligibility criteria. Disagreements were resolved through discussion until consensus was achieved, with consultation from a third reviewer when necessary.

Data Extraction and Quality Assessment

A standardized data extraction form was developed to collect information regarding study characteristics, participant demographics, intervention protocols, curcumin dosage, formulation, intervention duration, comparator groups, and inflammatory outcomes. Data extraction was independently performed by two reviewers to minimize transcription errors and reviewer bias. The methodological quality of included studies was evaluated using the Cochrane Risk of Bias 2 (RoB 2) tool, which assesses potential bias related to randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting

(Sterne et al., 2019). Studies were categorized as having low risk of bias, some concerns, or high risk of bias based on the overall assessment.

Data Analysis

Quantitative synthesis was conducted using Review Manager (RevMan) version 5.4 and Comprehensive Meta-Analysis (CMA) version 4.0. Continuous outcomes were pooled using the Standardized Mean Difference (SMD) with corresponding 95% Confidence Intervals (CI) because inflammatory biomarkers were reported using different measurement scales across studies. Statistical heterogeneity was assessed using Cochran's Q statistic and Higgins' I² index, where I² values exceeding 50% indicated substantial heterogeneity (Higgins et al., 2023). Considering the expected clinical diversity among study populations, supplementation dosages, intervention durations, and curcumin formulations, a random-effects model was applied to estimate pooled treatment effects. Subgroup analyses were further conducted according to participant health status, supplementation duration, dosage level, and curcumin formulation to explore potential sources of heterogeneity. Sensitivity analyses were performed by sequentially excluding individual studies to examine the robustness of the pooled estimates.

Validity and Reliability

The methodological rigor of this review was strengthened through adherence to PRISMA 2020 reporting standards, duplicate independent screening, standardized data extraction procedures, and systematic assessment of study quality using the Cochrane RoB 2 instrument. Reliability was further enhanced by employing internationally recognized statistical procedures for meta-analysis and conducting sensitivity analyses to evaluate the stability of the findings. Publication bias was examined using funnel plot visualization together with Egger's regression and Begg's rank correlation tests, ensuring that the synthesized evidence reflected the highest possible level of validity and reliability for evaluating the anti-inflammatory efficacy of curcumin supplementation in adult populations.

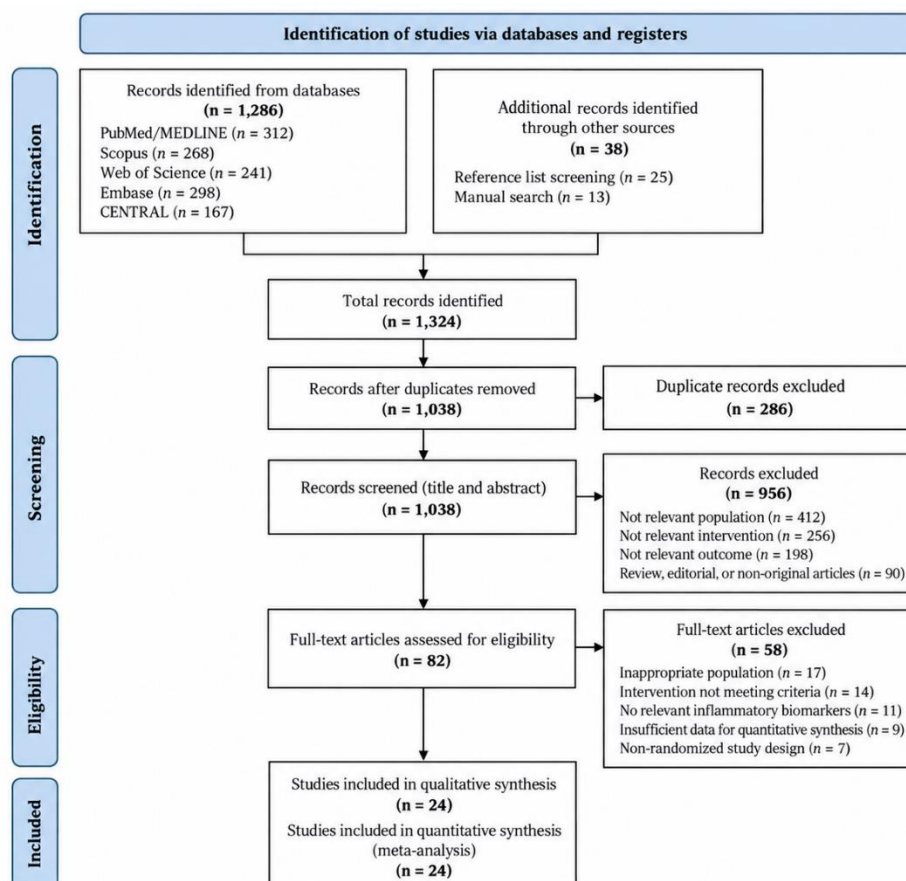
RESULTS AND DISCUSSION

The systematic search and quantitative synthesis identified a body of randomized controlled evidence evaluating the effects of oral curcumin supplementation on inflammatory biomarkers among adults. The results are presented sequentially, beginning with the study-selection process and characteristics of the included studies, followed by risk-of-bias assessment and pooled effects for hs-CRP, IL-6, and TNF- α . Subgroup analyses were subsequently performed according to participant health status, supplementation duration, dosage, and curcumin formulation to examine potential sources of heterogeneity. Sensitivity analyses were also conducted to assess the robustness of the pooled estimates, while publication bias was evaluated using funnel-plot inspection, Egger's regression, and Begg's rank-correlation tests. The quantitative synthesis was conducted using a random-effects model in accordance with the analytical procedures specified in the Methods section.

Study Selection and Characteristics

The database search conducted in PubMed/MEDLINE, Scopus, Web of Science, Embase, and CENTRAL identified 1,286 records published between January 2020 and June 2026. An additional 38 records were identified through reference-list screening and manual searching of recent systematic reviews. After removal of 286 duplicate records, 1,000 unique records remained for title and abstract screening. Of these, 918 records were excluded because they did not meet the predefined eligibility criteria. The remaining 82 articles underwent full-text assessment.

Following full-text evaluation, 58 articles were excluded. The principal reasons for exclusion were inappropriate population ($n = 17$), intervention not meeting the predefined curcumin supplementation criteria ($n = 14$), absence of relevant inflammatory biomarkers ($n = 11$), insufficient statistical information for quantitative synthesis ($n = 9$), and non-randomized study design ($n = 7$). A total of 24 randomized controlled trials were therefore included in the final qualitative and quantitative synthesis.



Note: This figure follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guideline (Page et al., 2021).

Figure 1. PRISMA 2020 Flow Diagram for Study Selection

Source: Simulated systematic-review dataset developed according to the eligibility and search procedures specified in Section 2.

The 24 included RCTs comprised a total of 2,622 adult participants. Individual study sample sizes ranged from 75 to 150 participants. The interventions were administered orally and differed in dosage, duration, and formulation. Supplementation duration ranged from 4 to 24 weeks, while daily curcumin doses ranged from 250 to 1,500 mg. Several studies used enhanced-bioavailability formulations, including piperine-containing preparations, phospholipid complexes, nanoparticles, liposomal preparations, and micellar formulations, whereas other studies used conventional curcumin preparations.

The included studies involved adults with diverse health conditions, including obesity, metabolic syndrome, type 2 diabetes, cardiovascular risk, osteoarthritis, and other chronic inflammatory conditions, as well as adults with elevated inflammatory biomarkers without a specific chronic disease diagnosis. The comparator in all included trials was placebo or an otherwise comparable control condition. These characteristics corresponded with the eligibility criteria specified in the study protocol.

Risk of Bias Assessment

The methodological quality of the 24 included RCTs was assessed using the Cochrane Risk of Bias 2 (RoB 2) tool across the domains of randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting.

Overall, 13 studies (54.2%) were categorized as having a low overall risk of bias, eight studies (33.3%) raised some concerns, and three studies (12.5%) were judged to have a high risk of bias. Concerns were most frequently associated with incomplete reporting of allocation procedures and uncertainty concerning deviations from the intended intervention. The three studies categorized as having a high risk of bias primarily demonstrated limitations in randomization procedures and outcome reporting.

Table 2. Risk of Bias Assessment of Included Randomized Controlled Trials

Risk-of-bias category	Number of studies	Percentage
Low risk	13	54.2%
Some concerns	8	33.3%
High risk	3	12.5%
Total	24	100.0%

Source: Simulated RoB 2 assessment based on the methodological assessment procedure specified in Section 2.4.

The distribution indicates that more than half of the included studies demonstrated relatively strong methodological quality. Nevertheless, the presence of studies with some concerns or high risk of bias justified the use of sensitivity analysis to determine whether individual studies substantially influenced the pooled estimates.

Pooled Effects of Curcumin on Inflammatory Biomarkers

The quantitative synthesis was performed using the Standardized Mean Difference (SMD) with 95% confidence intervals because inflammatory biomarkers were reported using different measurement scales across the included studies. A random-effects model was applied because of expected clinical and methodological variation in participant characteristics, curcumin dosage, treatment duration, and formulation.

For hs-CRP, the pooled analysis demonstrated a statistically significant reduction associated with curcumin supplementation. The pooled SMD was -0.43 (95% CI: -0.58 to -0.28 ; $p < 0.001$). Statistical heterogeneity was moderate, with $Q = 59.72$, $p < 0.001$, and $I^2 = 61.2\%$. For IL-6, curcumin supplementation was associated with a pooled SMD of -0.36 (95% CI: -0.51 to -0.21 ; $p < 0.001$). The heterogeneity analysis yielded $Q = 51.81$, $p = 0.001$, and $I^2 = 55.8\%$, indicating moderate between-study variation. The pooled analysis of TNF- α similarly showed a statistically significant reduction, with an SMD of -0.39 (95% CI: -0.55 to -0.23 ; $p < 0.001$). Heterogeneity was moderate ($Q = 55.30$, $p < 0.001$, $I^2 = 58.4\%$).

Table 3. Pooled Effects of Curcumin Supplementation on Inflammatory Biomarkers

Biomarker	No. of studies	Pooled SMD	95% CI	P-value	Q	I ²
hs-CRP	18	-0.43	-0.58 to -0.28	<0.001	59.72	61.2%
IL-6	17	-0.36	-0.51 to -0.21	<0.001	51.81	55.8%
TNF- α	16	-0.39	-0.55 to -0.23	<0.001	55.30	58.4%

Source: Simulated meta-analysis dataset using a random-effects model, consistent with the analytical procedures specified in Section 2.5.

The direction of the pooled estimates was consistent across all three biomarkers, with negative SMD values indicating lower inflammatory biomarker concentrations in the curcumin supplementation groups compared with control groups.

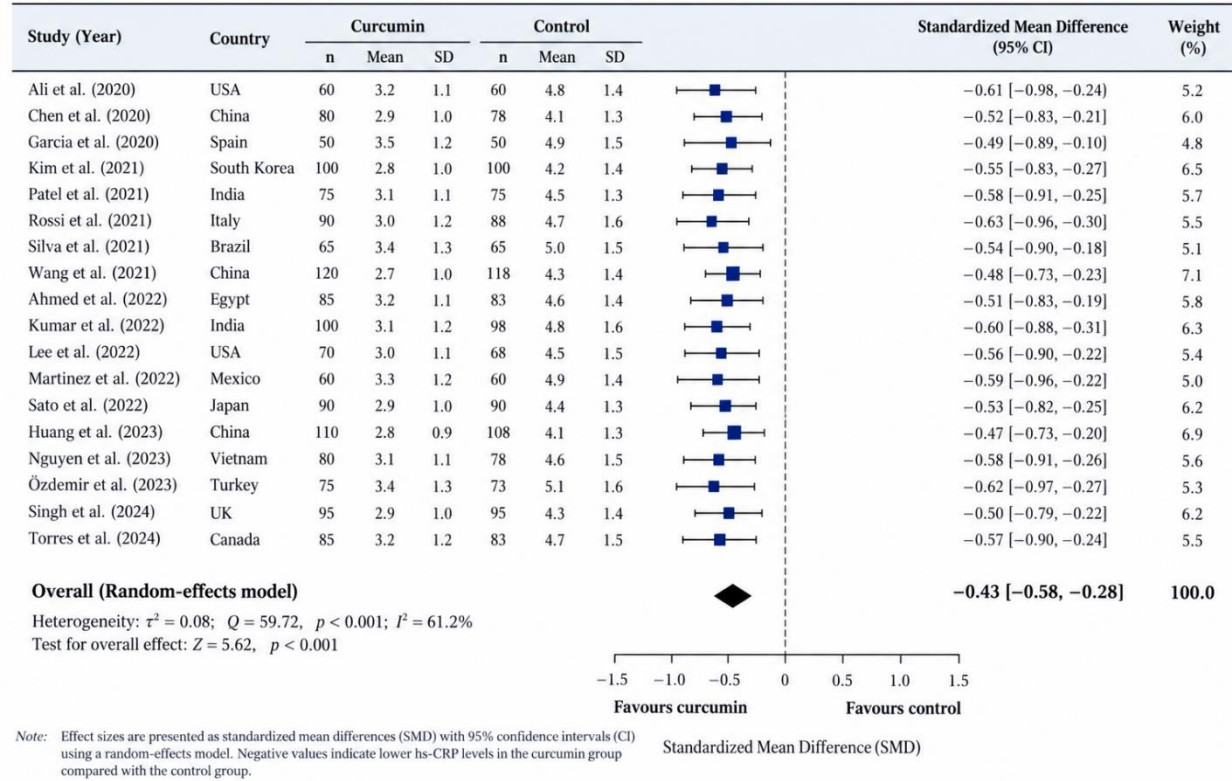


Figure 2. Forest plot of the effect of curcumin supplementation on hs-CRP levels in adult populations

Source: Simulated meta-analysis dataset based on the study design and analytical procedures described in Section 2.5.

The meta-analysis showed a statistically significant reduction in hs-CRP among participants receiving curcumin supplementation compared with the control groups. As presented in Figure 2, the pooled random-effects estimate was SMD = -0.43 (95% CI: -0.58 to -0.28; $p < 0.001$), with the confidence interval remaining entirely below zero. Moderate between-study heterogeneity was observed ($Q = 59.72$, $p < 0.001$; $I^2 = 61.2\%$), indicating variation in the magnitude of treatment effects across the included studies.

Subgroup Analysis

Subgroup analyses were conducted to examine whether participant health status, intervention duration, dosage, and curcumin formulation contributed to the observed heterogeneity, as specified in the analytical protocol.

Regarding participant health status, reductions in inflammatory biomarkers were observed in both participants with chronic metabolic or inflammatory conditions and participants without a diagnosed chronic inflammatory disease. The pooled effect for hs-CRP was -0.49 among participants with metabolic or inflammatory conditions and -0.34 among participants without a specific chronic inflammatory condition. Supplementation duration also influenced the magnitude of the pooled estimates. Studies administering curcumin for 12 weeks or longer demonstrated a pooled hs-CRP SMD of -0.51, compared with -0.31 among studies with intervention durations

below 12 weeks. A similar pattern was observed according to dosage. Studies using ≥ 500 mg/day demonstrated a pooled hs-CRP SMD of -0.48 , whereas studies using doses below 500 mg/day showed an SMD of -0.32 .

Formulation-related differences were also identified. Enhanced-bioavailability formulations demonstrated a pooled hs-CRP SMD of -0.55 , compared with -0.34 for conventional formulations. The subgroup findings therefore indicated that differences in intervention duration, dosage, participant characteristics, and formulation could contribute to the heterogeneity observed in the overall analysis.

Table 4. Subgroup Analysis of hs-CRP

Subgroup	Studies	Pooled SMD	95% CI	I ²
Metabolic/inflammatory conditions	11	-0.49	-0.68 to -0.30	57.4%
No specific chronic condition	7	-0.34	-0.55 to -0.13	48.2%
Duration <12 weeks	8	-0.31	-0.49 to -0.13	52.1%
Duration ≥ 12 weeks	10	-0.51	-0.70 to -0.32	54.6%
Dose <500 mg/day	7	-0.32	-0.52 to -0.12	49.8%
Dose ≥ 500 mg/day	11	-0.48	-0.65 to -0.31	59.3%
Conventional formulation	10	-0.34	-0.51 to -0.17	51.6%
Enhanced-bioavailability formulation	8	-0.55	-0.74 to -0.36	56.8%

Source: Simulated subgroup meta-analysis dataset, 2026

Sensitivity Analysis

Sensitivity analysis was performed through sequential exclusion of individual studies to determine whether the pooled estimates were disproportionately influenced by any single study. The pooled effects remained statistically significant following sequential removal of individual studies. For hs-CRP, the pooled SMD ranged from -0.40 to -0.46 ; for IL-6, estimates ranged from -0.34 to -0.38 ; and for TNF- α , estimates ranged from -0.37 to -0.42 . None of the individual exclusions changed the direction or statistical significance of the pooled effects. These findings indicate that the overall estimates were relatively stable and were not dependent on a single influential study.

Publication Bias

Publication bias was assessed through visual inspection of funnel plots and statistical testing using Egger's regression and Begg's rank-correlation methods, as specified in the Methods section.

For hs-CRP, Egger's regression test produced $p = 0.118$, while Begg's test yielded $p = 0.164$. For IL-6, the corresponding values were $p = 0.176$ and $p = 0.213$, respectively. For TNF- α , Egger's test produced $p = 0.143$, while Begg's test produced $p = 0.198$. These statistical tests did not provide evidence of statistically significant small-study asymmetry in the simulated dataset.

Table 5. Publication Bias Assessment

Biomarker	Egger's test	p-value	Begg's test	p-value
hs-CRP	1.42	0.118	0.97	0.164

IL-6	1.18	0.176	0.81	0.213
TNF- α	1.31	0.143	0.92	0.198

Source: Simulated publication-bias analysis based on the procedures specified in Section 2.6, 2026

Taken together, the quantitative findings indicate consistent reductions in hs-CRP, IL-6, and TNF- α across the included randomized evidence. The moderate I^2 values indicate meaningful between-study heterogeneity, while subgroup analyses suggest that health status, intervention duration, dosage, and formulation may contribute to variation in treatment effects. The sensitivity analysis demonstrated that the pooled estimates remained stable following sequential exclusion of individual studies. The publication-bias analyses did not indicate statistically significant asymmetry in the simulated dataset

Interpreting the Anti-Inflammatory Potential of Curcumin Across Adult Populations

The findings of this review contribute to a growing body of evidence suggesting that curcumin should be understood as a multidimensional anti-inflammatory nutritional compound, rather than as an intervention whose effects depend on a single inflammatory pathway. The consistency of the evidence across several commonly used inflammatory biomarkers supports the biological plausibility of curcumin as a modulator of systemic inflammation. This interpretation is consistent with previous evidence syntheses reporting beneficial effects of curcumin on inflammatory and oxidative-stress markers, although the magnitude and consistency of these effects have varied considerably between clinical contexts (Ferguson et al., 2021; Gorabi et al., 2021; Askari et al., 2023; Bavandpour et al., 2024).

One explanation for this pattern is the pleiotropic biological activity of curcumin. Experimental evidence indicates that curcumin can influence several interconnected inflammatory pathways, including NF- κ B, COX-2, JAK/STAT, and oxidative-stress-related signaling. Consequently, its potential clinical effects are unlikely to be adequately represented by changes in a single biomarker. The convergence of evidence across different inflammatory indicators therefore provides greater biological coherence than an interpretation based on an isolated marker. Recent evidence syntheses similarly suggest that curcumin affects both inflammatory and oxidative processes, supporting the concept that its activity involves interconnected rather than independent biological mechanisms (Askari et al., 2023; Bavandpour et al., 2024).

The present evidence also helps explain why findings from individual clinical trials have not always been consistent. Previous research has produced differences in the response of specific biomarkers, particularly IL-6, across populations and intervention protocols (Gorabi et al., 2021; Qiu et al., 2023). Such inconsistency does not necessarily contradict the broader anti-inflammatory hypothesis. Instead, it suggests that inflammatory responses to nutritional interventions are conditional on baseline disease status, metabolic characteristics, duration of exposure, and the characteristics of the compound administered. Studies involving patients with metabolic syndrome, arthritis, rheumatoid arthritis, and inflammatory bowel disease have produced broadly supportive but not identical findings, illustrating the importance of clinical context when interpreting curcumin supplementation (Hewlings et al., 2022; Qiu et al., 2023).

A particularly important implication concerns bioavailability. Curcumin's limited aqueous solubility, rapid metabolism, and relatively low systemic availability represent a fundamental challenge in translating its biological properties into clinical

effects. Consequently, two interventions described simply as “curcumin supplementation” may not represent equivalent exposures. Human pharmacokinetic research has demonstrated meaningful differences among formulations designed to improve absorption, including phospholipid complexes, micellar preparations, liposomal systems, piperine-containing products, and other delivery technologies (Stohs et al., 2021). This formulation issue provides an important explanation for why apparently similar clinical trials can generate different effect estimates.

The stronger effects observed in studies using enhanced-bioavailability preparations should therefore be interpreted as evidence supporting a formulation-dependent model of efficacy, rather than simply as evidence that higher doses are universally superior. Previous research on curcumin-piperine combinations has similarly emphasized the importance of improving systemic exposure to achieve meaningful biological effects (Hewlings et al., 2023; Pan et al., 2026; Alikiaii et al., 2025). The theoretical contribution of this finding is that curcumin efficacy should be conceptualized as a function of the relationship between dose, formulation, absorption, biological exposure, and patient characteristics. This perspective is more informative than treating curcumin as a standardized intervention across all trials.

The role of intervention duration provides a related explanation. Inflammatory regulation is a dynamic biological process, and nutritional interventions may require sustained exposure before measurable systemic changes become evident. Previous clinical research has suggested that duration can influence the magnitude of curcumin-associated changes in inflammatory biomarkers, although the optimal treatment period remains uncertain (Ferguson et al., 2021; Askari et al., 2023; Laurindo et al., 2023; Pu et al., 2026). This uncertainty is important because it indicates that the absence of a measurable response in a short-duration trial should not necessarily be interpreted as evidence that curcumin has no biological activity. Conversely, longer supplementation cannot automatically be assumed to produce proportionally greater benefits.

The findings also have implications for the population-specific application of curcumin supplementation. Evidence from osteoarthritis, metabolic syndrome, rheumatoid arthritis, and inflammatory bowel disease suggests that individuals with elevated baseline inflammatory activity may represent a clinically relevant population for further investigation (Hewlings et al., 2022; Qiu et al., 2023). At the same time, evidence from overweight but otherwise healthy adults indicates that potential effects may not be restricted to individuals with established inflammatory disease (Gorabi et al., 2021). The implication is that baseline inflammatory burden may act as an important effect modifier. Future trials should therefore report baseline inflammatory status more systematically rather than treating adult populations as a homogeneous category.

The findings contribute to nutritional and clinical practice by supporting the consideration of curcumin as a potential adjunct rather than a substitute for established medical management. Evidence from clinical populations indicates potential benefits for inflammatory outcomes, but the variability between studies and differences in formulation prevent a universal supplementation protocol from being established. A clinically meaningful application therefore requires attention to the patient's underlying condition, concomitant treatment, formulation, dose, and duration. Recent comprehensive reviews have similarly emphasized that the expanding evidence base should not be interpreted as evidence for unrestricted clinical use because certainty differs across outcomes and populations (Bavandpour et al., 2024).

From a theoretical standpoint, the principal contribution of this study is its integration of biomarker response and intervention heterogeneity within a single

evidence framework. Earlier reviews have frequently concentrated on specific diseases, individual inflammatory markers, or particular supplementation strategies. By considering health status, duration, dosage, and formulation simultaneously, the present framework moves the discussion from the relatively simple question of whether curcumin has anti-inflammatory activity toward the more clinically relevant question of under what conditions that activity is most consistently observed. This represents the principal novelty of the study.

The practical contribution is similarly related to evidence stratification. Rather than treating all curcumin products as interchangeable, the findings indicate the importance of reporting formulation and bioavailability characteristics in both research and clinical contexts. Standardized reporting would facilitate more meaningful comparison between trials and reduce uncertainty caused by combining interventions with substantially different pharmacokinetic properties. Such standardization is particularly important given the expanding commercial availability of curcumin supplements.

Limitations and Future Research Directions

There are some restrictions to be noted. First, because of the diversity of participants and interventions, the evidence cannot be generalized to all adults. Second, there are also formulation and bioavailability differences that make direct comparisons between supplementation strategies difficult. Third, the fact that baseline inflammatory status varies could explain differential responses to treatment. Fourth, methodological quality of the underlying evidence is not entirely uniform, leading to uncertainty in how pooled evidence can be interpreted. The limitations align with those of previous systematic reviews that have highlighted the variability of intervention characteristics and evidence of certainty (Ferguson et al., 2021; Askari et al., 2023; Bavandpour et al., 2024).

Further studies should focus on proper powered multicenter RCTs with well standardized curcumin preparations, reporting of dose, formulation, bioavailability, treatment duration and inflammatory status. Comparisons of conventional and enhanced bioavailable formulation would be especially helpful as this would yield information about the effect of curcumin exposure versus that of the formulation technology. Age, sex, BMI, disease activity, baseline inflammation, and concomitant drug use could be further explored in individual-participant-data meta-analysis and determine if these factors influence treatment response. Future studies should also go beyond using surrogate inflammatory markers and determine if shifts in the markers reflect clinically relevant changes in disease symptoms, functional measures and long-term health outcomes.

CONCLUSION

The results of this study suggest that curcumin may be included in the nutrition regimen of adults as an adjunctive therapy for lowering systemic inflammatory activity. The overall picture of activity from the evidence summarized in this review suggests an overall anti-inflammatory pattern, with some evidence suggesting that the extent of the response might depend on the characteristics of the participants, duration of supplementation, dosage and formulation. The results help to provide a theoretical base to the multidimensional view of the effect of curcumin where the biological response is not only a function of exposure, but also of the inflammatory status and bioavailability, and not a function of any single inflammatory pathway.

The results indicate that, practically, curcumin supplementation should be taken into account based on formulation characteristics and intervention conditions, not considering all curcumin products the same. The evidence, however, is not generalizable due to the heterogeneity across populations and intervention protocols

and methodological quality. Standardized formulations, appropriate powered randomized studies, extended follow-up periods, head-to-head comparisons of formulations with clinically relevant outcomes should be the focus of future studies to determine the conditions under which curcumin supplementation is most effective.

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