Scientific Research Publishing

Food and Nutrition Sciences, 2026, 17(2), 159-179
https://www.scirp.org/journal/fns
ISSN Online: 2157-9458
ISSN Print: 2157-944X

Black Tea and Systemic Inflammation: A Narrative Review of Inflammatory Markers and Their Role in Disease Modulation

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How to cite this paper: Derbyshire, E., Aslam, N. and Bond, T. (2026) Black Tea and Systemic Inflammation: A Narrative Review of Inflammatory Markers and Their Role in Disease Modulation. *Food and Nutrition Sciences*, **17**, 159-179.
https://doi.org/10.4236/fns.2026.172013

Received: November 30, 2025
Accepted: February 2, 2026
Published: February 5, 2026

Abstract

It is well established that chronic oxidative stress can drive systemic inflammation, contributing to the development of conditions such as asthma, type 2 diabetes, metabolic syndrome, cardiovascular disease, and osteoarthritis. Black tea is recognised for its bioactive anti-inflammatory properties, largely due to its diverse profile of bioactive compounds, including theaflavins, thearubigins, catechins, L-theanine, and quercetin. The present narrative review examined evidence from 11 meta-analyses, systematic/umbrella reviews, and 11 randomised controlled trials (n = 22 studies) published over the past 20 years, focusing specifically on black tea (with or without milk) and systemic inflammation. Most studies administered black tea intake at levels equivalent to 3 - 4 cups per day. Overall, black tea appears to exert anti-inflammatory and antioxidant effects, particularly in individuals with elevated baseline inflammation. These effects were most evident in longer-duration trials and those targeting populations with existing inflammatory conditions. Given the recognised role of diet in modulating inflammation, incorporating black tea and its array of bioactive compounds into daily routines may have public health relevance. Future research should prioritise longer and larger trials that reflect typical consumption patterns and expand the range of health outcomes assessed.

Keywords

Anti-Inflammatory, Bioactives, Black Tea, C-Reactive Protein, Disease Prevention, Inflammation

1. Introduction

Inflammation exists on a spectrum that can be turned up or down—it has diverse roles in tissue injury and is a key part of fighting disease [1]. It is an essential physiological defence mechanism, but nevertheless prolonged or excessive inflammation can cause disease [2]. Inflammation affects most people at some point during their life with an inflammatory response induced to protect the host from infection or injury and an appropriate systemic inflammatory responses helping the host to return to homeostasis [3]. Whilst inflammation may initially be a protective response, prolonged inflammation can have detrimental effects on health, such as contributing to tissue damage [4].

Systemic inflammation is associated with a wide range of diseases. For example, local and systematic inflammation play a central process in respiratory conditions such as asthma development [5] [6], affecting around 300 million people globally [7]. Prolonged systemic and adipose tissue inflammation is also a main driver behind metabolic and cardiovascular diseases such as type 2 diabetes mellitus and obesity-related cardiovascular disease [2]. In high-income populations between 2020 and 2035, severe obesity is anticipated to double in prevalence from 10 to 20% [8], thus potentially exacerbating related inflammatory conditions [8]. Metabolic Syndrome (MetS; a cluster of metabolic abnormalities) can also contribute to inflammatory pathways which is gaining importance given exponential rises in obesity globally [9].

Autoimmune diseases such as rheumatoid arthritis, systemic lupus erythematosus and systemic sclerosis also increase inflammation and are often linked to autonomic nervous system dysfunction [10]. Systemic inflammation may also be present in individuals with depression and/or Alzheimer's disease, which may be due to metabolic disturbances, neuroinflammation and amyloid pathology and immune dysregulation via the gut microbiome [11]. Other conditions, such as periodontal disease, also induce a systemic inflammatory state, with periodontal pathogens cross-reacting with antibodies, advancing cardiovascular atheroma plaque progression and development [12]. Knee osteoarthritis is also associated with systemic inflammation and has been linked to higher rates of daily fatigue, also known as "osteoarthritis fatigue" [13].

The diet has the potential to attenuate or exacerbate inflammation. For example, western-type diets may induce a state of chronic metabolic inflammation, referred to as "metaflammation" [14]. High-fat diets can contribute to gut barrier dysfunction, heighten intestinal permeability, induce leakage of bacterial metabolites into the circulation and contribute to low-grade systemic inflammation [15]. In contrast, other dietary components such as polyphenols and flavonoids, including flavan-3-ols and oligopeptides, may help to regulate the inflammatory response and potentially attenuate low-grade inflammation, possibly by exerting antioxidant effects, altering the activation and expression of proinflammatory cytokines and modulating the activity of reactive oxygen species-scavenging enzymes [16] [17]. Certain foods are now recognised for their ability to modulate inflammation

with tea being one of these [18]. The present narrative review examines the role of tea in inflammation, with a specific focus on systemic inflammation. While prior reviews have largely emphasised green tea or broadly addressed flavonoids and polyphenols, evidence specific to black tea remains dispersed and under-synthesized. This review addresses this gap by providing a focused overview of the evidence linking black tea consumption to systemic inflammatory processes.

2. Black Tea Components

Besides water, tea is the most commonly consumed beverage in the world, consumed by more than two-thirds of the global population [19]. It has been estimated that around 3 billion people globally drink tea, making it one of the most popular non-alcoholic beverages [20]. Black tea provides polyphenols, flavonoids (a subclass of polyphenols which includes theaflavins, thearubigins, catechins, flavonols and flavan-3-ols), and other compounds which have anti-inflammatory activities [21]-[23] (**Table 1**).

Table 1. Anti-inflammatory compounds typically present in black tea.

Black tea Flavonoids	Other black tea phenolics	Other compounds
Flavan-3-ols [67] [78]	Phenolic acids e.g. gallic acid [79]-[81]	L-theanine [33] [82]
Thearubigins formed during the oxidation of catechins, reddish-brown polymers [25]-[27] [83]		Caffeine [34]
Condensed tannins e.g. thearubigins [27] [84]		
Theaflavins formed during the oxidation of catechins [25] [83]		Selenium, iron, copper, manganese and zinc [50]
Residual catechins e.g. EGCG [83]		
Flavonols e.g. quercetin and kaempferol [30] [31]		

Key: EGCG, Epigallocatechin gallate.

Polyphenols are well recognised for their anti-inflammatory effects having roles in immune cell regulation, gene expression and the synthesis of proinflammatory cytokines [24]. Black tea flavonoids including theaflavins and thearubigins (oxidized derivates of black tea catechins during "aeration" previously termed fermentation) and flavan-3-ols can safeguard against oxidative stress, acting as antioxidants [17] [25], with beneficial effects against inflammation possibly being attributed to alterations in cell redox status and inhibition of signalling pathways, such as NF-κB activation [26]. Thearubigins are a major component of black tea, providing its distinctive dark brown colour with evidence suggestive of potential antioxidant and anti-inflammatory effects [27]. Gallic acid belongs to a group of phenolic acids which are naturally occurring compounds in tea produced by the hydrolysis of tannic acid [28]. Gallic acid also shows potential in terms of its ability to suppress pro-inflammatory responses and oxidative stress, often seen with conditions such as obesity [28].

Quercetin is a bioflavonoid present in plants and its presence in black tea also

contributes to anti-inflammatory activity [29] [30]. Kaempferol, sometimes referred to as kaempferide or kaempferol-3 is a naturally occurring flavonoid compound in tea that mediates inflammatory markers and has anti-inflammatory properties that may have a role in inflammatory diseases [31]. L-theanine is an amino acid with some of the highest levels found in black tea with a standard (200 ml) cup of tea providing up to 24.2 ± 5.7 mg [32] It has been found to inhibit oxidative damage induced by inflammatory reactions and protect against epithelial damage by suppressing the activation of the p38 MAPK signalling pathway; a stress-activated inflammation response pathway [33]. Finally, caffeine, widely consumed and present in black tea, is also thought to possess antioxidant and anti-inflammatory actions important to human health [34]-[36].

3. Methods

3.1. Inclusion and Exclusion Criteria

Studies were included if they met the following criteria: 1) English-language publications; 2) Human studies 3) Conducted in the last 20 years 4) Focused on black tea (as a beverage or extract) and 5) Identified publications were meta-analyses, systematic reviews, umbrella reviews, reviews or randomised controlled trials (RCTs).

Studies were excluded if they: 1) Were not full text, 2) Not undertaken during the specified timeline, 3) Used multi-interventions, 4) Related to another tea form and 5) Were irrelevant per se.

3.2. Sources and Search Strategy

Inflammation is a broad term that can encompass local, systemic, acute (short-term; typically 8 - 10 days) and chronic (long-term) inflammation [37]. Systemic inflammation can be low-grade *i.e.* subtle, ongoing immune activity or high-grade which can contribute to tissue degeneration and age-related diseases [38]. Systemic inflammation, as mentioned, often referred to as "metabolic inflammation" is characterised by elevated levels of acute-phase proteins such as C-reactive protein (CRP) and interleukin-6 (IL-6) and Tumour Necrosis Factor (TNF-α) [39]. This therefore formed the basis of the search terms.

PubMed, Science Direct and Semantic Scholar were searched. Specified search terms included: ("black tea" [Title/Abstract] OR "*Camellia sinensis*" [Title/Abstract] OR "tea flavonoids" [Title/Abstract] OR "tea flavan-3-ols" [Title/Abstract] OR "tea catechins" [Title/Abstract]) AND ("C-reactive protein" [Title/Abstract] OR "CRP" [Title/Abstract] OR "interleukin-6" [Title/Abstract] OR "IL-6" [Title/Abstract] OR "tumour necrosis factor alpha" [Title/Abstract] OR "TNF-alpha" [Title/Abstract] OR "TNF-α" [Title/Abstract] OR "TNF" [Title/Abstract] OR "inflammatory diseases" [Title/Abstract] OR "inflammation" [Title/Abstract] OR "chronic inflammation" [Title/Abstract] OR "immune response" [Title/Abstract] OR "autoimmune diseases" [Title/Abstract]).

The search was restricted to English-language, human studies published in the

last 20 years (1st September 2005 up until 19th September 2025). The filter was restricted to review (R), systematic review (SR) and meta-analysis (MA) publications and randomised controlled trials (RCTs). Reference lists were also searched to identify any additional relevant articles. This review was conducted according to the guideline of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement as shown in **Figure 1** [40].

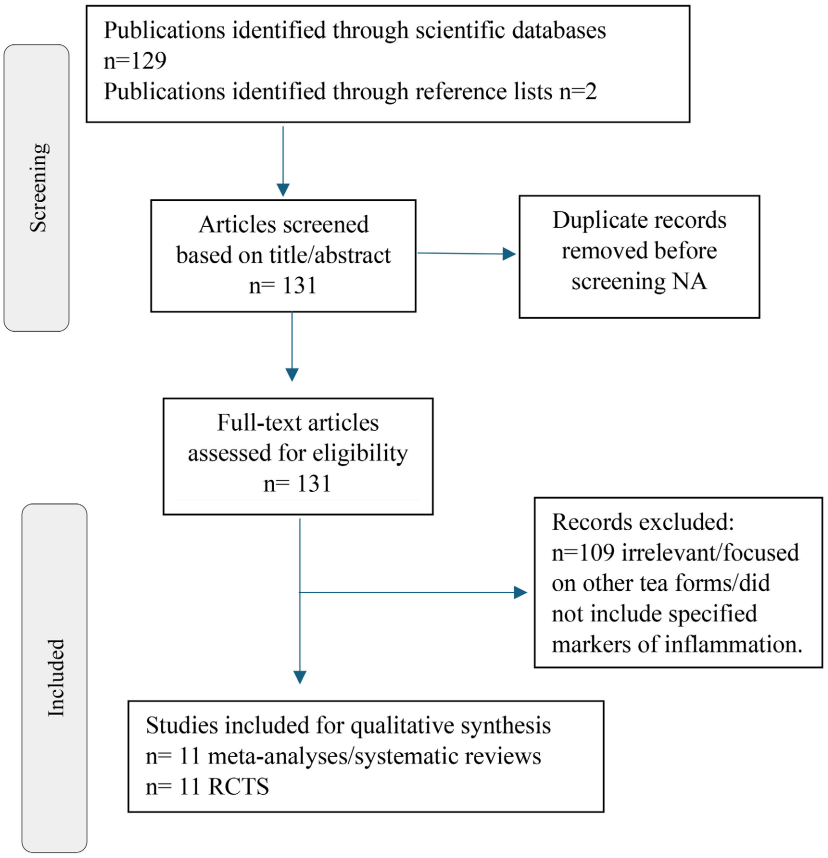

Figure 1. Algorithm flow diagram for included publications. Source: Flow of studies through different phases of the narrative review [40].

3.3. Screening Procedure

Authors assessed the titles and abstracts of all the identified studies and independently reviewed these to determine which should be included in the publication.

3.4. Data Extraction and Quality Assessment

The PICO (Population, Intervention, Comparison, Outcome) approach was used and the following information extracted from each trial: author, year, country, design, study population, intervention and comparison, outcomes, main findings and strengths/limitations and potential sources of bias. A strengths and limitation column was added to the RCT data extraction table as a measure of determining study quality.

4. Results

4.1. Findings from Review/Systematic Review and Meta-Analysis Publications

Eleven review/systematic review, umbrella review or meta-analysis publications were identified (Table 2). Four were undertaken in China [41]-[44], two in Italy [45] [46], two in the USA [47] [48] and one in Morocco [49], India [50] and Canada [51] respectively.

Table 2. Key Studies – Reviews & Meta-analysis publications.

Study (Author, Year, Country)	Number of studies analysed	Study Outcomes	Main Findings
Lamchabbek *et al.*, 2025 [49], Morocco	n = 65	Breast cancer	Observational studies found that black tea consumption was associated with a reduced risk of breast cancer. This may be due to anti-inflammatory properties.
Long *et al.* 2023 [41], China	n = 47 RCTs	Rheumatoid arthritis	Dietary polyphenols from foods (including tea polyphenols) may: - ↓ CRP - Improve oxidative stress.
Huang *et al.*, 2022 [42], China	--	Inflammatory bowel disease	Tea includes many active ingredients including polyphenols, polysaccharides and pigments that have promising anti-inflammatory and antioxidant properties.
Keller & Wallace, 2021 [48], USA	Umbrella review n = 23	Cardiovascular disease	2 cups of unsweet tea per day may have the potential to decrease CVD risk and progression due to flavonoid content.
Chowdhury & Barooah, 2020 [50], India	--	Innate immunity	Tea infusions are rich in alkaloids, caffeine and its intermediates, theophylline and theobromine, which appear to exert anti-inflammatory properties.
Liu *et al.*, 2020 [44], China	SR/MA n = 25 RCTs	Metabolic syndrome	Tea consumption could have protective effects on MetS.
Rothenberg *et al.*, 2019 [43], China	--	Depression	Black tea theaflavins and EGCG are anti-inflammatory agents acting via down-regulation of NF-κB signalling which along with L-theanine, polyphenols and polyphenol metabolites may collectively reduce the risk of depression.
Peluso *et al.*, 2013 [45], Italy	n = 25	TNF-α and IL-6 levels	Tea extracts (which included black tea) showed a significant anti-inflammatory effect and were associated with: - ↓ TNF-α - ↓ IL-6
Carini *et al.*, 2017 [46], Italy	--	Colorectal cancer and inflammatory bowel diseases	Theaflavin-3, 30-digallate in black tea appears to have protective effects against oxidative stress. Theaflavin-3, 30-digallate may be able to reduce inflammatory phenomena and symptoms associated with IBD and proliferation of CRC cells.
Renaud *et al.*, 2015 [51], Canada	--	Parkinson's Disease	ECGC is recognized to exert potent neuroprotective effects against oxidative stress and neuroinflammation.
De Meja *et al.*, 2009 [47], USA	--	Inflammation, cancer	Tea components may exert anti-inflammatory effects and aid inflammation which could progress to cancer.

Key: CRC, Colorectal Cancer; CRP, C-reactive protein; CVD, Cardiovascular Disease; ECGC; Epigallocatechin-3-gallate; IBD, Inflammatory Bowel Disease; IL-6, Interleukin-6; MA, meta-analysis; MetS, metabolic syndrome; NFκB, Nuclear Factor kapper-light-chain-enhancer of activated B cells; RCTs, randomised controlled trials; SR, Systematic Review; TNF-α, Tumour necrosis factor-alpha.

Publications focused on a range of inflammatory conditions including inflam-

matory bowel diseases [42] [46], cardiovascular disease (CVD) and metabolic syndrome [44] [48], cancer [46] [47] [49], markers of inflammation and immunity [45] [50], rheumatoid arthritis [41], depression [43] and Parkinson's Disease [51].

Focusing on inflammatory bowel disease Hung *et al.* (2002) identified that tea and its bioactive constituents (polyphenols, tea pigments, and polysaccharides) exhibit anti-inflammatory and antioxidant properties that may be relevant to inflammatory bowel disease management, particularly through modulation of oxidative stress and inflammatory signalling pathways [42]. Another earlier review [46] similarly concluded that black tea components, including theaflavin-3,3'-digallate, may attenuate intestinal inflammation by reducing oxidative stress and inflammatory activity, although the evidence was largely derived from *in vitro* and laboratory models, highlighting the need for human studies assessing clinical inflammatory markers.

An umbrella review [48] collating 23 systematic reviews on cardiovascular disease (CVD) concluded that consumption of approximately two cups of unsweetened tea per day may provide sufficient flavonoids to reduce CVD risk and progression. Proposed mechanisms included favourable effects on inflammatory markers such as TNF-α and IL-6, although the review emphasised the need for further intervention studies to confirm these pathways [48]. A systematic review and meta-analysis collating studies on tea consumption and metabolic syndrome found that black tea consumption had protective effects on systolic blood pressure in those with a body mass index of 28 or higher [44]. Mechanisms were unclear but it remains unclear whether these effects were mediated through changes in systemic inflammatory markers such as CRP or cytokines [44].

Three publications focused on breast cancer, colon cancer or cancer prevention [46] [47] [49]. A recent systematic review by Lamchabbek *et al.*, (2025) reported an inverse association between black tea consumption and breast cancer risk and noted that a higher dietary inflammatory index was associated with increased risk. However, as most included studies were case-control in design, causal relationships and direct effects on inflammatory markers could not be established. Further clinical and mechanistic studies looking at breast cancer, black tea consumption and anti-inflammatory markers would be worthwhile. An earlier review [46] suggested that theaflavin-3,3'-digallate may reduce colorectal cancer cell proliferation, potentially via anti-inflammatory and antioxidant mechanisms. Greater human data assessing markers such as NF-κB, TNF-α, or IL-6 is now needed. Another review by de Mejia *et al.* (2009) proposed that theaflavins and catechins may contribute to cancer prevention by mitigating chronic inflammation, a recognised driver of carcinogenesis [47].

Regarding markers of inflammation and immunity Peluso *et al.* (2013) evaluated data from 25 human trials finding that tea extracts which provide flavonoids reduced TNF-α and IL-6 levels in fixed and random effect models [45]. Another comprehensive review [50] explained that tea infusions provide black tea polyphenols, caffeine, EGCG, theaflavin, theophylline, theobromine, which have anti-inflammatory properties alongside certain micronutrients such as selenium, iron,

copper, manganese and zinc (accrued from the soil medium) which could enhance innate immune response.

In relation to rheumatoid arthritis, a systematic review and meta-analysis of 47 RCTs (tea polyphenols were included in 2 RCTs) found that dietary polyphenols could improve disease activity, possibly mediating rheumatoid arthritis by reducing C-reactive protein and/or oxidative stress levels [41]. A further comprehensive review [43] concluded that compounds present in tea such as black tea polyphenols, theaflavins, EGCG, teasaponin, L-theanine, and combinations of tea catechins and their metabolites appear to act as anti-inflammatory agents via down-regulation of NF-κB signalling which could collectively help to lower the risk of depression, as the neurobiology of depression has been linked to inflammation. Similarly, in relation to Parkinson's disease another review concluded that EGCG found in tea appears to inhibit neuroinflammation, oxidative stress, neuronal cell death and have neuroprotective effects [51].

Overall, black tea appears to have a potentially beneficial role in a range of conditions with inflammatory origins. The range of bioactive constituents present in black tea have been attributed to some of these potential anti-inflammation effects, alongside the suppression of oxidation stress [46] [50] [51]. However, much of the existing evidence is indirect or derived from non-habitual intake studies, demonstrating the need for well-designed human studies focusing on regular black tea consumption and clinically relevant inflammatory outcomes.

4.2. Findings from Randomised Controlled Trials

Eleven RCT publications were identified, with study durations ranging from 9 days to 6 months (**Table 3**). Three were undertaken in the USA [52]-[54], two in Iran [55] [56], two in Japan [57] [58], one in Kuwait [59], one in Mauritius [60], one in Israel [61] and one in the UK [62].

Across the studies, black tea was typically consumed in amounts ranging from 3 - 6 cups per day (approximately 600 - 900 ml), with intakes of 3 - 4 cups being most common [53] [56]-[61]. Widlansky at al. (2025) allocated adults to either 2 cups (450 ml) black tea or 900 ml (3 - 4 cups) of black tea daily. Arent *et al.* (2022) and Neyestani *et al.* (2010) used black tea extract with participants in the latter study drinking this in beverage form [52] [56].

Some research focused on typically healthy adult baseline populations. Tomioka *et al.* (2023) [57] in a single-blind, randomized, placebo-controlled trial allocated 72 adults to drink 3 cups of black tea/day (76.2 mg of black tea polymerized polyphenols) for 12 weeks and observed that an increase in butyrate-producing bacteria in the gut (Prevotella) may partly contribute to the suppressive effect of black tea consumption on acute upper respiratory tract inflammation. Earlier research [58] conducted by the same research team also providing 3 cups of black tea daily over 12 weeks found that this lowered acute upper respiratory tract inflammation risk. Steptoe *et al.* (2007) allocated 75 healthy non-smoking men to black tea or a placebo over 6-weeks, finding that the tea group had lower plasma CRP levels, which potentially may help contribute to sustained cardiovascular health [62].

Table 3. Key Studies—randomised controlled trials.

Study (Author, Year, Country)	Design	Population	Intervention and Comparison	Outcomes	Strengths & Limitations/Sources of Potential Bias
Tomioka *et al.*, 2023 [57], Japan	RCT - SB - PC	Healthy Japanese adults - n = 72 - 12 weeks	3 cups of black tea (Black Tea Polymerized Polyphenols 76.2 mg per day) or placebo	Improvement of mucosal immunity via butyrate-producing bacteria in the gut may contribute to the suppressive effect of black tea consumption on acute upper respiratory tract inflammation	Single not double-blind Fixed dose of black tea polyphenols Modest sample size
Arent *et al.*, 2022 [52], USA	RCT - DB	College males - n = 18 - 9 days	BTE (1760 mg BTE·d^{-1}) or placebo	Consumption of theaflavin-enriched black tea extract led to improved recovery and ↓ oxidative stress and DOMS responses to acute anaerobic intervals	Small sample size Short duration Used a specific population Limited inflammatory marker responses
Mirtaheri *et al.*, 2022 [55], Iran	RCT - TB	Females (30 - 65 yrs) - n = 22 in each group - 8 weeks	SSC + 2.4 g/d black tea or placebo	In the SSC group: - hs-CRP ↓ - IL-1β ↓ - MMP-3 ↓ vs. tea only P<0.05).	Multi-intervention Pilot RCT Short duration Small sample size Focused on a specific inflammatory condition
Tanaka *et al.* 2021 [58], Japan	RCT - SB - PC	Healthy Japanese adults (20 - 60 yrs) - n = 36 assigned to 2 arms	3 cups of black tea or a placebo	Black tea consumption activated NK cells incidence and frequency of acute upper respiratory tract inflammation ↓	RCT 20 weeks Small sample size Tea drank as a beverage
Mahmoud *et al.*, 2016 [59], Kuwait	RCT	Patients with T2DM - n = 30 - 12 weeks	3 cups (600 mL; high intake group) of black tea per day; or 1 cup (200 mL; low intake group) per day	Tea consumption correlated with reduced (pro-inflammatory) CD3$^+$ CD4$^+$ IL-17+ cells and reduced Th1-associated CD3$^+$ CD4$^+$ IFN-Y$^+$ cells	Small sample size 3 cups only consumed
Henning *et al.*, 2015 [53], USA	RCT (Phase III trial)	Men with prostate cancer - n = 93 - 31 days	6 cups daily of brewed black tea daily, green tea or a control	No effects on NFκB or systemic oxidation were seen for black tea	Short-term trial
Bahorun *et al.*, 2010 [60], Mauritius	RCT	Adults susceptible to ischemic heart disease - n = 232 - 12 weeks	3 cups of back tea (9 g black tea) daily of control (hot water) - 12 weeks - 3-week wash-out	CRP in the high-risk group: - ↓ by 53.4% in men - ↓ by 41.1% in women in the tea group	Longer trial Larger sample size
Neyestani *et al.*, 2010 [56], Iran	RCT	Adults with T2DM - n = 46 - 12 weeks	One-week run-in period then in the intervention: 150, 300, 450 and 600 ml of BTE during the weeks 1, 2, 3 and 4. Control group: 150 ml BTE throughout	2 cups of BTE daily ↓ malondialdehyde. 4 cups (600 ml BTE) daily ↓ CRP and glutathione	Small sample size Short study duration

Continued

Mukamal *et al.*, 2007 [61], Israel	RCT (pilot)	Adults aged 55 yrs+ with diabetes or cardiovascular risk factors - n = 31 - 6 months	3 glasses/day or standardized black tea preparation or water	There were no statistically significant effects of black tea on inflammatory markers of cardiovascular risk/	Measured in glasses per day, not reflective or normal black tea consumption Potentially poor compliance
Steptoe *et al.*, 2007 [62], UK	RCT	Healthy men (18 – 55 yrs) - n = 37 - 12 weeks	4-week washout where caffeinated beverages were excluded except placebo caffeinate tea	Monocyte-platelet aggregates ↓ Plasma CRP ↓	Small sample size Short study duration
Widlansky *et al.*, 2005 [54], USA	RCT	Adults - n = 66 - 4 weeks	2 cups; 450 ml of black tea (acute) 3 - 4 cups - 900 ml of black tea per day (chronic),	Changes in catechin levels did not correlate with changes CRP	Short study duration

Key: BTE, black tea extract; CRP, c-reactive protein; DB, double-blind; DOMS, delayed onset muscle soreness; hs-CRP, high-sensitivity c-reactive protein; IL-17, interleukin-17; MMP-3, Matrix Metalloproteinase-3; NFκB, Nuclear Factor kapper-light-chain-enhancer of activated B cells; NK, natural killer; PC, placebo-controlled; RCT, randomised controlled trial; SB, single-blind; SSC, Stachys schtschegleevii; TB, triple blind; T2DM, type 2 diabetes mellitus. Note: $CD3^+$ $CD4^+$ IFN-γ^+ are Th1 cells, a subset of T-helper cells.

Five studies [54] [56] [59]-[61] recruited adults with either type 2 diabetes mellitus or cardiovascular risk factors as baseline. Mahmoud *et al.* (2016) [59] and Neyestani *et al.* (2010) [56] both recruited adults with T2DM at the study start. Mahmoud *et al.* (2016) allocated adults (n = 38) to consumed either 200 ml (1 cup) or 600 ml (3 cups) black tea over a 12-week period finding that tea drinkers had more T cells, IL-10 cells (an anti-inflammatory signal) and produced fewer IL-17 and IFN-γ cells which tend to drive inflammation [59]. Neyestani *et al.* (2010) allocated patients with T2DM to different levels of black tea intake finding that 2 cups of black tea (extract dissolved in water) showed a suppressing effect on serum malondialdehyde (a marker of oxidative stress) [56]. Serum C-reactive protein levels significantly decreased, and glutathione levels increased following the intake of 4 cups (600 ml) of black tea extract daily [56].

Mukamal *et al.* (2007) recruited allocated 28 adults (55 years+) with diabetes or two or more cardiovascular risk factors at baseline and allocated them to drink 3 glasses of black tea (extract, dissolved in water), or water daily for 6 months, but no differences in inflammatory markers were observed [61]. A large randomized controlled study [60] (n = 232) with Mauritian adults susceptible to ischemic heart diseases allocated to 9 g/day of black tea leaves (equivalent to three cups and 738 mg polyphenols) for 12 weeks observed reductions in CRP levels. Another trial consisting of 66 adults with coronary heart disease and providing 450 ml or 900 ml black tea daily over 4 weeks found that catechin levels did not correlate with CRP or plasma markers of oxidative stress indicating that it could be other polyphenolic and flavonoid components in tea that responsible for anti-inflammatory effects [54].

In relation to other health conditions Henning *et al.* (2015) allocated men (n = 93) diagnosed with prostate cancer to six cups of black tea daily, green tea or a water control finding that black tea did not affect NFkB—a key inflammatory marker [53]. Arent *et al.* (2010) [52] provided male collegiate students (n = 18) with black tea extract (1760 mg/day) or a placebo for 9 days finding that whilst IL-6 response was unaffected levels of oxidative stress were reduced and rates of exercise recovery improved. Another study [55] combining 2.4 g/d black tea with the medicinal plant Stachys schtschegleevii (a medicinal plant from the mint family (Lamiaceae)) significantly reduced high-sensitivity CRP and IL-1β levels, although black tea alone did not lead to significant reductions in these markers.

In summary, in healthy adults, regular black tea intake reduced markers of inflammation such as CRP and appeared to support immune regulation, possibly via gut microbiota changes [57] [58] [62]. In people with type 2 diabetes or cardiovascular risk, black tea at times improved inflammatory and oxidative stress markers (e.g., increased IL-10, reduced IL-17, CRP, and malondialdehyde), although not all trials showed reported benefits [56] [59]-[61]. In contrast, in men with prostate cancer, black tea did not alter key inflammatory markers (NF-κB), potentially reflecting differences in underlying inflammatory pathways, disease-driven immune dysregulation, or limited study duration and statistical power. Among athletes, black tea extract reduced oxidative stress and improved recovery without altering IL-6 [52]. Overall, the evidence suggests that black tea may exert anti-inflammatory and antioxidant effects, particularly in metabolic risk populations, with variability likely driven by population-specific biology and study design factors.

4.3. Potential Mechanisms of Action

Tea polyphenols are proposed to exert anti-inflammatory effects via several pathways including: 1) acting as antioxidants and inducing the endogenous antioxidant defence system, 2) regulating and inhibiting major inflammatory signalling pathways such as NF-κB, activator protein-1 and 3) reinforcing gut barrier integrity and improving microbiota balance, which may benefit inflammatory bowel conditions [63]. Regarding flavonoids the presence of a C2-C3 double bond (C-ring) and hydroxyl groups at the C3', C4', C5, and C7 positions of both rings A and B of a flavonoid skeleton are thought to underpin its potential anti-inflammatory effects [64]. Research shows that such flavonoids activate antioxidant pathways that can exert anti-inflammatory effects [65]. In black tea catechins when oxidised to theaflavins and thearubigins can also induce their anti-inflammatory effects by operating at the gut level with their fermentation improving the profile of gut microbiota [66].

In black tea, theaflavins represent one of the principle bioactive groups of compounds [67]. Experimental studies show that black tea polyphenol extracts, including theaflavins show anti-inflammatory effects in murine models of high-fat, high-sugar (obesogenic diets) [68]. Theaflavin-2 has been found to exhibit anti-

inflammatory effects in two murine models of inflammation [69]. Matrix metalloproteinase (MMP) are a group of enzymes that break down extracellular matrix proteins and are upregulated during certain inflammatory diseases such as rheumatoid arthritis, osteoarthritis, inflammatory bowel disease and Alzheimer's disease, with polyphenols thought to suppress MMP gene expression and enzyme activity inducing anti-inflammatory effects [70]. Theaflavin-3,3'-digallate, in particular, could help to protect cartilage and prevent osteoarthritis, by inhibiting proinflammatory factors, scavenging reactive oxygen species and suppressing pathways that delay inflammatory processes [71]. In dental models black tea theaflavin mixtures have been found to reduce the secretion of key inflammatory mediators, including IL-1β, IL-6, IL-8 and TNF-α secretion [72]. Inhibition of interleukin-8 expression has also been reported, further supporting an anti-inflammatory role for theaflavin [73].

5. Discussion

Diet is increasingly being recognised as a modifiable determinant of systemic inflammation, with tea representing a widely consumed source of bioactive compounds [74]. This review highlights that black tea, rich in flavan-3-ols e.g. theaflavins, thearubigins and other polyphenols, demonstrates meaningful anti-inflammatory and antioxidant effects across diverse populations [25] [27] [73]. Theaflavins, in particular, appears to be one of the predominant bioactives in black tea that exerts anti-inflammatory effects via a range of mechanisms, including attenuating oxidative stress and modulating levels of inflammatory markers [71] [72].

Meta-analytical and RCT evidence suggests that black tea consumption can reduce inflammatory biomarkers such as CRP, IL-6 and malondialdehyde, particularly in individuals with baseline metabolic risk, including type 2 diabetes and cardiovascular disease [41] [45] [48] [56] [59] [60]. Evidence also supports possible benefits in upper respiratory tract inflammation [75], likely mediated by gut microbiota modulation [57] and potential benefits for inflammatory bowel diseases [42] [46]. In contrast, trials in prostate cancer populations reported no significant effects on NF-κB activity, highlighting that benefits may be condition-specific [53].

The apparent anti-inflammatory benefits of black tea are more consistent in metabolic conditions, suggesting a greater effect where systemic inflammation is already elevated. However, inconsistencies across studies limit the ability to draw firm conclusions. In most studies intake levels of 3 - 4 cups/glasses of black tea were administered [54] [57]-[61], although Henning *et al.* (2015) administered 6 cups of brewed black tea daily [53]. Variability in dose, study duration, tea preparation, and small sample sizes all contribute to heterogeneous findings. Few recent trials have directly compared black tea to other tea types, which would help clarify whether observed effects are unique to black tea or reflect tea polyphenols more broadly.

Given its low cost, wide availability and cultural acceptance, black tea could

represent a simple adjunct to dietary strategies for reducing systemic inflammation, particularly in populations at risk of type 2 diabetes, metabolic syndrome and cardiovascular disease. Future trials should employ standardised preparations and longer follow-up to better determine clinical significance. Regarding strengths and limitations future research should be undertaken using standardised tea preparations to enable transparent and objective cross-comparisons between studies [36]. The challenges of quantification of the thearubigins—an important class of black tea flavan-3-ols should also be addressed if the impacts of the key classes of black tea bioactives are to be fully understood. There is also a need to study tea consumption more widely in relation to a greater range of inflammatory conditions, such as asthma, multiple sclerosis, psoriasis, atopic dermatitis and inflammatory bowel conditions, to establish whether benefits can be more widely translated. More data focused on habitual tea intakes in relation to inflammatory health conditions is also needed.

Overall, it should be recognised that different tea preparations and storage conditions may contribute to different bioactive profiles [22]. Including black tea within the diet may help to provide some of these bioactive components, with studies focusing on habitual intakes pointing towards 3 - 4 cups daily [57]-[60] being most useful. It should be recognised that individuals already with baseline levels of systemic inflammation e.g. type 2 diabetes [56] [59] or susceptible to ischemic heart disease [60] may benefit most from drinking black tea. Black tea can be viewed as an inexpensive and useful complementary or adjunctive food from a health perspective [76] [77], with potential for greater inclusion in dietary, policy, and health-related guidelines. However, interpretation of the existing evidence is complicated by common confounding factors that were often insufficiently controlled for in the reviewed studies, including the addition of for example sugar, or lemon, which may modify polyphenol bioavailability and metabolic responses and contribute to variability in observed outcomes.

6. Conclusion

In conclusion, habitual black tea consumption, typically around 3 - 4 cups daily, may confer anti-inflammatory and antioxidant effects, particularly in those with elevated baseline inflammation. Black tea (with or without milk) contains a wide array of bioactive compounds, including polyphenols such as the flavan-3-ols theaflavins, thearubigins, catechins, flavonols, l-theanine, and caffeine. Many of these constituents have demonstrated anti-inflammatory properties both individually and synergistically. The combined action of these compounds may contribute to the modulation of inflammatory pathways and oxidative stress, offering potential benefits in the prevention or management of chronic diseases linked to inflammation. However, despite these promising findings, greater standardisation of intervention protocols—such as dosage, duration, and tea composition—as well as the inclusion of more diverse clinical population groups, will be critical. These steps are essential to strengthen the evidence-base and more clearly deter-

mine the role of black tea as part of dietary recommendations and future public health strategies aimed at improving public health and wellbeing.

Disclosure

The time spent writing this publication was provided by the Tea Advisory Panel (www. teaadvisorypanel.com) which is supported by a restricted educational grant from the UK TEA & INFUSIONS ASSOCIATION (UKTIA), the trade association for the UK tea industry. UKTIA plays no role in producing the outputs of the panel. Independent panel members include nutritionists, biochemists, medical herbalists, dietitians, dentists, and doctors.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

Conflicts of Interest

The authors declare no conflicts of interest.

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List of Abbreviations

CRP	C-reactive protein
CXCL8	C-X-C motif chemokine ligand 8 (IL-8)
EGCG	Epigallocatechin-3-gallate
FMD	Flow-mediated dilation
GPX	Glutathione peroxidase
HS	Hibiscus sabdariffa
hs CRP	High sensitivity C-reactive protein
IL-1	Interleukin 1
IL-1β	Interleukin-1 beta
IL-6	Interleukin-6
MA	Meta-analysis
MAPK	Mitogen-activated protein kinase
MDA	Malondialdehyde
MMP	Matrix metalloproteinase
NFκB	Nuclear Factor kapper-light-chain enhancer of activated B cells
NO	Nitric oxide
MetS	Metabolic Syndrome
RCT	Randomised controlled trial
ROS	Reactive oxygen species
SOD	Superoxide dismutase
SR	Systematic review
SSC	Stachys schtschegleevii
T2DM	Type 2 Diabetes Mellitus
TAC	Total antioxidant capacity
TFs	Theaflavins
TNF-α	Tumour necrosis factor-alpha