integrity Research Journals

**Journal of Bioscience and Biotechnology Discovery**
Volume 10(5), pages 102-111, December 2025
Article Number: BE4444331
ISSN: 2536-7064
https://doi.org/10.31248/JBBD2025.243
https://integrityresjournals.org/journal/JBBD

*Review Article*

# Lycopene and health: From antioxidant properties to disease prevention

**Muhammad Salihu Ibrahim[1]*, Rumanatu Ibrahim Baba[2], Maryam Habeeb Muhammad[3], Abubakar Usman Zage[1] and Mas'ud Abubakar[4]**

[1]Department of Pharmaceutical Technology, School of Science and Technology, Federal Polytechnic Kabo, Kano, Nigeria.
[2]Kano State Primary Health Care Management Board, Kano Nigeria.
[3]Department of Pharmaceutical Technology, School of Science and Technology, Kano State Polytechnic, Kano, Nigeria.
[4]Department of Animal Health and Production Technology, School of Science and Technology, Federal Polytechnic, Kabo, Nigeria.

*Corresponding author. Email: muhammadsalihu@fedpolykabo.edu.ng



Received 14th November 2025; Accepted 15th December 2025

**ABSTRACT:** Lycopene, a non-provitamin A carotenoid predominantly found in tomatoes and other red fruits, has emerged as a bioactive compound of considerable interest due to its potent antioxidant and anti-inflammatory properties. Recognized as one of the most effective singlet oxygen quenchers among dietary carotenoids, lycopene plays a central role in mitigating oxidative stress and preserving cellular integrity. A growing body of experimental and epidemiological evidence suggests that lycopene intake is inversely associated with the risk of several chronic diseases, including cardiovascular disorders, certain cancers, metabolic syndromes, and neurodegenerative conditions. These protective effects are primarily attributed to lycopene's ability to neutralize reactive oxygen species, modulate inflammatory mediators, regulate gene expression, and enhance intercellular communication. Additionally, factors such as dietary composition, food processing, and individual metabolic variations significantly influence lycopene's bioavailability and physiological efficacy. This review synthesizes current findings on the mechanistic pathways through which lycopene exerts its health-promoting effects, emphasizing its antioxidant and anti-inflammatory roles as pivotal mechanisms in disease prevention. Understanding these molecular interactions not only strengthens the evidence for lycopene's functional relevance in human health but also underscores its potential application in nutrition-based therapeutic strategies aimed at reducing the global burden of chronic diseases.

**Keywords:** Antioxidant, carotenoids, chronic disease prevention, human health, lycopene, oxidative stress.

## INTRODUCTION

Lycopene ($C_{40}H_{56}$) is an acyclic carotenoid found abundantly in red-colored fruits and vegetables such as tomatoes, watermelon, and pink grapefruit (Ibrahim *et al*. 2017; Ibrahim *et al*. 2025). Unlike β-carotene, lycopene does not exhibit provitamin A activity but has been widely recognised for its exceptional antioxidant capacity. However, it possesses superior antioxidant capacity, positioning it as a compound of significant biological relevance in human nutrition and disease prevention (Tufail *et al*., 2024).

Over the past decades, substantial research has highlighted the protective role of lycopene against oxidative stress–related chronic diseases, including cardiovascular disease, cancer, diabetes, and neurodegenerative disorders (Przybylska, 2020).

Reactive oxygen species (ROS) and oxidative stress play pivotal roles in the initiation and progression of numerous chronic diseases, including cardiovascular disorders, cancer, neurodegenerative diseases, and metabolic dysfunctions. The imbalance between the generation of ROS and the antioxidant defence system leads to oxidative damage of cellular lipids, proteins, and nucleic acids, ultimately impairing cellular function and promoting pathological processes (Jomova *et al*., 2023). In recent years, growing attention has been directed toward naturally occurring antioxidants as potential modulators of redox homeostasis and inflammation. Among these, lycopene, a bright red carotenoid, has emerged as one of the most potent dietary antioxidants (Shafe *et al*., 2024).

Chemically, lycopene is an acyclic, open-chain carotenoid composed of 11 conjugated and two non-conjugated double bonds, a structure that underlies its remarkable singlet oxygen–quenching and free radical–scavenging capabilities. Its antioxidant activity is reported to be superior to that of other carotenoids, such as β-carotene and lutein (Tufail et.al, 2024). Beyond its direct antioxidant effects, lycopene exhibits a broad spectrum of biological activities, including modulation of intracellular signalling pathways, gene expression, and enzyme activities involved in oxidative stress and inflammation. It has been shown to regulate the nuclear factor erythroid 2–related factor 2 (Nrf2) pathway, enhancing endogenous antioxidant defences, while concurrently inhibiting the nuclear factor kappa B (NF-κB) pathway, thereby reducing pro-inflammatory cytokine production (Khan *et al*., 2021).

Epidemiological and experimental studies consistently demonstrate that higher dietary intake or plasma concentrations of lycopene are inversely associated with the risk of several chronic diseases. In cardiovascular health, lycopene has been shown to reduce low-density lipoprotein (LDL) oxidation, improve endothelial function, and lower blood pressure. In oncology, lycopene exhibits antiproliferative and pro-apoptotic effects in various cancer cell lines and animal models, with notable evidence in prostate, breast, and gastric cancers (Maaz *et al*. 2025). Moreover, in neurodegenerative and metabolic disorders, lycopene contributes to the attenuation of oxidative stress–induced neuronal damage, modulation of glucose and lipid metabolism, and protection of mitochondrial integrity (Cai *et al*., 2023). These findings collectively highlight lycopene's potential as a multifunctional bioactive compound that bridges the gap between nutrition and disease prevention.

Despite these promising findings, lycopene's health benefits are influenced by factors such as bioavailability, isomeric form, and dietary matrix. Lycopene is more efficiently absorbed from processed tomato products than from raw fruits, and its uptake is enhanced in the presence of dietary lipids due to its lipophilic nature (Arballo *et al*. 2021). Understanding the relationship between lycopene's biochemical properties, absorption kinetics, and its biological effects is essential for optimising its preventive and therapeutic applications. In light of its potent antioxidant properties and wide-ranging physiological effects, lycopene represents a promising dietary component for the prevention and mitigation of oxidative stress–related diseases (Bin-Jumah *et al*., 2022). Given the growing scientific interest in functional foods and nutraceuticals, lycopene has attracted attention not only as a dietary antioxidant but also as a potential preventive and therapeutic agent against oxidative stress–related diseases.

This review aims to examine the current state of knowledge on lycopene, emphasising its antioxidant and anti-inflammatory mechanisms, and to elucidate how these properties contribute to the prevention of major chronic diseases. By integrating findings from cellular, animal, and human studies, this paper seeks to provide a mechanistic understanding of lycopene's health-promoting potential and highlight directions for future research and clinical application.

## LYCOPENE BIOAVAILABILITY AND METABOLISM

Lycopene's absorption is influenced by dietary fat, food matrix, and isomeric configuration. In raw tomatoes, lycopene exists mainly in the all-trans form, which is less bioavailable than the cis isomers formed during heat processing (Moran *et al*. 2015; Honda *et al*., 2017). Cooking, blending, and consuming lycopene with fat-rich foods significantly increase its absorption (Arballo *et al*., 2021). After intestinal absorption, lycopene is incorporated into chylomicrons and distributed via the lymphatic system. It accumulates in lipid-rich tissues such as the liver, prostate, and adrenal glands. Lycopene metabolites, known as lycopenoids, may also contribute to its biological functions through modulation of gene expression and antioxidant activity (Grabowska *et al*., 2019).

## LYCOPENE CHEMICAL STRUCTURE AND ANTIOXIDANT MECHANISMS

Lycopene is composed of 11 conjugated and 2 nonconjugated double bonds, responsible for both its deep red colour and its ability to neutralise ROS (Honda *et al*., 2017; Sen, 2019). Lycopene's primary and most recognised mechanism of action is its role as a powerful antioxidant. It efficiently scavenges ROS and is particularly effective at quenching singlet oxygen (Shafe *et al*., 2024). This potent antioxidant activity is crucial for protecting cells from oxidative damage, a fundamental factor in the initiation and progression of numerous chronic diseases, including cardiovascular diseases, various cancers, and neurodegenerative disorders (Przybylska and Tokarczyk, 2022).

Its chemical structure, characterised by an extended conjugated polyene chain, enables it to donate electrons to free radicals, thereby neutralising them, halting propagative chain reactions, and preventing oxidative damage to vital biomolecules such as lipids, proteins, and DNA. It reacts directly with peroxyl radicals, terminating lipid peroxidation chain reactions (Müller *et al*., 2016).

Lycopene is considered one of the most effective singlet oxygen quenchers among dietary carotenoids, demonstrating superior efficacy compared to β-carotene (twice as effective) and α-tocopherol (up to 10 times more effective). Its lipophilic nature allows it to preferentially accumulate in cellular membranes and lipoproteins, where it can exert a more pronounced protective effect against lipid peroxidation and oxidative stress in these critical cellular components (Tufail *et al*., 2024). Beyond direct free radical neutralization, lycopene can also indirectly enhance the body's antioxidant defenses by activating other endogenous mechanisms that increase overall antioxidant potential such as Redox modulation, where Lycopene was found to upregulates endogenous antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GRx) and glutathione peroxidase (GPx), enhancing the body’s oxidative defense (Chen *et al*., 2022).

## LYCOPENE AND OXIDATIVE STRESS

Oxidative stress is a key factor in the aetiology of chronic diseases. Lycopene effectively reduces ROS levels, lipid peroxidation, and oxidative DNA damage (Jomova *et al*., 2024). Experimental models demonstrate that lycopene supplementation decreases malondialdehyde (a marker of oxidative stress) levels and enhances total antioxidant capacity. Lycopene combats oxidative stress both directly by neutralising free radicals and indirectly by activating cellular antioxidant systems, such as the antioxidant enzyme expression like SOD, CAT, GPx and downregulates pro-oxidant enzymes like NADPH oxidase. This dual action helps protect lipids, proteins, DNA, and mitochondria, making lycopene a key dietary molecule for reducing oxidative damage in tissues like the brain, heart, and liver (Ismail *et al*., 2023). Furthermore, lycopene downregulates pro-inflammatory pathways, particularly the NF-κB signalling cascade, resulting in reduced secretion of cytokines such as TNF-α (tumour necrosis factor α), IL-1β (, interleukin-1 β), and IL-6 (interleukin-6) (Chen *et al*., 2022). These combined antioxidant and anti-inflammatory actions underlie many of lycopene’s protective effects.

Oxidative stress and inflammation are closely interdependent biological processes, with each capable of amplifying the other. Lycopene’s dual ability to reduce oxidative load and suppress inflammatory signalling provides a synergistic protective effect. By limiting ROS accumulation, lycopene indirectly prevents the activation of redox-sensitive inflammatory pathways, while its suppression of pro-inflammatory mediators further reduces oxidative stimuli. This integrated mechanism contributes to maintaining redox balance and preventing the onset or progression of oxidative stress–related pathologies.

## LYCOPENE AND HEALTH EFFECT

### Anti-inflammatory effects

In addition to its antioxidant capabilities, lycopene exhibits significant anti-inflammatory effects by actively modulating inflammatory responses. This involves inhibiting the release of key pro-inflammatory cytokines, such as TNF-α and IL-6, while also promoting negative feedback mechanisms that suppress chronic inflammation. This anti-inflammatory action plays a vital role in mitigating conditions like cardiovascular disease, where lycopene contributes to improved vascular function and a reduction in oxidative stress-induced inflammation (Cha *et al*., 2017; Van Steenwijk *et al*., 2020). Specifically, by lowering TNF-α levels, lycopene helps to reduce chronic inflammation and associated risks, including endothelial dysfunction and atherosclerosis. Research indicates that the anti-inflammatory activity of lycopene, particularly when combined with Vitamin E, can be comparable to, and in some instances superior to, the effects of individual compounds, demonstrating a clear dose-dependent response (Hazewindus *et al*., 2012; Fararh *et al*., 2019).

The consistent description of lycopene as both a "potent antioxidant" and possessing "anti-inflammatory effects" in the scientific literature points to a deeper relationship between these two mechanisms. Oxidative stress is a known trigger for inflammatory pathways, and conversely, chronic inflammation can generate further ROS, creating a self-perpetuating cycle. Lycopene's broad spectrum of health benefits is not merely a sum of isolated antioxidant or anti-inflammatory actions. Instead, it arises from a synergistic interplay where lycopene simultaneously addresses both oxidative damage and inflammatory responses (Karaköy *et al*., 2022). By tackling these two fundamentals and interconnected pathological processes, lycopene provides a more comprehensive and robust protective effect against the complex aetiology of chronic diseases. This dual, often intertwined, action makes it particularly effective in conditions where both oxidative stress and chronic inflammation are central to disease pathogenesis. This reinforces the concept of pleiotropic effects in natural compounds, where a single molecule can influence multiple biological pathways, suggesting that nutritional strategies incorporating such compounds may offer more effective and holistic disease prevention.

## Cardiovascular Health

Lycopene demonstrates significant potential in managing key cardiovascular risk factors, contributing to improved heart and vascular function. A growing body of evidence links higher plasma lycopene concentrations with reduced cardiovascular risk (Mozos *et al*., 2018). Lycopene lowers LDL oxidation, improves endothelial function, and reduces arterial stiffness (Joung *et al*., 2023). Clinical trials have demonstrated that lycopene supplementation can decrease systolic blood pressure and improve lipid profiles (He *et al*., 2015). Its cardioprotective effects are attributed to decreased oxidative modification of LDL cholesterol and improved vascular reactivity (Joung *et al*., 2023).

### *Impact on blood pressure and lipid profiles*

Lycopene exhibits significant reductions in blood pressure, particularly beneficial for hypertensive individuals. Systematic reviews and meta-analyses support lycopene's role in decreasing systolic blood pressure in both healthy individuals and those with hypertension (Mirahmadi *et al*., 2023). Clinical studies have observed substantial improvements in systolic blood pressure at lycopene doses of 15 mg or higher. For instance, one study noted a decrease in systolic blood pressure by 11.8 mmHg and diastolic blood pressure by 6.9 mmHg in a watermelon group (Przybylska and Tokarczyk, 2022). Favourable alterations in lipid profiles have been consistently reported, including reductions in total cholesterol (TC), triglycerides (TG), and low-density lipoprotein cholesterol (LDL-c), alongside increases in high-density lipoprotein cholesterol (HDL-c). One study specifically noted significant reductions in TC and LDL-c, with a mean decrease in TG by 38.05 mg/dL, using 1.44 mg of lycopene from watermelon extract over 6 weeks in patients with metabolic syndrome. Another study observed a significant increase in HDL with dietary lycopene intake (Joung *et al*. 2023). Lycopene is considered a valuable component for its role in reducing levels of TG, TC, and LDL (Mirahmadi *et al*., 2023).

### *Anti-atherosclerotic effects*

Lycopene positively impacts cardiovascular health, with a particular focus on its anti-atherosclerotic properties (Montesano *et al*., 2019). Atherosclerosis, characterized by persistent inflammation and oxidative stress, is a leading cause of cardiovascular morbidity and mortality. Its anti-atherosclerotic effects are attributed to its ability to improve lipid profiles, reduce arterial stiffness, and lower the levels of pro-inflammatory cytokines (Rejali *et al*., 2022).

Lycopene contributes to decreasing hypercholesterolemia by influencing liver gene expression, specifically PCSK-9 (pro-protein convertase subtilisin/kexin 9) and HMGR (HMG-CoA reductase), which enhances LDL-receptor activity and consequently facilitates the removal of LDL-C from the bloodstream (Yanai, 2017; Mozos *et al*., 2018). As a potent antioxidant, lycopene neutralises ROS and lipid peroxyl radicals, which are key contributors to oxidative stress and endothelial dysfunction, critical factors in atherosclerosis progression. Its anti-inflammatory actions reduce the levels of pro-inflammatory cytokines such as IL-1β, IL-6, and TNF-α, all of which are implicated in the development and progression of atherosclerotic plaques. Lycopene also improves vascular function by increasing the activity of antioxidant enzymes like CAT and SOD, blocking angiotensin-converting enzyme, and enhancing nitric oxide production, all contributing to better vascular health (Hsieh *et al*., 2022).

### *Cancer risk and mortality*

Dietary intake of tomatoes and tomato products rich in lycopene has been consistently associated with a decreased risk of various chronic diseases, including cancer (Xu *et al*., 2021). Higher consumption and elevated blood levels of lycopene are associated with a 5-11% relative reduction in overall cancer risk (Balali *et al*., 2025). Furthermore, higher blood lycopene concentrations are linked to an 11-24% reduction in cancer-related mortality. Dose-response analyses suggest that a beneficial range for dietary lycopene intake for cancer risk reduction is approximately 5-7 mg/day, with analyses indicating no additional reductions in cancer risk observed when intake exceeded 10 mg/day. While high tomato consumption alone did not significantly alter overall cancer risk, it was associated with an 11% lower risk of cancer-related mortality (Balali *et al*., 2025). This observation suggests that there is an optimal dosage range for achieving specific health benefits from lycopene, and critically, a saturation or threshold point beyond which additional intake yields diminishing returns or no further observable benefit. This indicates a physiological limit to how much benefit can be derived from increasing lycopene consumption. This is vital information for guiding both supplement recommendations and public health dietary guidelines, implying that advocating for excessively high doses might be unnecessary and economically inefficient.

### *Cancer prevention*

Lycopene has garnered significant attention for its potential role in cancer prevention and management, with evidence suggesting protective effects across various cancer types (Di Sano *et al*., 2022). Epidemiological studies consistently report an inverse relationship between lycopene intake and the incidence of certain cancers, notably prostate, lung, and stomach cancers (Song *et al*., 2021; Maaz *et al*., 2025). Lycopene influences cancer biology through multiple pathways: inhibition of insulin-like growth factor-1 (IGF-1) signalling, modulation of apoptosis and cell-cycle arrest, and suppression of oxidative DNA damage (Ozkan *et al*., 2023).

Serum and tissue lycopene levels have been inversely correlated with the incidence of several specific cancer types, including breast cancer and prostate cancer (Kapała *et al*., 2022). Lung cancer has shown the most robust response to lycopene, with higher blood lycopene levels associated with a significant 35% lower lung cancer mortality risk (Balali *et al*., 2025). Experimental studies demonstrate that lycopene can inhibit lung cancer cell growth and prevent tumorigenesis through multiple mechanisms (Cheng *et al*., 2020). These include modulating cellular redox status, inducing cell cycle arrest and apoptosis, regulating growth factor signalling (e.g., the IGF-1 pathway), and inhibiting cell invasion, angiogenesis (new blood vessel formation), and metastasis (cancer spread). Importantly, lycopene metabolites, such as apo-10′-lycopenoic acid, may also contribute to these protective effects. Lycopene intake has been associated with lower risks of breast cancer (Yin *et al*., 2025).

The evidence for a direct reduction in prostate cancer risk solely from dietary lycopene intake is less clear and requires more targeted studies. However, some meta-analyses suggest a linear inverse association between dietary lycopene intake and prostate cancer risk (Graff *et al*., 2016). Lycopene tends to accumulate significantly in the prostate gland, with over 80% of the lycopene in this tissue being in the cis-isomer form. The prostate gland's preferential accumulation of lycopene underscores its role in prostate cancer prevention (Mirahmadi *et al*., 2020).

The extensive list of health benefits across diverse physiological systems (cardiovascular, cancer, eye, skin, male fertility, bone, metabolic syndrome) is striking. A consistent theme across the available data is the role of oxidative stress and inflammation as underlying pathological drivers for these varied conditions (Rejali *et al*. 2022). Lycopene's fundamental antioxidant and anti-inflammatory properties are repeatedly cited as the mechanistic basis for its effects in each of these areas. This suggests that lycopene should not be viewed as a specific treatment for a single disease but rather as a broad-spectrum protective agent. Its efficacy stems from its ability to address fundamental cellular damage pathways—oxidative stress and inflammation—which are common denominators in the pathogenesis of many chronic, age-related diseases. This supports a preventative and supportive role across the human lifespan, rather than a targeted therapeutic intervention for an established condition, by enhancing the body's intrinsic resilience against cellular insults.

### Metabolic syndrome and related conditions

In metabolic syndrome and diabetes, lycopene improves insulin sensitivity and reduces adipose inflammation by modulating oxidative and inflammatory pathways. Animal studies indicate that lycopene mitigates hepatic steatosis and oxidative stress in nonalcoholic fatty liver disease (NAFLD) models (Chen *et al*., 2022). Lycopene has shown promising potential in the management of metabolic syndrome (MetS) and its associated pathologies (Mirahmadi *et al*., 2023). Lower serum lycopene levels have been significantly associated with an increased risk of NAFLD (Viña *et al*., 2025). Clinical trials involving patients with MetS have reported significant improvements in several metabolic markers, including systolic blood pressure, fasting blood glucose, LDL, TC, and TG in lycopene-supplemented groups. Some studies have also observed a significant increase in serum HDL levels in patients with MetS following lycopene supplementation (Mirahmadi *et al*., 2023).

While observational studies suggest an inverse association between circulating lycopene levels and the risk of metabolic disorders, the overall evidence remains somewhat fragmented due to inconsistencies in study design, diverse population characteristics, varied supplementation protocols, and differing outcome measures (Viña *et al*., 2025). Interestingly, the beneficial effects of lycopene on metabolic syndrome appear to be more pronounced in normal-weight and overweight individuals, but not statistically significant for obese participants. This difference may be attributed to the heightened state of inflammation and oxidative stress typically observed in obesity, which might overwhelm lycopene's protective capacity (Han *et al*., 2016). This finding highlights the growing importance of personalized nutrition, suggesting that a "one-size-fits-all" approach to lycopene supplementation for metabolic health might not be effective across all BMI (body mass index) categories. For obese individuals, lycopene might need to be part of a broader, more aggressive, and multifaceted intervention strategy to address the underlying severe inflammation and oxidative stress, or its efficacy is simply limited in the context of advanced metabolic dysregulation.

### Eye health

Lycopene, similar to other carotenoids like lutein and zeaxanthin, may contribute to eye health by reducing the risk of age-related macular degeneration (AMD) and cataracts in later life (Jiang *et al*., 2019). Its powerful antioxidant properties are crucial in protecting ocular tissues from oxidative stress, a known contributing factor in the pathogenesis of various eye diseases (Böhm *et al*., 2023). Lycopene offers a degree of UV protection (estimated at approximately SPF-3) by counteracting the oxidative stress induced by damaging UV light, which can harm the retina and increase the risk of AMD. Lycopene contributes to retinal protection by reducing photooxidative stress and maintaining macular pigment density (Alabdulmunem, 2022).

## Skin health

Lycopene protects against UV-induced skin damage and erythema by scavenging photoinduced free radicals. It enhances collagen synthesis and skin elasticity. Lycopene's potent antioxidant action provides a level of intrinsic UV protection for the skin, although it is not sufficient as a standalone sun protection measure. It actively protects the skin against oxidative stress triggered by UV radiation, which is a primary cause of cellular damage. Studies have shown that topical application of lycopene offers significant protection to cellular DNA from UV radiation, helping to stabilise DNA structure and reduce the need for the body's internal DNA repair pathways (Zhang *et al*., 2024). Furthermore, lycopene has been found to reverse the UVB-induced depletion of essential substances vital for DNA synthesis and cellular repair in the skin. By inhibiting cellular damage, lycopene may help reduce inflammation, promote new cell renewal, and strengthen the skin by preventing the destruction of collagen fibres, thereby contributing to its anti-ageing effects (Petyaev *et al*., 2019).

## Neuroprotective effect

Neurodegenerative diseases such as Alzheimer’s and Parkinson’s are characterised by oxidative and inflammatory damage. Lycopene’s neuroprotective mechanisms include inhibition of microglial activation, reduction of amyloid-beta accumulation, and preservation of mitochondrial integrity (Guo *et al*., 2023).

Lycopene is a potent scavenger of ROS and reactive nitrogen species (RNS) (Shafe *et al*., 2024). Oxidative stress contributes to neuronal damage in diseases such as Alzheimer’s disease, Parkinson’s disease, and ischemic stroke (Wu *et al*., 2022; El-Kazaz *et al*., 2025). Lycopene protects neuronal lipids, proteins, and DNA from oxidative damage, helping maintain mitochondrial function and cell viability. Lycopene reduces the expression of pro-inflammatory cytokines (e.g., TNF-α, IL-1β, IL-6) and inhibits NF-κB signaling a central pathway in neuroinflammation (Guo *et al*., 2023). It downregulates microglial activation, which helps prevent chronic neuroinflammation associated with neurodegenerative disorders. Lycopene helps maintain mitochondrial membrane potential, reducing cytochrome c release and caspase activation (key steps in apoptosis). It modulates the Bcl-2/Bax ratio, promoting cell survival (Sadek *et al*., 2016). Bcl is anti-apoptotic, while Bax is pro-apoptotic. Bcl-2 helps maintain mitochondrial membrane integrity and inhibits the release of pro-death molecules (like cytochrome c) while Bax promotes apoptosis by forming pores in the mitochondrial membrane, causing cytochrome c release, leading to caspase activation and eventually cell death (Soleymaninejad *et al*., 2017). This contributes to the preservation of neuronal energy metabolism under stress conditions such as ischemia or toxin exposure. Lycopene can also reduce Aβ (amyloid-beta) accumulation and tau hyperphosphorylation in experimental models. Mechanisms may involve inhibition of oxidative stress–induced kinase activation and improvement of autophagy and proteasomal clearance (Guo *et al*., 2023).

In models of Parkinson’s disease (e.g., MPTP or rotenone-induced neurotoxicity), lycopene was found to preserve dopaminergic neurons in the substantia nigra, restore dopamine levels and reduce oxidative and inflammatory markers in brain tissue (Prema *et al*., 2015). Lycopene reduces infarct size and improves behavioural recovery in animal models of cerebral ischemia–reperfusion injury (Wu *et al*., 2022). These effects are mediated through reduced oxidative damage, inhibition of apoptosis, and improved cerebral blood flow.

Epidemiological studies suggest that higher dietary or plasma lycopene levels correlate with better cognitive performance and lower risk of dementia (Crowe-White *et al*., 2019). Human intervention trials are limited but indicate potential cognitive benefits and reduced markers of oxidative stress and inflammation (Wang *et al*., 2024). Preclinical studies demonstrate improved cognitive performance and reduced neuronal apoptosis with lycopene supplementation (Yu *et al*., 2017).

## Male fertility

Lycopene is being investigated as a promising potential treatment option for male infertility, particularly given its antioxidant properties that directly counteract oxidative stress (Türkler *et al*., 2020). Excessive ROS are a major cause of idiopathic male factor infertility, leading to oxidative stress that damages sperm membranes, DNA, and induces apoptosis, ultimately decreasing sperm viability and motility (Nouri *et al*., 2019; Babaei *et al*., 2022). Lycopene effectively reduces the incidence of oxidative stress, thereby mitigating the damage inflicted upon spermatozoa. Human clinical trials have reported notable improvements in various sperm parameters, including sperm count, concentration, motility, viability, and morphology, as well as increased pregnancy rates, with daily supplementation of 4-8 mg of lycopene for durations ranging from 3 to 12 months (Durairajanayagam *et al*., 2014). Beyond its oxidative mechanisms, proposed nonoxidative mechanisms in the testis include aiding in gap junction communication, modulation of gene expression, regulation of the cell cycle, and immunoenhancement (Yamamoto *et al*., 2017), though these require further dedicated research.

## Bone health

Lycopene has demonstrated a potential protective effect against bone loss, an issue particularly prevalent in postmenopausal women (Walallawita *et al*., 2020). Preclinical studies using osteoporotic mouse models have shown that lycopene supplementation (e.g., 50 mg/kg/day for 8 weeks) significantly preserved bone mass, substantially enhanced bone strength (evidenced by the ability of bones to withstand higher maximum loads), and improved overall bone density and microarchitecture. A key mechanism identified is lycopene's ability to target cellular senescence, a dysfunctional cellular state that contributes to tissue degeneration and ageing. Lycopene treatment significantly reduced the number of senescent cells in the bone tissue of osteoporotic mice. This reduction in senescent cells was accompanied by a decrease in the pro-inflammatory senescence-associated secretory phenotype (SASP) factor IL-6, which is known to exacerbate bone loss and fragility (Wang *et al*., 2023). Lycopene's effect on the skeletal organisation promotes better jaw mineralisation and guards against osteoporosis.

Advanced glycation end products (AGEs), predominantly generated under conditions of chronic hyperglycemia, play a pivotal role in promoting oxidative stress and disrupting normal bone remodelling. By engaging the receptor for AGEs (RAGE), these compounds stimulate osteoclastic bone resorption while suppressing osteoblastic bone formation. AGEs also compromise bone matrix integrity, leading to reduced bone quality and elevated fracture risk. Moreover, AGE accumulation enhances the generation of ROS, further intensifying oxidative stress through RAGE-dependent pathways. This signalling cascade activates NF-κB translocation and upregulates cathepsin K (CatK) expression, ultimately resulting in augmented bone resorption (Yamamoto and Sugimoto, 2016). However, emerging evidence indicates that lycopene may enhance bone quality through its potent antioxidant activity, potentially mediated by modulation of the AGE/RAGE/NF-κB signalling pathway in obese mice. These findings suggest that lycopene supplementation could represent a promising strategy for the prevention and management of obesity-induced osteoporosis (Xia *et al*., 2022).

## CONCLUSION

In conclusion, lycopene exerts a wide range of health-promoting effects that are primarily mediated through its potent antioxidant and anti-inflammatory properties. As a highly efficient scavenger of reactive oxygen species, lycopene mitigates oxidative stress, thereby protecting cellular structures, lipids, proteins, and DNA from oxidative damage. This antioxidative capacity plays a critical role in reducing the risk of chronic, non-communicable diseases, including cardiovascular diseases, various cancers, and neurodegenerative disorders. Moreover, lycopene's ability to modulate inflammatory pathways and downregulate pro-inflammatory cytokines contributes to its protective effects against inflammation-mediated tissue injury. The synergistic interaction of these mechanisms underscores lycopene's potential as a functional dietary compound with significant implications for disease prevention and health maintenance. Continued research is warranted to further elucidate its bioavailability, molecular targets, and clinical efficacy across diverse populations.

## CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

## REFERENCES

Alabdulmunem, M. A. (2022). Antioxidant effect of lycopene on retinal pigment epithelial cell line. *Medical Research Archives*, *10*(12), 1-7.

Arballo, J., Amengual, J., & Erdman Jr, J. W. (2021). Lycopene: A critical review of digestion, absorption, metabolism, and excretion. *Antioxidants*, *10*(3), 342.

Babaei, A., Asadpour, R., Mansouri, K., Sabrivand, A., & Kazemi-Darabadi, S. (2022). Lycopene improves testicular damage and sperm quality in experimentally induced varicocele: Relationship with apoptosis, hypoxia, and hyperthermia. *Food science & nutrition*, *10*(5), 1469-1480.

Balali, A., Fathzadeh, K., Askari, G., & Sadeghi, O. (2025). Dietary intake of tomato and lycopene, blood levels of lycopene, and risk of total and specific cancers in adults: a systematic review and dose–response meta-analysis of prospective cohort studies. *Frontiers in Nutrition*, *12*, 1516048.

Bin-Jumah, M. N., Nadeem, M. S., Gilani, S. J., Mubeen, B., Ullah, I., Alzarea, S. I., Ghoneim, M. M., Alshehri, S., Al-Abbasi, F. A., & Kazmi, I. (2022). Lycopene: A Natural Arsenal in the War against Oxidative Stress and Cardiovascular Diseases. *Antioxidants*, *11*(2), 232.

Böhm, E. W., Buonfiglio, F., Voigt, A. M., Bachmann, P., Safi, T., Pfeiffer, N., & Gericke, A. (2023). Oxidative stress in the eye and its role in the pathophysiology of ocular diseases. *Redox Biology*, *68*, 102967.

Cai, Z., Chen, F., Wang, Y., Wang, X., Yang, X., & Zhang, C. (2023). Lycopene Maintains Mitochondrial Homeostasis to Counteract the Enterotoxicity of Deoxynivalenol. *Antioxidants (Basel, Switzerland)*, *12*(11), 1958.

Cha, J. H., Kim, W. K., Ha, A. W., Kim, M. H., & Chang, M. J. (2017). Anti-inflammatory effect of lycopene in SW480 human colorectal cancer cells. *Nutrition research and practice*, *11*(2), 90-96.

Chen, J., Song, Y., Zhang, L., & Gao, Y. (2022). Lycopene in human health and disease prevention: Mechanisms and clinical evidence. Food Science and Human Wellness, 11(4), 853-868.

Cheng, J., Miller, B., Balbuena, E., & Eroglu, A. (2020). Lycopene protects against smoking-induced lung cancer by inducing base excision repair. *Antioxidants*, *9*(7), 643.

Crowe-White, K. M., Phillips, T. A., & Ellis, A. C. (2019). Lycopene and cognitive function. *Journal of Nutritional Science*, *8*, e20.

Di Sano, C., Lazzara, V., Durante, M., D'Anna, C., Bonura, A., Dino, P., Uasuf, C. G., Pace, E., Lenucci, M. S., & Bruno, A. (2022). The protective anticancer effect of natural lycopene supercritical $co_2$ watermelon extracts in adenocarcinoma lung cancer cells. *Antioxidants*, *11*(6), 1150.

Durairajanayagam, D., Agarwal, A., Ong, C., & Prashast, P. (2014). Lycopene and male infertility. *Asian journal of andrology*, *16*(3), 420-425.

El-Kazaz, S. E., Hafez, M. H., Noreldin, A. E., & Khafaga, A. F. (2025). Lycopene alleviates cognitive dysfunctions in an Alzheimer's disease rat model via suppressing the oxidative and neuroinflammatory signalling. *Tissue & Cell*, *96*, 102975.

Fararh, K. M., El-Aziz, A. M. A., & Alhelbawy, N. A. (2019). Anti-inflammatory, immunomodulatory and anti-oxidant effects of lycopene and vitamin e in e. coli infected broilers. *International Journal of Advanced Research*, *7*(7), 790-800.

Grabowska, M., Wawrzyniak, D., Rolle, K., Chomczyński, P., Oziewicz, S., Jurga, S., & Barciszewski, J., (2019). Let food be your medicine: nutraceutical properties of lycopene, *Food and Function*, *10*(6), 3090-3102.

Graff, R. E., Pettersson, A., Lis, R. T., Ahearn, T. U., Markt, S. C., Wilson, K. M., Rider, J. R., Fiorentino, M., Finn, S., Kenfield, S. A., Loda, M., Giovannucci, E. L., Rosner, B., & Mucci, L. A. (2016). Dietary lycopene intake and risk of prostate cancer defined by ERG protein expression. *The American journal of clinical nutrition*, *103*(3), 851-860.

Guo, Y., Fan, Z., Zhao, S., Yu, W., Hou, X., Nie, S., Xu, S., Zhao, C., Han, J., & Liu, X. (2023). Brain-targeted lycopene-loaded microemulsion modulates neuroinflammation, oxidative stress, apoptosis and synaptic plasticity in β-amyloid-induced Alzheimer's disease mice. *Neurological Research*, *45*(8), 753-764.

Han, G.-M., Soliman, G. A., Meza, J. L., Islam, K. M. M., & Watanabe-Galloway, S. (2016). The influence of BMI on the association between serum lycopene and the metabolic syndrome. *British Journal of Nutrition*, *115*(7), 1292-1300.

Hazewindus, M., Haenen, G. R., Weseler, A. R., & Bast, A. (2012). The anti-inflammatory effect of lycopene complements the antioxidant action of ascorbic acid and α-tocopherol. *Food Chemistry*, *132*(2), 954-958.

He, Q., Zhou, W., Xiong, C., Tan, G., & Chen, M. (2015). Lycopene attenuates inflammation and apoptosis in post-myocardial infarction remodelling by inhibiting the nuclear factor-κB signalling pathway. *Molecular Medicine Reports, 11*(1), 374-378.

Honda, M., Kudo, T., Kuwa, T., Higashiura, T., Fukaya, T., Inoue, Y., Kitamura, C., & Takehara, M. (2017). Isolation and spectral characterization of thermally generated multi-Z-isomers of lycopene and the theoretically preferred pathway to di-Z-isomers. Bioscience, biotechnology, and biochemistry, *81*(2), 365-371.

Hsieh, M.-J., Huang, C.-Y., Kiefer, R., Lee, S.-D., Maurya, N., & Velmurugan, B. K. (2022). Cardiovascular disease and possible ways in which lycopene acts as an efficient cardio-protectant against different cardiovascular risk factors. *Molecules*, *27*(10), 3235.

Ibrahim, M. S., Abdullahi, A., & Zage, A. U. (2025). Assessment of the effect of different preservation techniques on the level of antioxidant vitamins and total antioxidant capacity in tomato (*Solanum lycopersicon*). *Scholarly Journal of Science and Technology Research & Development, 4*(1), 49-60.

Ibrahim, M. S., Ibrahim, Y. I., Mukhtar, Z. G., & Karatas, F. (2017). Amount of vitamin A, vitamin E, vitamin C, malondialdehyde, glutathione, ghrelin, beta-carotene, lycopene in fruits of Hawthorn, Midland (Crataegus laevigata). *Journal of Human Nutrition & Food Science*, *5*(3), 1112-1117.

Ismail, R. F., Hamed, M., & Sayed, A. E. D. H. (2023). Lycopene supplementation: effects on oxidative stress, sex hormones, gonads and thyroid tissue in tilapia *Oreochromis niloticus* during Harness® exposure. *Frontiers in Physiology*, *14*, 1237159.

Jiang, H., Yin, Y., Wu, C. R., Liu, Y., Guo, F., Li, M., & Ma, L. (2019). Dietary vitamin and carotenoid intake and risk of age-related cataract. The American journal of clinical nutrition, 109(1), 43-54.

Jomova, K., Alomar, S. Y., Alwasel, S. H., Nepovimova, E., Kuca, K., & Valko, M. (2024). Several lines of antioxidant defense against oxidative stress: antioxidant enzymes, nanomaterials with multiple enzyme-mimicking activities, and low-molecular-weight antioxidants. *Archives of Toxicology*, *98*(5), 1323-1367.

Jomova, K., Raptova, R., Alomar, S. Y., Alwasel, S. H., Nepovimova, E., Kuca, K., & Valko, M. (2023). Reactive oxygen species, toxicity, oxidative stress, and antioxidants: chronic diseases and ageing. *Archives of Toxicology*, *97*(10), 2499-2574.

Joung, H. R., Gang, G., & Go, G. W. (2023). Lycopene and cardiovascular health: A systematic review reveals promising benefits in blood pressure, lipid profiles, and oxidative stress. Industrial Food Engineering, *27*(4), 271-277.

Kapała, A., Szlendak, M., & Motacka, E. (2022). The Anti-Cancer Activity of Lycopene: A Systematic Review of Human and Animal Studies. *Nutrients*, *14*(23), 5152.

Karaköy, Z., Cadirci, E., & Dincer, B. (2022). A New Target in Inflammatory Diseases: Lycopene. *The Eurasian Journal of Medicine*, *54*(Suppl1), 23-28.

Khan, U. M., Sevindik, M., Zarrabi, A., Nami, M., Ozdemir, B., Kaplan, D. N., Selamoglu, Z., Hasan, M., Kumar, M., Alshehri, M. M., & Sharifi-Rad, J. (2021). Lycopene: Food Sources, Biological Activities, and Human Health Benefits. *Oxidative Medicine and Cellular Longevity*, *2021*, 2713511.

Maaz, M., Sultan, M. T., Khalid, M. U., Raza, H., Imran, M., Hussain, M., Al Abdulmonem, W., Alsagaby, S. A., Abdelgawad, M. A., Ghoneim, M. M., Khan, M. A., Yehuala, T. F., Selim, S., & Mostafa, E. M. (2025). A comprehensive review on the molecular mechanism of lycopene in cancer therapy. *Food Science & Nutrition*, *13*(7), e70608.

Mirahmadi, M., Aghasizadeh, M., Esmaily, H., Baharara, H., Mohammadi-bajgiran, M., Assaran-Darban, R., Ferns, G. A., Hadizaheh, F., & Mobarhan, M. G. (2023). The effects of lycopene intake on blood pressure and lipid profile of patients with metabolic syndrome; a randomized clinical trial. *Journal of Food and Nutrition Research*, *11*(9), 602-607.

Mirahmadi, M., Azimi-Hashemi, S., Saburi, E., Kamali, H., Pishbin, M., & Hadizadeh, F. (2020). Potential inhibitory beffect of lycopene on prostate cancer. *Biomedicine & Pharmacotherapy*, *129*, 110459.

Montesano, D, Blasi, F, & Cossignani, L (2019). Lycopene and cardiovascular disease: An Overview. *Annals of Short Reports. 2,* 1033.

Moran, N. E., Cichon, M. J., Riedl, K. M., Grainger, E. M., Schwartz, S. J., Novotny, J. A., Erdman, J. W., Jr, & Clinton, S. K. (2015). Compartmental and noncompartmental modelling of $^{13}$C-lycopene absorption, isomerisation, and distribution kinetics in healthy adults. *The American journal of clinical nutrition*, *102*(6), 1436-1449.

Mozos, I., Stoian, D., Caraba, A., Malainer, C., Horbańczuk, J. O., & Atanasov, A. G. (2018). Lycopene and vascular health. *Frontiers in Pharmacology*, *9*, 521.

Müller, L., Caris-Veyrat, C., Lowe, G., & Böhm, V. (2016). Lycopene and its antioxidant role in the prevention of cardiovascular diseases—a critical review. *Critical Reviews in Food Science and Nutrition*, *56*(11), 1868-1879.

Nouri, M., Amani, R., Nasr-Esfahani, M., & Tarrahi, M. J. (2019). The effects of lycopene supplement on the spermatogram and seminal oxidative stress in infertile men: A randomized, double-blind, placebo-controlled clinical trial. *Phytotherapy Research*, *33*(12), 3203-3211.

Ozkan, G., Günal-Köroğlu, D., Karadag, A., Capanoglu, E., Cardoso, S. M., Al-Omari, B., Calina, D., Sharifi-Rad, J., & Cho, W. C. (2023). A mechanistic updated overview on lycopene as potential anticancer agent. *Biomedicine & Pharmacotherapy*, *161*, 114428.

Petyaev, I. M., Pristensky, D. V., Morgunova, E. Y., Zigangirova, N. A., Tsibezov, V. V., Chalyk, N. E., Klochkov, V. A., Blinova, V. V., Bogdanova, T. M., Iljin, A. A., Sulkovskaya, L. S., Chernyshova, M. P., Lozbiakova, M. V., Kyle, N. H., & Bashmakov, Y. K. (2019). Lycopene presence in facial skin corneocytes and sebum and its association with circulating lycopene isomer profile: Effects of age and dietary supplementation. *Food Science & Nutrition*, *7*(4), 1157-1165.

Prema, A., Janakiraman, U., Manivasagam, T., & Thenmozhi, A. J. (2015). Neuroprotective effect of lycopene against MPTP induced experimental Parkinson's disease in mice. *Neuroscience Letters*, *599*, 12-19.

Przybylska, S. (2020). Lycopene–a bioactive carotenoid offering multiple health benefits: a review. *International journal of food Science and Technology*, *55*(1), 11-32.

Przybylska, S., & Tokarczyk, G. (2022). Lycopene in the prevention of cardiovascular diseases. *International journal of molecular sciences*, *23*(4), 1957.

Rejali, L., Ozumerzifon, S., Nayeri, H., Williams, S., & Asgary, S. (2022). Risk reduction and prevention of cardiovascular diseases: biological mechanisms of lycopene. *Bioactive Compounds in Health and Disease*, *5*(10), 202-221.

Sadek, K., Abouzed, T., & Nasr, S. (2016). Lycopene modulates cholinergic dysfunction, Bcl-2/Bax balance, and antioxidant enzymes gene transcripts in monosodium glutamate (E621) induced neurotoxicity in a rat model. *Canadian Journal of Physiology and Pharmacology*, *94*(4), 394-401.

Sen, S. (2019). The chemistry and biology of lycopene: Antioxidant for human health. *International Journal of Advancement in Life Sciences Research*, *2*(4), 08-14.

Shafe, M. O., Gumede, N. M., Nyakudya, T. T., & Chivandi, E. (2024). Lycopene: a potent antioxidant with multiple health benefits. *Journal of nutrition and Metabolism*, *Volume 2024,* Article ID 6252426, 17 pages.

Soleymaninejad, M., Joursaraei, S. G., Feizi, F., & Jafari Anarkooli, I. (2017). The effects of lycopene and insulin on histological changes and the expression level of Bcl-2 family genes in the hippocampus of Streptozotocin-induced diabetic rats. *Journal of Diabetes Research, Volume 2017,* Article ID 4650939, 9 pages.

Song, X., Luo, Y., Ma, L., Hu, X., Simal-Gandara, J., Wang, L. S., Bajpai, V. K., Xiao, J., & Chen, F. (2021, August). Recent trends and advances in the epidemiology, synergism, and delivery system of lycopene as an anti-cancer agent. In *Seminars in cancer biology* (Vol. 73, pp. 331-346). Academic Press.

Tufail, T., Bader Ul Ain, H., Noreen, S., Ikram, A., Arshad, M. T., & Abdullahi, M. A. (2024). Nutritional benefits of lycopene and beta-carotene: A comprehensive overview. *Food Science & Nutrition*, *12*(11), 8715-8741.

Türkler, C., Onat, T., Yildirim, E., Kaplan, S., Yazici, G., Mammadov, R., & Sunar, M. (2020). An experimental study on the use of lycopene to prevent infertility due to acute oxidative ovarian damage caused by a single high dose of methotrexate. *Advances in Clinical and Experimental Medicine*, *29*(1), 5-11.

Van Steenwijk, H. P., Bast, A., & de Boer, A. (2020). The Role of Circulating Lycopene in Low-Grade Chronic Inflammation: A Systematic Review of the Literature. *Molecules*, *25*(19), 4378.

Viña, I., Robles, A., & Viña, J. R. (2025). Association between lycopene and metabolic disease risk and mortality: Systematic Review and Meta-Analysis. *Life*, *15*(6), 944.

Walallawita, U. S., Wolber, F. M., Ziv-Gal, A., Kruger, M. C., & Heyes, J. A. (2020). Potential role of lycopene in the prevention of postmenopausal bone loss: evidence from molecular to clinical studies. *International journal of molecular sciences*, *21*(19), 7119.

Wang, J., Li, L., Li, L., Shen, Y., & Qiu, F. (2024). Lycopene alleviates age-related cognitive deficit via activating liver-brain fibroblast growth factor-21 signalling. *Redox Biology*, *77*, 103363.

Wang, S., Heng, K., Song, X., Zhai, J., Zhang, H., & Geng, Q. (2023). Lycopene improves bone quality in SAMP6 mice by inhibiting oxidative stress, cellular senescence, and the SASP. *Molecular Nutrition & Food Research*, *67*(24), 2300330.

Wu, S., Guo, X., Shang, J., Li, Y., Dong, W., Peng, Q., Xie, Z., & Chen, C. (2022). Effects of lycopene attenuating injuries in ischemia and reperfusion. *Oxidative Medicine and Cellular Longevity, Volume 2022,* Article ID 9309327, 21 pages.

Xia, B., Zhu, R., Zhang, H., Chen, B., Liu, Y., Dai, X., Ye, Z., Zhao, D., Mo, F., Gao, S., Wang, X. D., Bromme, D., Wang, L., Wang, X., & Zhang, D. (2022). Lycopene improves bone quality and regulates AGE/RAGE/NF-κB signaling pathway in high-fat diet-induced obese mice. *Oxidative Medicine and Cellular Longevity, Volume 2022,* Article ID 3697067, 14 pages.

Xu, X., Li, S., & Zhu, Y. (2021). Dietary intake of tomato and lycopene and risk of all-cause and cause-specific mortality: results from a prospective study. *Frontiers in Nutrition*, *8*, 684859.

Yamamoto, M., & Sugimoto, T. (2016). Advanced glycation end products, diabetes, and bone strength. *Current osteoporosis reports*, *14*(6), 320-326.

Yamamoto, Y., Aizawa, K., Mieno, M., Karamatsu, M., Hirano, Y., Furui, K., Miyashita, T., Yamazaki, K., Inakuma, T., Sato, I., Suganuma, H., & Iwamoto, T. (2017). The effects of tomato juice on male infertility. Asia Pacific journal of clinical nutrition, 26(1), 65-71.

Yanai, H. (2017). Anti-atherosclerotic effects of tomatoes. *Functional Foods in Health and Disease*, *7*(6), 411-428.

Yin, S., Xu, X., Li, Y., Fang, H., & Ren, J. (2025). Lycopene as a potential anticancer agent: Current evidence on synergism, drug delivery systems and epidemiology. *Oncology Letters*, *30*(4), 462.

Yu, L., Wang, W., Pang, W., Xiao, Z., Jiang, Y., & Hong, Y. (2017). Dietary lycopene supplementation improves cognitive performances in tau transgenic mice expressing P301L mutation via inhibiting oxidative stress and tau hyperphosphorylation. *Journal of Alzheimer's Disease*, *57*(2), 475-482.

Zhang, X., Zhou, Q., Qi, Y., Chen, X., Deng, J., Zhang, Y., Li, R., & Fan, J. (2024). The effect of tomato and lycopene on clinical characteristics and molecular markers of UV-induced skin deterioration: A systematic review and meta-analysis of intervention trials. *Critical Reviews in Food Science and Nutrition*, *64*(18), 6198-6217.