Chapter 11
Anti-inflammatory Foods in Ageing and Longevity

Ceren Gezer

Abstract Inflammageing underlies ageing- and age-related chronic diseases, while age-related chronic diseases also underpin inflammageing and ageing. The featured inflammageing mechanisms are the inflammasome; DNA damage including telomere shortening; accumulated cellular senescence; immunosenesence; increased synthesis of proinflammatory miRNAs through activation of pathways such as NF-κB, mTOR, and sirtuins; dysbiosis of the gut microbiota; and meta-inflammation. It is observed that fruits, vegetables, olive oil, fish oil, whole grains, legumes, nuts, flavonoid-rich green tea, carotenoids, omega-3 fatty acids, fibre, and pre- and pro-biotics can inhibit these mechanisms and promote the prevention of chronic diseases such as diabetes, cardiovascular diseases, cancer, and neurodegenerative diseases that underpin inflammageing and ageing. However, the studies are mostly in vitro and in vivo animal model studies. Thus, there is a need for more prospective and clinical studies on anti-inflammatory foods in ageing and longevity. Moreover, it is important to consider that explaining the relation between diet, low-grade chronic inflammation, and ageing not only depends on a single food component in the concept of anti-inflammatory food, but also dietary pattern. Even though there are scarce human studies on benefits of these potential anti-inflammatory effects in ageing and longevity, adopting a Mediterranean dietary pattern and recommended consumption amounts can be suggested.

Keywords Ageing · Food · Inflammation · Longevity · Phytochemical · Mediterranean diet

11.1 Introduction

Inflammation is a response of tissue to infection agents such as pathogens and toxins in the immune system. In acute inflammation, the aim is to provide physiological homeostasis to destroy pathogens and induce repair mechanisms of tissue. During

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this process of acute inflammation, heat, swelling, redness, and pain are distinguished (Fougère et al. 2017). Different from this acute response is chronic inflammation, which is a low-grade, sustained, and systemic response of tissue that causes degeneration via inflammatory markers such as inflammatory cytokines (interleukin (IL)-6, IL-1, and tumour necrosis factor (TNF)-α), chemokines (monocyte chemoattractant protein-1 (MCP-1)), cell adhesion molecules (VCAM-1, ICAM-1), and acute phase proteins (C-reactive protein).

Ageing, diet, smoking, etc., have been identified as chronic pro-inflammatory factors. It has been shown that chronic inflammation underlies ageing- and age-related diseases such as cancer, diabetes, obesity, and atherosclerosis (Guarner and Rubio-Ruiz 2015). Thus, ageing is characterized by increased levels of inflammatory markers, and this age-related inflammation is termed inflammageing (Sanada et al. 2018; Calder et al. 2017).

There are many mechanisms that have a role in inflammageing. Some of the mechanisms related to inflammageing are oxidative stress, glycation, immunosenesence, mitochondrial dysfunction, chronic infections, epigenetic and hormonal changes, and diet (Fougère et al. 2017; Ekmekcioğlu 2020). The balance between these inflammageing sources and sources of anti-inflammageing factors such as healthy nutrition is important to restrain age-related diseases. With respect to diet, dietary pattern is assumed that have positive effects on chronic inflammation in age-related diseases (Monti et al. 2017).

It has been shown that the food contents of fibre, flavonoids, carotenoids, and omega-3 fatty acids have anti-inflammatory effects, while simple carbohydrates, and saturated and trans fatty acids have pro-inflammatory effects (Galland 2010). Thus, foods rich in anti-inflammatory components (whole grains, fruits, vegetables, legumes, nuts, and tea) can be called anti-inflammatory foods. The Mediterranean Diet is a dietary pattern composed of a high amount of the anti-inflammatory foods and a low amount of foods poor in these pro-inflammatory components. This diet is related to lower chronic inflammation (Calder et al. 2011). Therefore, explaining the relation between diet, low-grade chronic inflammation, and ageing not only depends on single food content in the concept of anti-inflammatory food, but also dietary pattern. In this chapter, the aim is to underline featured foods with anti-inflammatory effects in ageing and longevity.

11.2 Anti-inflammatory Dietary Pattern, Ageing, and Longevity

Inflammation has been assessed with inflammatory cytokines, chemokines, cell adhesion molecules, and acute phase proteins as biomarkers. As an acute inflammation response in infection, microbial cell membranes and nucleic acid are recognized by pathogen-associated molecular patterns (PAMPs) such as toll-like receptors (TLRs) and retinoic acid-inducible gene-1-like receptors (RLRs). As a chronic inflammation response in inflammatory diseases, substances called danger-associated molecular patterns (DAMPs) are secreted. However, it is indicated that sometimes, it is very hard to differentiate these responses as either acute or chronic (Kourtgen and Bauer 2018).

Even though there are various biomarkers to assess acute and chronic inflammation, only a few of them are acceptable in clinical and epidemiological studies that are related to diseases and diet as a factor relevant to chronic inflammation. In this context, the mostly assessed pro-inflammatory cytokines are TNF-α, IL-1, and IL-6, and the anti-inflammatory cytokines are IL-4, IL-10, IL-13, and transforming growth factor (TGF)-β. Actually, there is not a certain line to define the cytokines as pro- and anti- inflammatory, and its depends on the local environment of released cytokines, cytokine receptor density, synergistic and competing factors, and tissue response. However, most commonly, TNF-α, IL-1, and IL-6 are found as pro-inflammatory.

Besides cytokines, other commonly assessed biomarkers are chemokines, and MCP-1/CCL2 is the most featured one. It is responsible for modulating migration and infiltration of monocytes and macrophages. Cell adhesion molecules are responsible for modulating migration of leucocytes, and VCAM-1 is one of the key types. Both MCP-1 and VCAM-1 have key roles in the basic inflammation process in endothelial cells. Also, acute-phase proteins are commonly assessed for inflammation, and lipopolysaccharide-binding protein (LBP), fibrinogen, serum amyloid A, ceruloplasmin, and CRP are the most used ones. CRP is used to evaluate the level of infection and the development and risk of chronic inflammatory diseases such as cancer (Wu and Schauss 2012; Casas et al. 2014). According to meta-analysis results, healthy dietary patterns are negatively associated with CRP levels in adults (Neale et al. 2016).

Overall, concerning dietary pattern or food components, the most used key biomarkers are included in a posteriori methods in research. While these a posteriori results are important to assess the relation between diet and inflammation, a priori methods using diet scores are also important (Calder et al. 2011). There are some indices that are used to evaluate dietary patterns and the risk of chronic diseases, such as the Healthy Eating Index, Dietary Approaches to Stop Hypertension Index, Diet Inflammatory Index, and Mediterranean Diet Scores (Calle and Andersen 2019; Marcason 2010). It has been indicated that the Diet Inflammatory Index is more advantageous than other indices to determine risk of inflammatory diseases related to diet (Wirth et al. 2016). On the other hand, Mediterranean Diet Scores have also been indicated as good indices to observe relations with inflammatory biomarkers to evaluate inflammatory disease risk (Casas et al. 2014).

In general, the studies on inflammatory biomarkers and dietary patterns are observational, and the common points of these different indices are that they are mostly based on fruits and vegetables (Barbaresko et al. 2013). The results mostly depend on observational short-term studies, and dietary patterns are more effective to evaluate diet-related inflammatory biomarkers and predict disease risk from a broader perspective (Corley et al. 2015). There are many cofactors that effect inflammatory biomarkers, and it is hard to identify mechanisms of dietary patterns and inflammation. Studies on inflammation and dietary patterns point out foods and food components that are potentially anti-inflammatory (Calle and Andersen 2019). Therefore, to understand the anti-inflammatory mechanisms of diet, intervention studies based on specific food are important. Thus, in a holistic view dietary pattern, food and food components are combined with each other, and all of them are related to ageing and lifespan. This chapter focuses on food components and inflammatory pathways to explain effects on ageing and lifespan.

11.3 Anti-inflammatory Foods, Ageing, and Longevity

Since older people have increased levels of cytokines and chemokines, it can be said that systemic low-grade chronic inflammation mostly rises with age. This inflammation type involves most of the tissues (such as adipose and muscle tissues), organs (such as the brain and liver), systems (such as the immune system), and ecosystems (such as the gut microbiota). The circadian rhythm, chronic stress, xenobiotics, diet, dysbiosis, obesity, chronic infections, and physical inactivity trigger systemic low-grade chronic inflammation. Eventually, chronic low-grade inflammation causes tissue damage and hence metabolic syndrome, type 2 diabetes, cardiovascular diseases, cancer, neurogenerative diseases, sarcopenia, osteoporosis, and immunosenesence (Monti et al. 2017; Furman et al. 2019). Thus, inflammageing underlies ageing- and age-related chronic diseases, while age-related chronic diseases underpin inflammageing and ageing (Franceschi et al. 2018).

There are several molecular mechanisms related to inflammageing: (i) oxidative stress, dysfunction of mitochondria, and endoplasmic reticulum stress cause increased production of DAMPs that activate inflammasome and NF-κB. (ii) DNA damage, including telomere shortening, occurs through oxidative stress and other factors and triggers secretion of pro-inflammatory compounds. (iii) Cellular senescence increases with age, accumulated senescence cells acquire senescence-associated secretory phenotype (SASP), and senescent cells drag along neighbour cells to senescence through SASP. (iv) In immunosenesence, age-related changes occur in innate and adaptive immune cells, which is also accepted as a characteristic of inflammageing as chronic activation of the innate immune system. (v) Age-related increase production of galactosylated immunoglobulin (Ig-G-GO) occurs, and (vi) there is increased synthesis of proinflammatory miRNAs through activation of pathways such as NF-κB, mTOR, sirtuins, and TGF-β pathways. (vii) There is also dysbiosis of the gut microbiota, and viii) meta-inflammation mediated by excess nutrients (particularly glucose and fatty acids) and energy trigger stress in pancreas, liver, muscle, and adipose tissue, resulting with secretion of cytokines, chemokines, and adipokines (Cevenini et al. 2013; Monti et al. 2017; Calder et al. 2017). Overall, the immune system, adipose tissue, liver, muscle, and gut microbiota contribute to inflammageing and meta-inflammation (circulating molecular mediator) and thus multi-system inflammation (cardiovascular diseases, obesity, type 2 diabetes, cancer, neurodegenerative diseases, etc.) (Cevenini et al. 2013; Monti et al. 2017).

A healthy dietary pattern such as the Mediterranean diet can prevent and mitigate inflammatory diseases by anti-inflammatory effects. This diet is characterized by high consumption of fruits, vegetables, whole grains, legumes, nuts, olive oil, and fish oil, so the intake of bioactive components such as phytochemicals, vitamins, and fatty acids is high (Estruch 2010). These components play a potential a key role in suppression of molecular mechanisms of inflammageing.

11.3.1 Fruits and Vegetables

Fruits and vegetables are indispensable parts of a healthy dietary pattern since not only are they rich in micronutrients, but they are also rich in various phytochemicals, such as phenolics and carotenoids. Each fruit and vegetable differs in phenolic composition, so consuming various types of fruits and vegetables is important while aiming to reach suggested healthy consumption amounts. Flavonoids are the most common phenolic compounds found in fruits and vegetables that and are relevant to inflammation (Zhang et al. 2015; Oz and Kafkas 2017).

Nuclear factor (NF)-κβ and activator protein-1 (AP-1) are commonly used molecular targets to assess inflammation and in phytochemical treatment studies. NF-κβ has a pivotal role in inflammatory response. The phosphorylation status of these factors is regulated by mitogen-activated protein kinase (MAPK) cascades. MAPK involves subgroups such as p38, extracellular signal-regulated kinase (ERK), and C-jun N-terminal kinase (JNK) signalling pathways and activates NF-κβ and AP-1 as an inflammatory response. In addition, lipopolysaccharide (LPS) is a PAMP that binds to TLR4 and hence activates NF-κβ and AP-1 mediated by MAPKs. Also, it is known that TNF-α, IL-6, and CRP activate NF-κβ. NF-κβ is also responsible for the expression of enzymes such as cyclooxygenase (COX)-2 and the inducible nitric oxide synthase (iNOS), as well as chemokines and adhesion molecules (Chung et al. 2021).

Resveratrol is the most common stilbene compound abundantly found in grapes, berries, peanuts, and wine. Resveratrol exhibits anti-inflammatory effects via suppression of NF-κB, JAK-STAT, and AP-1 signalling pathways, which cause the production of inflammatory mediators such as IL-1β, TNF-α, IL-6, IL-8, and NO in vitro and in vivo. Also, resveratrol suppresses COX and lipoxygenase (LOX) enzyme activities in the synthesis of leucotriens, eicosonoids such as thromboxanes, and prostanoids such as prostaglandins (Csiszar 2011; Ma et al. 2015; de Sá Coutinho et al. 2018; Banez et al. 2020). In addition, in association with these mechanisms, resveratrol exerts neuro- and cardioprotection effects, prevents cancer, and ameliorates the ageing process. These effects of resveratrol are supported in clinical trials, but there is a need for more studies (Banez et al. 2020).

Flavones, flavonols, and flavanones are the three flavonoid subgroups. Apigenin and luteolin are the most common flavones. Apigenin occurs in apple, orange, grapefruit, chamomile, celery, parsley, and onion. Apigenin inhibits activation of NF-κB, which is a transcription factor that has a crucial role in iNOS and COX-2 expression and mitigates IL-1β, TNF-α, IL-6, and inflammatory cell infiltration in vitro and in vivo (Ai et al. 2017; Dang et al. 2018; Xie et al. 2019). It is suggested that a diet rich in apigenin attenuates LPS-induced inflammation via regulation of gene expression in vivo by inhibiting IL-1β production via caspase-1 activation, inhibiting IL-1β and IL-6 production via inhibition of ERK1/2, and inhibiting TNF-α-induced activation of NF-kB (Wang et al. 2014; Zhang et al. 2014; Arango et al. 2015).

Apigenin also reduces LPS-induced inflammation in vitro by suppressing NO and prostaglandin production by inhibiting iNOS and COX-2, respectively, as well as caspase-3 activity, which is a central modulator of apoptosis. Thus, apigenin can reduce the risk of chronic diseases such as diabetes, cardiovascular diseases, cancer, and Alzheimer's disease (Duarte et al. 2013; Choi et al. 2014). In addition, both apigenin and luteolin inhibit TNFα-induced expression of CCL2/MCP-1 and CXCL1/KC (Funakoshi-Tago et al. 2011). Luteolin occurs in many vegetables, such as artichoke, broccoli, pepper, thyme, turnip, cucumber, and celery. Luteolin inhibits IL-1β and TNF-α expression by regulating transcription factors such as STAT3, NF-κB, and AP-1 in vitro and in vivo. Therefore, it has been suggested that luteolin may reduce risk of inflammatory diseases such as neurodegenerative diseases and cancer (Nabavi et al. 2015; Hayasaka et al. 2018; Aziz et al. 2018).

Quercetin is the most common flavonol and is found in apples, onions, berries, and capers. It decreases CRP, SAA, fibrinogen, TNF-α, IL-1β, IL-6, and NO in vitro and in vivo. Quercetin inhibits TNF-α by inactivation of ERK, c-Jun, and NF-κB, as well as the activation of peroxisome proliferator-activated receptor gamma (PPARγ) (Kleemann et al. 2011; Li et al. 2016). Also, quercetin inhibits COX-2 activity (Lesjak et al. 2018). Thus, similar to apigenin and luteolin, quercetin may also reduce the risk of chronic inflammatory diseases.

Hesperidin and naringenin are the most common flavonones and are abundantly found in citrus fruits (Yi et al. 2017). It is indicated that hesperidin inhibits NF-κB and thus iNOS and COX-2 activities in vitro and in vivo (Parhiz et al. 2015; Tejada et al. 2018). In addition, hesperidin suppresses the production of IL-2, IL-4, IL-10, NF-κB/p65, COX-2, IL-1β, TNF-α, MMP-3, and MMP-9, while it stimulates production of IL-10 in chondrocytes and chondroitin mesenchymal stem cells in vitro (Xiao et al. 2018a, b; Tsai et al. 2019). Another flavanone, naringenin, either activates SIRT1 enzyme and prevents senescence in vitro or reduces TNF-α and IL-6 in vivo in myocardial cells and tissues (Testai et al. 2020). Therefore, flavonones can prevent cardiovascular diseases, diabetes, and cancer (Yi et al. 2017).

Anthocyanins are another subgroup of flavonoids and are mostly found in berries, where they result in unique colours. The abundant types of anthocyanins are cyanidin, pelargonidin, peonidin, delphinidin, petunidin, and malvidin. Similar to other flavonoids, anthocyanins also exhibit anti-inflammatory effects by reducing iNOS and COX-2 activity, as well as modulate NF-κβ and MAPK signalling cascades, thus reducing TNF-α, IL-1β, IL-6, and NO production in vitro and in vivo (Vendrame and Klimis-Zacas 2015). Despite this, there is a need for more evidence on those mechanisms of action of anthocyanins to support their use in epidemiological and clinical trials (Joseph et al. 2014). Furthermore, it has been indicated that anthocyanins can also modulate the gut microbiota, and all of the other mechanisms of action provide protection from chronic inflammatory diseases (Morais et al. 2016; Ma et al. 2018). Overall, flavonoids have anti-inflammatory effects and play a role in preventing chronic diseases, such as cardiovascular diseases and cancer (Griffithd et al. 2016).

Lycopene, β-carotene, and lutein are carotenoids that are more commonly present in foods. Lycopene mainly occurs in tomatoes and tomato products. Lycopene inhibits LPS-induced NO, IL-6, TNF-α, and secretory phospholipase A2 production by suppressing ERK, p38MAPK, NF-κB, and high-mobility group box 1 (HMGB1) activation in vitro and in vivo (Feng et al. 2010; Lee et al. 2012; Marcotorchino et al. 2012; He et al. 2015). Lycopene also inhibits LPS-induced COX-2 and iNOS activities in human keratinocyte cells (Kim et al. 2014). Lycopene also suppresses high-fat-diet-induced inflammation via reduction of NF-κB/p65 (Fenni et al. 2017). Lycopene reduces SAA levels in overweight individuals (McEneny et al. 2013), and lycopene and lutein together attenuate VCAM-1, ICAM-1, and TNF-α-induced leukocyte adhesion and the NF-κB signalling pathway in human endothelial cells (Armoza et al. 2013).

Lutein is mainly found in corn and tangerines and attenuates IL-6 production and COX-2 activity. It also suppresses AP-1 activation by the inhibition of JNK/p38 in human keratinocyte cells (Arscott 2013; Oh et al. 2013). Lutein also suppresses NF-κB activation by inhibition of JNK/p38 and Akt in LPS-activated BV-2 microglia cells (Wu et al. 2015). In addition, lutein inhibits NF-κB and COX-2 activation and reduces IL-1β production in retinal ischemic/hypoxic injury in vitro and in vivo (Li et al. 2012). Lutein suppresses activation of NF-κB, inhibits COX-2 activity, and decreases IL-6, TNF-α, and IL-1β in primary chondrocyte cells (Qiao et al. 2018). Thus, lutein can reduce the risk of inflammatory diseases such as osteoarthritis, age-related macular degeneration, cardiovascular diseases, and neurodegenerative diseases (Kijlstra et al. 2012). β-carotene present in carrots (Arscott 2013).

LPS-induced NF-κB, JAK2/STAT3, and JNK/p38 MAPK activation is suppressed by β-carotene in macrophages (Li et al. 2018). β-carotene inhibits virus-induced NO, IL-1b, IL-6, and MCP-1 production and NF-κB, JNK/p38, and ERK activation in macrophages (Lin et al. 2012). Both β-carotene and lycopene reduce the inflammatory response in vitro (Di Tomo et al. 2012; Kawata et al. 2018). To sum up, even though there are contrary results about the mechanisms of action related to anti-inflammatory effects of carotenoids, they can lower the risk of cardiovascular diseases, type 2 diabetes, dementia, and cancer (Ciccone et al. 2013; Kaulmann and Bohn 2014; Honarvar et al. 2017).

In a comprehensive manner, phytochemicals in fruits and vegetables ameliorate the inflammatory response in the short and long term (Joseph et al. 2016). These effects on inflammageing mainly occur by mitigating NF-κB. Also, phytochemicals attenuate cellular senescence and immunosenesence in immune cells (Sharma and Padwad 2020). Studies have been mostly in vitro and in vivo animal studies, and there is a need for epidemiological and clinical studies to support these effects in humans and improving dietary recommendations.

11.3.2 Olive Oil

Olive oil is one of the crucial components of the Mediterranean diet responsible for positive health effects (Virruso et al. 2014). Olive oil is obtained solely from the olive tree fruit (*Olea europaea* L.). A number of processes are used, and virgin olive oil is obtained exclusively by specific mechanical processes that do not alter the oil. The virgin olive oils are classified as extra virgin olive oil (EVOO), virgin, and lampante according to the degree of acidity. All of these virgin oils mainly contain monounsaturated fatty acids, particularly oleic acid, as well as tocopherols, tocotrienols, b-carotene, phytosterols, flavonoids, and phenolic compounds, such as oleuropein, hydroxytyrosol, and oleocanthal (Ghanbari et al. 2012; Souza et al. 2017).

It has been suggested that phenolic compounds found in olive oil, such as hydroxytyrosol, tyrosol, and oleocanthal, can mitigate NF-kB and relevant signalling cascades, suppress eicosonoid synthesis, and enzyme activities i*n vitro* and in vivo (Souza et al. 2017). A systematic review and meta-analysis of randomized controlled trials on regular dietary intake of olive oil indicated that olive oil is associated with decreased levels of CRP, IL-6, and TNF-α (Fernandes et al. 2020). Oleic acid is abundantly found in olive oil, but it has higher concentrations in seed oils such as sunflower, rapeseed, and soybean oil. However, olive oil contains specific phenolics that are not present in seed oils. The specific phenolic compounds have anti-inflammatory effects in vitro and in *vivo,* hence reducing the risk of chronic disease development (Cicarelle et al. 2012).

It has been indicated that EVOO and its phenolic compounds inhibit NF-kB and STATs and modulate JAK/STATs, ERK/MAPKs, JNK, and AKT pathways in immune-mediated inflammatory diseases such as rheumatoid arthritis, inflammatory bowel disease, multiple sclerosis, and psoriasis (Santangelo et al. 2017). In addition, EVOO reduces NO and PGE2 by suppression of iNOS and COX-2 expression. It also inhibits MAPK and NF-kB and thus TNFα and IL-6 production in LPS or IFNγ-stimulated murine macrophages (Cárdeno et al. 2014a, b). Moreover, the olive oil polyphenol hydroxytyrosol reduces PGE2 due to inhibition of COX-2 activity in human monocytes (Rosignoli et al. 2013). Hydroxytyrosol also inhibits NF-kB and thus TNF-α (Killeen et al. 2014).

Another olive oil polyphenol oleocanthal inhibits COX-1, COX-2, and iNOS activities, as well as tau-tau interaction in neuron cells (Lucas et al. 2011; Cicerale et al. 2012). Thus, according to these in vitro an in vivo study results, virgin olive oils can prevent cardiovascular disease, cancer, diabetes, degenerative joint diseases, and neurodegenerative diseases, which is basically related to their hydroxytyrosol and oleocanthal content. However, clinical trials are scarce (Parkinson and Cicerale 2016).

11.3.3 Fish Oil

α-linolenic acid is a short-chain plant form of omega-3 fatty acid, and eicosapentaenoic acid (EPA) and docosahexaenoic (DHA) are long-chain fatty acids (FAs) that are the marine forms of omega-3 fatty acids. These fatty acids occur in sea foods in lean and oily fish. Some sea foods, oily fish, and livers of some lean fish include much more marine omega-3 fatty acids (Calder 2010). Omega-3 fatty acids inhibit pro-inflammatory leucocyte chemotaxis, adhesion molecule expression, and leucocyte-endothelial adhesive interactions. In particular, EPA upregulates 3 series of prostoglandins and leukotriens that are low-proinflammatory compounds compared to 2 series of prostoglandins and 4 series of leucotriens upregulated by AA (Calder 2012).

Obesity is seen as an inflammatory disease due to TNF-α and IL-6 increasing and adiponectin decreasing in adipocytes. In addition, CRP increases from hepatocytes mediated by IL-6 (Ellulu et al. 2015). Omaga-3 PUFAs suppress NF-kB and thus CRP and IL-6 production. Also, omega-3 FAs up-regulate PPARγ, which induces fat cell differentiation and maturation. Therefore, omega-3 FAs promote adipogenesis and a healthy expansion of adipose tissue, while omega-6 FAs have reverse effects on expansion of adipose tissue.

The free fatty acid receptor (FFAR) family has a role in both energy homeostasis and the inflammatory response in different cell types. Macrophage infiltration into adipose tissue is decreased via omega-3 PUFAs, which activate FFAR4/G protein-coupled receptor 120 (Jayarathne et al. 2017; Albracht-Schulte et al. 2018). In addition, resolving D series and resolving E series are synthesized from DHA and EPA, respectively, which have anti-inflammatory effects due to inhibiting inflammatory cytokine synthesis and clearance of inflammatory cells related to cardiovascular health (Oppedisano et al. 2020).

Many of these effects are related to changes in fatty acid composition of cell membranes. The changes can modify membrane fluidity and cell signalling, evoke gene expression changes, and change the pattern of lipid mediator production. For instance, richness in $n-6$ fatty acid AA composition of cell membranes leads to an inflammatory response (Calder 2012). Thus, the omega-6/omega-3 balance is important for inflammatory processes and thus health maintenance.

It has been indicated that if the omega-6/omega-3 ratio is 3–5:1, mortality is decreased (Candela et al. 2011). In addition, it has been observed that omega-3 FAs attenuates cellular senescence of immune cells via telomere shortening and inhibition of SASP. Also, it ameliorates harmful effects of the cellular and humoral immune response during immunosenesence (Sharma and Padwad 2020).

Overall, in clinical studies, dietary omega-3 fatty acids have been related to lower inflammatory biomarkers such as CRP, TNF-α, IL-6, and IL-1, as well as endothelial activation in cardiovascular disease, diabetes, chronic renal disease, Alzheimer's disease, sepsis, acute pancreatitis, and cancer (Rangel-Huerta et al. 2012; Mocellin et al. 2016; Layè et al. 2017; Natto et al. 2019). In addition, marine $n-3$ fatty acids were tested in animal models of rheumatoid arthritis (RA), inflammatory bowel disease (IBD) and asthma. They showed positive effects in clinical trials on RA, but not in IBD and asthma (Calder 2015; Akbar et al. 2017).

11.3.4 Whole Grains

The most consumed whole grain foods are whole wheat, whole oats, whole barley, whole rye and their flours, bulgur, brown rice, amaranth, sorghum, and their products such as bread, granola, etc. It is reported that whole grains lower CRP levels in epidemiological studies (Lefevre and Jonnalagadda 2012). Moreover, two meta-analyses of randomized control trials reported that whole grain consumption is negatively related to high-sensitivity-CRP (hs-CRP), CRP, TNF-α, IL-6, and IL-1β levels (Xu et al. 2018; Hajihashemi and Haghighatdoost 2018).

In this context, two main components of whole grains are featured: dietary fibre and phytochemicals since there is robust scientific evidence about them. However, they have primary effects on consumer acceptability related to qualities such as colour, texture of the whole-grain product, and their synergistic effects (Awika et al. 2018). Furthermore, the anti-inflammatory mechanisms of action depend on β-glukan (a dietary fibre), as well as alkylresorcinols and avenanthramides (phytochemicals). These show anti-inflammatory effects by modulating the gut microbiota. While β-glukan is fermented into short-chain fatty acids, alkylresorcinols and avenanthramides are fermented into phenolic acids such as cinnamic acid, cafeic acid, and ferulic acid by the gut microbiota. These microbial-derived metabolites inhibit LPS, IFN-γ, and reactive oxygen species-induced NF-κB expression and hence attenuate TNF-α, IL-1β, IL-6, and CRP (Sang et al. 2020). Thus, bioactive components of whole grains have anti-inflammatory activities that could reduce the risk of chronic diseases such as diabetes, cardiovascular disease, cancer, and dementia (Lee et al. 2015).

11.3.5 Legumes

Soybeans, kidney beans, lentils, and cowpeas are common legumes, which are rich in fibre and protein (Rebello et al. 2014). Legumes contain various bioactive compounds, such as phenolics, peptides, and saponins, which exhibit anti-inflammatory effects (Serventi and Dsouza 2020). Legume seed hulls are rich in phenolics, and it is indicated that lentil hulls inhibit 15-LOX, COX-1, and COX-2 activities (Boudjo et al. 2013). Legume proteins, particularly soybean and bean proteins, are digested into bioactive peptides that can modify NO, PGE2 (and thus iNOS), and COX- 2 activities, as well as cytokines and chemokines in vitro and in vivo (Reyes-Díaz et al. 2019). It is also observed that legume saponins, particularly soy saponins, attenuate NO, TNF-α, PGE2, and MCP-1, suppress iNOS and COX-2 activities, and mitigate NF-κB activation (Zhu et al. 2018).

A meta-analysis of randomized clinical trials demonstrated that decreased CRP and hs-CRP levels are associated with non-soy legume consumption, although more clinical studies are needed to clarified the effects of non-soy legume consumption on inflammatory markers (Salehi-Abargouei et al. 2015). To conclude, legumes contain various bioactive compounds that display anti-inflammatory effects, thus suggesting they could prevent inflammatory diseases. However, there is a need for more studies on the anti-inflammatory impact of legumes (not only clinical but also animal and molecular study models).

11.3.6 Nuts

The common tree nuts are almonds, Brazil nuts, cashews, hazelnuts, pecans, pistachios, and walnuts. Almonds, hazelnuts, pine nuts, pistachios, and walnuts are mostly involved in the Mediterranean diet. They are rich in unsaturated fatty acids, protein, fibre, tocopherols, phytosterols, and polyphenols (Ros 2015). The phytochemical content of tree nuts can vary considerably by nut type, and they have been associated with anti-inflammatory impact (Bolling et al. 2011). It has been demonstrated that increased nut consumption is related to decreased inflammatory disease mortality (Gopinath et al. 2011). In addition, an epidemiologic study, the National Health and Nutrition Examination Survey (NHANES), found that increased nut and seed consumption is related to increased telomere length, thus decreasing aging and cell senescence (Tucker 2017).

On the other hand, a meta-analysis of randomized controlled trials suggests that nut consumption significantly decreases leptin while having no significant effect on CRP, IL6, adiponectin, IL10, and TNF-a (Mazidi et al. 2016). Similarly, another meta-analysis of randomized controlled trials also suggests that nut consumption significantly reduced ICAM-1 levels but had no effect on other inflammatory markers such as CRP, IL-6 TNF-α, E-selectin, and VCAM-1 (Xiao et al. 2018a, b). Another meta-analysis of randomized controlled trials suggests favourable effects of nut consumption on flow-mediated dilation as a measure of endothelial function (Neale et al. 2017). The results of these three meta-analyses about non-significant changes in inflammatory biomarkers consider that there is a need for more randomized controlled trials on the relationship of nut consumption and inflammation.

11.3.7 Green Tea

Green tea has anti-inflammatory effects from the main bioactive component, catechins, which are in the flavonoid subgroup of flavan-3-ols. The four main catechins in green tea are (-)-epicatechin (EC), (-)-epigallocatechin (EGC), (-)-epicatechin-3-gallate (ECG), and (-)-epigallocatechin-3-gallate (EGCG). The most abundant catechin is EGCG (59%), followed by EGC (≈19%), ECG (≈14%), and EC (≈6%).

Green tea catechins exert anti-inflammatory effects by increased IL-10 and decreased IL-1β, TNF-α, IL-6, IL-8, interferon gamma (INF-γ), CRP, matrix metalloproteinases (MMPs), ICAM-1, VCAM-1, and E-selection in vitro and in vivo (Reyaert 2017). In addition, green tea catechins also inhibit COX-2 expression. EGCG is the most effective green tea catechin and suppresses NF-κB/p38 expression as well (Riegsecker et al. 2013; Ohishi et al. 2016; Fechtner et al. 2017). High glucose increases VCAM-1 expression and thus induces inflammation, but EGCG mitigates PKC and NF-κB signalling in human umbilical-vein endothelial cells (Yang et al. 2013). EGCG also attenuates PCB-126-induced endothelial cell inflammation via suppression of NF-κB/p65, IL-6, CRP, ICAM-1, VCAM-1, and IL-1α/β production (Liu et al. 2016).

Similarly, EGCG suppresses infrasound-induced increases in NF-κB/p65 and inhibits IL-1β, IL-6, IL-18, and TNF-α in microglia (Cai et al. 2014). Moreover, EGCG attenuates TNF-a, MCP-1, ICAM-1, NO, VEGF, and MMP-2 production and NF-kB and MAPK signalling pathways in LPS-stimulated in L02 hepatocytes (Liu et al. 2014). Furthermore, it affects the accumulation of senescent cells related to ageing and age-related diseases. Activation of SIRT3 delays senescence and SASP-induced inflammation. EGCG possesses anti-inflammatory effects by activating SIRT3 and reducing IL-6 in 3T3-L1 preadipocytes (Lilja et al. 2020). It has been reported that EGCG's anti-inflammatory effects mostly depend on in vitro and in vivo animal studies (Lu and Yen 2015). However, green tea can demonstrate the prevention of RA, osteoarthritis, cardiovascular diseases, cancer, neurodegenerative disease, and metabolic syndrome in association with the main component, EGCG (Afzal et al. 2015).

11.3.8 Prebiotics and Probiotics

Firmicutes, Bacteroidetes, Proteobacteria, and Actinobacteria are the most abundant phyla of gut microbiota in humans. Gram-positive probiotic bacteria, lactic acid bacteria, and *Bifidobacteria* are in Firmicutes and Actinobacteria, respectively. In contrast, the phyla Bacteroidetes and Proteobacteria include Gram-negative bacteria that have LPS induce pro-inflammatory macrophage activity and hence cause infection or diseases under certain conditions (Wang et al. 2020). Dysbiosis is generally related to impairment of the gut barrier function, so LPS moves through leaky tight junctions into circulation. Also, LPS activates NF-κβ and AP-1 due to binding to TLR4. As a result of dysbiosis, types of secondary bile acids that are converted from primary bile acids in gut are also changed. Therefore, the pro-inflammatory farnesoid X receptor (FXR) signalling pathway is activated in enterocytes and adipocytes.

In addition, it has been suggested that IL-6, TNF-α, and CRP levels are linked with specific gut microbial species (Bander et al. 2020). A meta-analysis of randomized clinical trials demonstrated that CRP and NO levels are lowered by probiotic supplementation (Tabrizi et al. 2019). Another meta-analysis of randomized clinical trials indicated that hs-CRP, TNF-a, IL-6, IL-12, and IL-4 levels decrease as a result of probiotic supplementation (Milajerdi et al. 2020). Moreover, it has been reported that probiotics ameliorate the immune response during immunosenesence and mitigate cellular senescence in immune cells (Sharma and Padwad 2020).

Acetate, propionate, and butyrate are short-chain fatty acids that are known as products of the gut microbiota. Dietary fibre and resistant starches are prebiotics fermented by gut microbiota. Primarily, butyrate is the most effective SCFA associated with the inflammatory process. There are several anti-inflammatory mechanisms of action of butyrate. Firstly, butyrate minimizes transfer of LPS from the gut to circulation. Secondly, it binds to G-protein-coupled receptor 43 (GPR43), an SCFA receptor that regulates inflammatory signals and is expressed in macrophages. Thirdly, butyrate inhibits NF-kB, IFN-γ, and PPAR-γ (Lescheid 2014; Wang et al. 2020).

It is suggested that butyrate is mainly a product of Ruminococcaceae, Eubacterium, Clostridia, and Firmicutes (Ohira et al. 2017). It has been observed that altered gut microbiota (in other words, dysbiosis) is related to systemic inflammation and thus diabetes, obesity, cardiovascular diseases, cancer, and inflammatory bowel diseases (Boulangé et al. 2016; Lescheid, 2014; Wang et al. 2020). Prebiotics and probiotics ameliorate or prevent these diseases via the mechanisms of action mentioned. However, standardization of the methodology and biomarkers are needed to clarify the link between prebiotics, probiotics, the gut microbiota, inflammation, and morbidity.

11.4 Conclusion

In conclusion, fruits, vegetables, olive oil, fish oil, whole grains, legumes, nuts, flavonoid-rich green tea, carotenoids, omega-3 fatty acids, and fibre demonstrate anti-inflammatory effects. Basically, they inhibit TNF-α, IL-1, and IL-6 production by suppressing NF-κB, and they inhibit iNOS and COX activity. Also, they exhibit anti-inflammatory effects via modification of the gut microbiota, reduced accelerated senescence of cells, and reduced immunosenesence. According to these mechanisms, these foods promote the prevention of chronic diseases such as diabetes, cardiovascular diseases, cancer, and neurodegenerative diseases, which underpin inflammageing and ageing. However, the studies have mostly been in vitro and animal model studies. Thus, there is a need for more prospective and clinical studies on anti-inflammatory food components and food. Moreover, it is important to consider the dietary pattern to evaluate anti-inflammatory effects of foods from a wider perspective. Even though there are scarce human studies on benefits of these potential anti-inflammatory effects in ageing and longevity, adopting a Mediterranean dietary pattern and recommended consumption amounts can be suggested.

Compliance with Ethical Standards

Conflict of Interest All authors declare they have no conflict of interest /or/ I have no conflict of interest.

References

Afzal M, Safer A, Menon M (2015) Green tea polyphenols and their potential role in health and disease. Inflammopharmacology 23:151–161. https://doi.org/10.1007/s10787-015-0236-1

Ai X, Qin Y, Liu H et al (2017) Apigenin inhibits colonic inflammation and tumorigenesis by suppressing STAT3-NF-κB signaling. Oncotarget 8:100216–100226. https://doi.org/10.18632/oncotarget.22145

Akbar U, Yang M, Kurian D et al (2017) Omega-3 fatty acids in rheumatic diseases. J Clin Rheumatol 23:330–339. https://doi.org/10.1097/rhu.0000000000000563

Albracht-Schulte K, Kalupahana N, Ramalingam L et al (2018) Omega-3 fatty acids in obesity and metabolic syndrome: a mechanistic update. J Nutr Biochem 58:1–16. https://doi.org/10.1016/j.jnutbio.2018.02.012

Arango D, Mayra Diosa-Toro M (2015) Rojas-Hernandez LS (2015) Dietary apigenin reduces LPS-induced expression of miR-155 restoring immune balance during inflammation. Mol Nutr Food Res 59:763–772. https://doi.org/10.1002/mnfr.201400705

Armoza A, Haim Y, Basiri A et al (2013) Tomato extract and the carotenoids lycopene and lutein improve endothelial function and attenuate inflammatory NF-κB signaling in endothelial cells. J Hypertens 31:521–529. https://doi.org/10.1097/hjh.0b013e32835c1d01

Arscott SA (2013) Food sources of carotenoids. In: Tanumihardjo SA (ed) Carotenoids and human health, 1st edn. Springer, New York, pp 3–19

Awika J, Rose D, Simsek S (2018) Complementary effects of cereal and pulse polyphenols and dietary fiber on chronic inflammation and gut health. Food Funct 9:1389–1409. https://doi.org/10.1039/c7fo02011b

Aziz N, Kim MY, Cho JY (2018) Anti-inflammatory effects of luteolin: a review of in vitro, in vivo, and in silico studies. J Ethnopharmacol 225:342–358. https://doi.org/10.1016/j.jep.2018.05.019

Banez M, Geluz M, Chandra A et al (2020) A systemic review on the antioxidant and anti-inflammatory effects of resveratrol, curcumin, and dietary nitric oxide supplementation on human cardiovascular health. Nutr Res 78:11–26. https://doi.org/10.1016/j.nutres.2020.03.002

Bander ZA, Nitert M, Mousa A et al (2020) The gut microbiota and inflammation: an overview. Int J Environ Res Public Health 17:7618. https://doi.org/10.3390/ijerph17207618

Barbaresko J, Koch M, Schulze MB (2013) Dietary pattern analysis and biomarkers of low-grade inflammation: a systematic literature review. Nutr Rev 71(8):511–527. https://doi.org/10.1111/nure.12035

Bolling B, Chen C, McKay D et al (2011) Tree nut phytochemicals: composition, antioxidant capacity, bioactivity, impact factors. A systematic review of almonds, Brazils, cashews, hazelnuts, macadamias, pecans, pine nuts, pistachios and walnuts. Nutr Res Rev 24:244–275. https://doi.org/10.1017/s095442241100014x

Boudjou S, Oomah B, Zaidi F et al (2013) Phenolics content and antioxidant and anti-inflammatory activities of legume fractions. Food Chem 138:1543–1550. https://doi.org/10.1016/j.foodchem.2012.11.108

Boulangé C, Neves A, Chilloux J et al (2016) Impact of the gut microbiota on inflammation, obesity, and metabolic disease. Genome Med 8:42. https://doi.org/10.1186/s13073-016-0303-2

Cai J, Jing D, Shi M et al (2014) Epigallocatechin gallate (EGCG) attenuates infrasound-induced neuronal impairment by inhibiting microglia-mediated inflammation. J Nutr Biochem 25:716–725. https://doi.org/10.1016/j.jnutbio.2014.02.012

Calder PC (2010) Omega-3 fatty acids and inflammatory processes. Nutrients 2:355–374. https://doi.org/10.3390/nu2030355

Calder PC (2015) Marine omega-3 fatty acids and inflammatory processes: effects, mechanisms and clinical relevance. Biochim Biophys Acta Mol Cell Biol Lipids 1851:469–484. https://doi.org/10.1016/j.bbalip.2014.08.010
Calder PC (2012) Omega-3 polyunsaturated fatty acids and inflammatory processes: nutrition or pharmacology? Br J Clin Pharmacol 75:645–662. https://doi.org/10.1111/j.1365-2125.2012.04374.x
Calder PC, Ahluwalia N, Brouns F et al (2011) Dietary factors and low-grade inflammation in relation to overweight and obesity. Br J Nutr 106:S5-78. https://doi.org/10.1017/S0007114511005460
Calder PC, Bosco N, Bourdet-Sicard R et al (2017) Health relevance of the modification of low grade inflammation in ageing (inflammageing) and the role of nutrition. Ageing Res Rev 40:95–119. https://doi.org/10.1016/j.arr.2017.09.001
Candela CG, Lopez LMB, Kohen VL (2011) Importance of a balanced omega 6/omega 3 ratio for the maintenance of health nutritional recommendations. Nutr Hosp 26(2):323–329. https://doi.org/10.3305/nh.2011.26.2.5117
Cárdeno A, Sánchez-Hidalgo M, Aparicio-Soto M et al (2014a) Extra virgin olive oil polyphenolic extracts downregulate inflammatory responses in LPS-activated murine peritoneal macrophages suppressing NFκB and MAPK signalling pathways. Food Funct 5:1270–1277. https://doi.org/10.1039/c4fo00014e
Cárdeno A, Sanchez-Hidalgo M, Aparicio-Soto M, Alarcón-de-la-Lastra C (2014b) Unsaponifiable fraction from extra virgin olive oil inhibits the inflammatory response in LPS-activated murine macrophages. Food Chem 147:117–123. https://doi.org/10.1016/j.foodchem.2013.09.117
Calle MC, Andersen CJ (2019) Assessment of dietary patterns represents a potential, yet variable, measure of inflammatory status: a review and update. Dis Markers https://doi.org/10.1155/2019/3102870
Casas R, Emilio S, Ramon Estruch R (2014) The immune protective effect of the mediterranean diet against chronic low-grade inflammatory diseases. Endocr Metab Immune Disord Drug Targets 14:245–254
Cevenini E, Monti D, Franceschi C (2013) Inflamm-ageing. Curr Opin Clin Nutr Metab Care 16(1):14–20. https://doi.org/10.1097/MCO.0b013e32835ada13
Choi JS, Islam N, Ali Y et al (2014) Effects of C-glycosylation on anti-diabetic, anti-Alzheimer's disease and anti-inflammatory potential of apigenin. Food Chem Toxicol 64:27–33. https://doi.org/10.1016/j.fct.2013.11.020
Chung H, Kim D, Lee E et al (2021) Redefining chronic inflammation in aging and age-related diseases: proposal of the senoinflammation concept. Aging Dis 10(2):367–382. https://doi.org/10.14336/AD.2018.0324
Cicerale S, Lucas LJ, Keast RSJ (2012) Oleocanthal: a naturally occurring anti-inflammatory agent in virgin olive oil. In: Boskou D (ed) Olive oil-constituents, quality, health properties and bioconversions, 1st edn. IntechOpen, Rijeka, pp 357–374
Ciccone M, Cortese F, Gesualdo M et al (2013) Dietary intake of carotenoids and their antioxidant and anti-inflammatory effects in cardiovascular care. Mediators Inflamm 2013:1–11. https://doi.org/10.1155/2013/782137
Corley J, Kyle JAM, Starr JM (2015) Dietary factors and biomarkers of systemic inflammation in older people: the Lothian Birth Cohort 1936. Br J Nutr 114(7):1188–1198. https://doi.org/10.1017/S000711451500210X
Csiszar A (2011) Anti-inflammatory effects of resveratrol: possible role in prevention of age-related cardiovascular disease. Ann N Y Acad Sci 1215:117–122. https://doi.org/10.1111/j.1749-6632.2010.05848.x
Dang Y, Li Z, Wei Q et al (2018) Protective effect of apigenin on acrylonitrile-induced inflammation and apoptosis in testicular cells via the NF-κB pathway in rats. Inflammation 41:1448–1459. https://doi.org/10.1007/s10753-018-0791-x
de Sá Coutinho D, Pacheco M, Frozza R, Bernardi A (2018) Anti-inflammatory effects of resveratrol: mechanistic insights. Int J Mol Sci 19:1812. https://doi.org/10.3390/ijms19061812

Di Tomo P, Canali R, Ciavardelli D et al (2012) β-Carotene and lycopene affect endothelial response to TNF-α reducing nitro-oxidative stress and interaction with monocytes. Mol Nutr Food Res 56:217–227. https://doi.org/10.1002/mnfr.201100500

Duarte S, Arango D, Parihar A et al (2013) Apigenin protects endothelial cells from lipopolysaccharide (LPS)-induced inflammation by decreasing caspase-3 activation and modulating mitochondrial function. Int J Mol Sci 14:17664–17679. https://doi.org/10.3390/ijms140917664

Ekmekcioğlu C (2020) Nutrition and longevity – from mechanisms to uncertainties. Crit Rev Food Sci Nutr 60(18):3063–3082. https://doi.org/10.1080/10408398.2019.1676698

Ellulu M, Khaza'ai H, Abed Y et al (2015) Role of fish oil in human health and possible mechanism to reduce the inflammation. Inflammopharmacology 23:79–89. https://doi.org/10.1007/s10787-015-0228-1

Estruch R (2010) Anti-inflammatory effects of the Mediterranean diet: the experience of the PREDIMED study. Proc Nutr Soc 69:333–340. https://doi.org/10.1017/S0029665110001539

Fechtner S, Singh A, Chourasia M et al (2017) Molecular insights into the differences in anti-inflammatory activities of green tea catechins on IL-1β signaling in rheumatoid arthritis synovial fibroblasts. Toxicol Appl Pharmacol 329:112–120. https://doi.org/10.1016/j.taap.2017.05.016

Feng D, Ling WH, Duan RD (2010) Lycopene suppresses LPS-induced NO and IL-6 production by inhibiting the activation of ERK, p38MAPK, and NF-κB in macrophages. Inflamm Res 59:115–121. https://doi.org/10.1007/s00011-009-0077-8

Fenni S, Hammou H, Astier J et al (2017) Lycopene and tomato powder supplementation similarly inhibit high-fat diet induced obesity, inflammatory response, and associated metabolic disorders. Mol Nutr Food Res 61:1601083. https://doi.org/10.1002/mnfr.201601083

Fernandes J, Fialho M, Santos R et al (2020) Is olive oil good for you? A systematic review and meta-analysis on anti-inflammatory benefits from regular dietary intake. Nutrition 69:110559. https://doi.org/10.1016/j.nut.2019.110559

Funakoshi-Tago M, Nakamura K, Tago K et al (2011) Anti-inflammatory activity of structurally related flavonoids, apigenin, luteolin and fisetin. Int Immunopharmacol 11:1150–1159. https://doi.org/10.1016/j.intimp.2011.03.012

Furman D, Campisi J, Verdin E et al (2019) Chronic inflammation in the etiology of disease across the lifespan. Nat Med 25(12):1822–1832. https://doi.org/10.1038/s41591-019-0675-0

Fougère B, Boulanger B, Nourhashémi F et al (2017) Chronic inflammation: accelerator of biological aging. J Gerontol A Biol Sci Med Sci 72(9):1218–1225. https://doi.org/10.1093/gerona/glw240

Franceschi C, Garagnani P, Parini P et al (2018) Inflammaging: a new immune–metabolic viewpoint for age-related diseases. Nat Rev Endocrinol 14(10):576–590. https://doi.org/10.1038/s41574-018-0059-4

Galland L (2010) Diet and inflammation. Nutr Clin Pract 25:634–640. https://doi.org/10.1177/0884533610385703

Ghanbari R, Anwar F, Alkharfy K et al (2012) Valuable nutrients and functional bioactives in different parts of olive (Olea europaea L.)-a review. Int J Mol Sci 13:3291–3340. https://doi.org/10.3390/ijms13033291

Gopinath B, Buyken A, Flood V et al (2011) Consumption of polyunsaturated fatty acids, fish, and nuts and risk of inflammatory disease mortality. Am J Clin Nutr 93:1073–1079. https://doi.org/10.3945/ajcn.110.009977

Griffithd K, Aggarwal BB, Singh RB et al (2016) Food antioxidants and their anti-inflammatory properties: a potential role in cardiovascular diseases and cancer prevention. Diseases 4(3):28. https://doi.org/10.3390/diseases4030028

Guarner V, Rubio-Ruiz ME (2015) Low-grade systemic inflammation connects aging, metabolic syndrome and cardiovascular disease. In: Yashin AI, Jazwinski SM (eds) Aging and health – a systems biology perspective. Basel, Karger. Interdiscipl Top Gerontol vol 40, pp 99–106

Hajihashemi P, Haghighatdoost F (2018) Effects of whole-grain consumption on selected biomarkers of systematic inflammation: a systematic review and meta-analysis of randomized controlled trials. J Am Coll Nutr 38:275–285. https://doi.org/10.1080/07315724.2018.1490935

Hayasaka N, Shimizu N, Komoda T et al (2018) Absorption and metabolism of luteolin in rats and humans in relation to in vitro anti-inflammatory effects. J Agric Food Chem 66:11320–11329. https://doi.org/10.1021/acs.jafc.8b03273

He Q, Zhou W, Xiong C et al (2015) Lycopene attenuates inflammation and apoptosis in post-myocardial infarction remodeling by inhibiting the nuclear factor-κB signaling pathway. Mol Med Rep 11:374–378. https://doi.org/10.3892/mmr.2014.2676

Honarvar NM, Saedisomeolia A, Abdolahi M et al (2017) Molecular anti-inflammatory mechanisms of retinoids and carotenoids in Alzheimer's disease: a review of current evidence. J Mol Neurosci 61:289–304. https://doi.org/10.1007/s12031-016-0857-x

Jayarathne S, Koboziev I, Park OH et al (2017) Anti-inflammatory and anti-obesity properties of food bioactive components: effects on adipose tissue. Prev Nutr Food Sci 22(4):251–262. https://doi.org/10.3746/pnf.2017.22.4.251

Joseph SV, Edirisinghe I, Burton-Freeman FM (2014) Berries: anti-inflammatory effects in humans. J Agric Food Chem 62:3886–3903. https://doi.org/10.1021/jf4044056

Joseph S, Edirisinghe I, Burton-Freeman B (2016) Fruit polyphenols: a review of anti-inflammatory effects in humans. Crit Rev Food Sci Nutr 56:419–444. https://doi.org/10.1080/10408398.2013.767221

Kaulmann A, Bohn T (2014) Carotenoids, inflammation, and oxidative stress—implications of cellular signaling pathways and relation to chronic disease prevention. Nutr Res 34:907–929. https://doi.org/10.1016/j.nutres.2014.07.010

Kawata A, Murakami Y, Suzuki S (2018) Anti-inflammatory activity of β-carotene, lycopene and tri-n-butylborane, a scavenger of reactive oxygen species. In Vivo 32(2):255–264. https://doi.org/10.21873/invivo.11232

Kijlstra A, Tian Y, Kelly E et al (2012) Lutein: more than just a filter for blue light. Prog Retin Eye Res 31:303–315. https://doi.org/10.1016/j.preteyeres.2012.03.002

Killeen M, Linder M, Pontoniere P et al (2014) NF-κβ signaling and chronic inflammatory diseases: exploring the potential of natural products to drive new therapeutic opportunities. Drug Discover Today 19:373–378. https://doi.org/10.1016/j.drudis.2013.11.002

Kim C, Park M, Kim S et al (2014) Antioxidant capacity and anti-inflammatory activity of lycopene in watermelon. Int J Food SciTechnol 49:2083–2091. https://doi.org/10.1111/ijfs.12517

Kleemann R, Verschuren L, Morrison M et al (2011) Anti-inflammatory, anti-proliferative and anti-atherosclerotic effects of quercetin in human in vitro and in vivo models. Atherosclerosis 218:44–52. https://doi.org/10.1016/j.atherosclerosis.2011.04.023

Kourtgen A, Bauer M (2018) Biomarkers in inflammation. In: Cavaillon JM, Mervyn Singer M (eds) Inflammation: from molecular and cellular mechanisms to the clinic, 1st edn. Wiley-VCH, Weinheim, pp 1541–1566

Layé S, Nadjar A, Joffre C et al (2017) Anti-inflammatory effects of omega-3 fatty acids in the brain: physiological mechanisms and relevance to pharmacology. Pharmacol Rev 70:12–38. https://doi.org/10.1124/pr.117.014092

Lee Y, Han S, Song B et al (2015) Bioactives in commonly consumed cereal grains: implications for oxidative stress and inflammation. J Med Food 18:1179–1186. https://doi.org/10.1089/jmf.2014.3394

Lee W, Ku SK, Bae JW et al (2012) Inhibitory effects of lycopene on HMGB1-mediated pro-inflammatory responses in both cellular and animal models. Food Chem Toxicol 50:1826–1833. https://doi.org/10.1016/j.fct.2012.03.003

Lefevre M, Jonnalagadda S (2012) Effect of whole grains on markers of subclinical inflammation. Nutr Rev 70:387–396. https://doi.org/10.1111/j.1753-4887.2012.00487.x

Lescheid DW (2014) Probiotics as regulator of inflammation: a review. Funct Food Health Dis 4(7):299–311. https://doi.org/10.31989/ffhd.v4i7.2

Lesjak M, Beara I, Simin N et al (2018) Antioxidant and anti-inflammatory activities of quercetin and its derivatives. J Funct Foods 40:68–75. https://doi.org/10.1016/j.jff.2017.10.047

Lilja S, Oldenburg J, Pointner A et al (2020) Epigallocatechin gallate effectively affects senescence and anti-SASP via SIRT3 in 3T3-L1 preadipocytes in comparison with other bioactive substances. Oxid Med Cell Longev 2020:4793125. https://doi.org/10.1155/2020/4793125

Lin H, Chang T, Yang D et al (2012) Regulation of virus-induced inflammatory response by β-carotene in RAW264.7 cells. Food Chem 134:2169–2175. https://doi.org/10.1016/j.foodchem.2012.04.024

Li R, Hong P, Zheng X (2018) β-carotene attenuates lipopolysaccharide-induced inflammation via inhibition of the NF-κB, JAK2/STAT3 and JNK/p38 MAPK signaling pathways in macrophages. Anim Sci J 90:140–148. https://doi.org/10.1111/asj.13108

Li S, Fung F, Fu Z et al (2012) Anti-inflammatory effects of lutein in retinal ischemic/hypoxic injury: in vivo and in vitro studies. Invest Ophthamol Vis Sci 53:5976. https://doi.org/10.1167/iovs.12-10007

Liu D, Perkins J, Hennig B (2016) EGCG prevents PCB-126-induced endothelial cell inflammation via epigenetic modifications of NF-κB target genes in human endothelial cells. J Nutr Biochem 28:164–170. https://doi.org/10.1016/j.jnutbio.2015.10.003

Liu Q, Qian Y, Chen F et al (2014) EGCG attenuates pro-inflammatory cytokines and chemokines production in LPS-stimulated L02 hepatocyte. Acta Biochim Biophys Sin 46:31–39. https://doi.org/10.1093/abbs/gmt128

Li Y, Yao J, Han C et al (2016) Quercetin, inflammation and immunity. Nutrients 8:167. https://doi.org/10.3390/nu8030167

Lu CC, Yen GC (2015) Antioxidant and anti-inflammatory activity of functional foods. Curr Opin Food Sci 2:1–8. https://doi.org/10.1016/j.cofs.2014.11.002

Lucas L, Russell A, Keast R (2011) Molecular mechanisms of inflammation. anti-inflammatory benefits of virgin olive oil and the phenolic compound oleocanthal. Curr Pharm Des 17:754–768. https://doi.org/10.2174/138161211795428911

Ma C, Wang Y, Dong L et al (2015) Anti-inflammatory effect of resveratrol through the suppression of NF- B and JAK/STAT signaling pathways. Acta Biochim Biophys Sin 47:207–213. https://doi.org/10.1093/abbs/gmu135

Ma C, Sun Z, Zeng Y et al (2018) Molecular mechanism and health role of functional ingredients in blueberry for chronic disease in human beings. Int J Mol Sci 19:2785. https://doi.org/10.3390/ijms19092785

Marcason W (2010) J Am Diet Assoc 110(11):1780. https://doi.org/10.1016/j.jada.2010.09.024

Marcotorchino J, Romier B, Gouranton E et al (2012) Lycopene attenuates LPS-induced TNF-α secretion in macrophages and inflammatory markers in adipocytes exposed to macrophage-conditioned media. Mol Nutr Food Res 56(5):725–732. https://doi.org/10.1002/mnfr.201100623

Mazidi M, Rezaie P, Ferns G et al (2016) Impact of different types of tree nut, peanut, and soy nut consumption on serum C-reactive protein (CRP). Medicine 95:e5165. https://doi.org/10.1097/md.0000000000005165

McEneny J, Wade L, Young I et al (2013) Lycopene intervention reduces inflammation and improves HDL functionality in moderately overweight middle-aged individuals. J Nutr Biochem 24:163–168. https://doi.org/10.1016/j.jnutbio.2012.03.015

Milajerdi A, Mousavi S, Sadeghi A et al (2020) The effect of probiotics on inflammatory biomarkers: a meta-analysis of randomized clinical trials. Eur J Nutr 59:633–649. https://doi.org/10.1007/s00394-019-01931-8

Mocellin M, Camargo C, Nunes E et al (2016) A systematic review and meta-analysis of the n-3 polyunsaturated fatty acids effects on inflammatory markers in colorectal cancer. Clin Nutr 35:359–369. https://doi.org/10.1016/j.clnu.2015.04.013

Monti D, Ostan R, Borelli V et al (2017) Inflammaging and omics in human longevity. Mech Ageing Dev 165(Pt B):129–138. https://doi.org/10.1016/j.mad.2016.12.008

Morais CA, de Rosso VV, Estadella D et al (2016) Anthocyanins as inflammatory modulators and the role of the gut microbiota. J Nutr Biochem 33:1–7. https://doi.org/10.1016/j.jnutbio.2015.11.008

Nabavi SF, Braidy N, Gortzi O et al (2015) Luteolin as an anti-inflammatory and neuroprotective agent: a brief review. Brain Res Bull 119:1–11. https://doi.org/10.1016/j.brainresbull.2015.09.002
Natto Z, Yaghmoor W, Alshaeri H et al (2019) Omega-3 fatty acids effects on inflammatory biomarkers and lipid profiles among diabetic and cardiovascular disease patients: a systematic review and meta-analysis. Sci Rep 9:18867. https://doi.org/10.1038/s41598-019-54535-x
Neale EP, Batterham MJ, Tapsell LC (2016) Consumption of a healthy dietary pattern results in significant reductions in C-reactive protein levels in adults: a meta-analysis. Nutr Res 36:391–401. https://doi.org/10.1016/j.nutres.2016.02.009
Neale E, Tapsell L, Guan V et al (2017) The effect of nut consumption on markers of inflammation and endothelial function: a systematic review and meta-analysis of randomised controlled trials. BMJ Open 7:e016863. https://doi.org/10.1136/bmjopen-2017-016863
Oh J, Kim J, Park J et al (2013) Radical scavenging activity-based and AP-1-targeted anti-inflammatory effects of lutein in macrophage-like and skin keratinocytic cells. Mediators Inflamm 2013:787042. https://doi.org/10.1155/2013/787042
Ohira H, Tsutsui W, Fujioka Y (2017) Are short chain fatty acids in gut microbiota defensive players for inflammation and atherosclerosis? J Atheroscler Thromb 24:660–672. https://doi.org/10.5551/jat.rv17006
Ohishi T, Goto S, Monira P et al (2016) Anti-inflammatory action of green tea. Antiinflamm Antiallergy Agents Med Chem 15:74–90. https://doi.org/10.2174/1871523015666160915154443
Oppedisano F, Macrì R, Gliozzi M et al (2020) The anti-inflammatory and antioxidant properties of n-3 PUFAs: their role in cardiovascular protection. Biomedicines 8:306. https://doi.org/10.3390/biomedicines8090306
Oz AT, Kafkas E (2017) Phytochemicals in fruits and vegetables. In: Waisundara VY, Shiomi N (eds) Superfood and functional food - an overview of their processing and utilization, 1st edn. IntechOpen, Rijeka, pp 175–184
Parhiz H, Roohbakhsh A, Sultani F et al (2015) Antioxidant and anti-inflammatory properties of the citrus flavonoids hesperidin and hesperetin: an updated review of their molecular mechanisms and experimental models. Phytother Res 29(3):323–331. https://doi.org/10.1002/ptr.5256
Parkinson L, Cicerale S (2016) The health benefiting mechanisms of virgin olive oil phenolic compounds. Molecules 21:1734. https://doi.org/10.3390/molecules21121734
Rangel-Huerta O, Aguilera C, Mesa M et al (2012) Omega-3 long-chain polyunsaturated fatty acids supplementation on inflammatory biomakers: a systematic review of randomised clinical trials. Br J Nutr 107:S159–S170. https://doi.org/10.1017/s0007114512001559
Rebello C, Greenway F, Finley J (2014) A review of the nutritional value of legumes and their effects on obesity and its related co-morbidities. Obes Rev 15:392–407. https://doi.org/10.1111/obr.12144
Reyes-Díaz A, Del-Toro-Sánchez C, Rodríguez-Figueroa J et al (2019) Legume proteins as a promising source of anti-inflammatory peptides. Curr Protein Pept Sci 20:1204–1217. https://doi.org/10.2174/1389203720666190430110647
Reygaert W (2017) An update on the health benefits of green tea. Beverages 3:6. https://doi.org/10.3390/beverages3010006
Riegsecker S, Wiczynski D, Kaplan M et al (2013) Potential benefits of green tea polyphenol EGCG in the prevention and treatment of vascular inflammation in rheumatoid arthritis. Life Sci 93:307–312. https://doi.org/10.1016/j.lfs.2013.07.006
Ros E (2015) Contribution of nuts to the Mediterranean diet. In: Preedy VR, Watson RR (eds) The Mediterranean diet an evidence based approach, 1st edn. Academic Press, Massachusetts, pp 175–184
Rosignoli P, Fuccelli R, Fabiani R et al (2013) Effect of olive oil phenols on the production of inflammatory mediators in freshly isolated human monocytes. J Nutr Biochem 24:1513–1519. https://doi.org/10.1016/j.jnutbio.2012.12.011
Qiao Y, Jiang P, Gao Y (2018) Lutein prevents osteoarthritis through Nrf2 activation and down-regulation of inflammation. Arch Med Sci 14:617–624. https://doi.org/10.5114/aoms.2016.59871

Salehi-Abargouei A, Saraf-Bank S, Bellissimo N et al (2015) Effects of non-soy legume consumption on C-reactive protein: a systematic review and meta-analysis. Nutrition 31:631–639. https://doi.org/10.1016/j.nut.2014.10.018

Sanada F, Taniyama Y, Muratsu J et al (2018) Source of chronic inflammation in aging. Front Cardiovasc Med 5:12. https://doi.org/10.3389/fcvm.2018.00012

Sang S, Idehen E, Zhao Y et al (2020) Emerging science on whole grain intake and inflammation. Nutr Rev 78:21–28. https://doi.org/10.1093/nutrit/nuz079

Santangelo C, Varì R, Scazzocchio B et al (2017) Anti-inflammatory activity of extra virgin olive oil polyphenols: which role in the prevention and treatment of immune-mediated inflammatory diseases? Endocr Metab Immune Disord Drug Targets 18:36–50. https://doi.org/10.2174/1871530317666171114114321

Serventi L, Dsouza L (2020) Bioactives in legumes. In: Serventi L (ed) Upcycling legume water: from wastewater to food ingredients, 1st edn. Springer, New York, pp 139–153

Sharma R, Padwad Y (2020) Nutraceuticals-based immunotherapeutic concepts and opportunities for the mitigation of cellular senescence and aging: a narrative review. Ageing Res Rev 63:101141. https://doi.org/10.1016/j.arr.2020.101141

Souza P, Marcadenti A, Portal V (2017) Effects of olive oil phenolic compounds on inflammation in the prevention and treatment of coronary artery disease. Nutrients 9:1087. https://doi.org/10.3390/nu9101087

Tabrizi R, Ostadmohammadi V, Akbari M et al (2019) The effects of probiotic supplementation on clinical symptom, weight loss, glycemic control, lipid and hormonal profiles, biomarkers of inflammation, and oxidative stress in women with polycystic ovary syndrome: a systematic review and meta-analysis of randomized controlled trials. Probiotics Antimicrob Proteins. https://doi.org/10.1007/s12602-019-09559-0

Tejada S, Pinya S, Martorell M et al (2018) Potential anti-inflammatory effects of hesperidin from the genus *citrus*. Curr Med Chem 25:4929–4945. https://doi.org/10.2174/0929867324666170718104412

Testai L, Piragine E, Piano I et al (2020) The citrus flavonoid naringenin protects the myocardium from ageing-dependent dysfunction: potential role of SIRT1. Oxid Med Cell Longev 2020:4650207. https://doi.org/10.1155/2020/4650207

Tsai YF, Chen YR, Chen JP et al (2019) Effect of hesperidin on anti-inflammation and cellular antioxidant capacity in hydrogen peroxide-stimulated human articular chondrocytes. Process Biochem 85:175–184. https://doi.org/10.1016/j.procbio.2019.07.014

Tucker LA (2017) Consumption of nuts and seeds and telomere length in 5,582 men and women of the national health and nutrition examination survey (NHANES). J Nutr Health Aging 21(3):233–240. https://doi.org/10.1007/s12603-017-0876-5

Vendrame S, Klimis-Zacas D (2015) Anti-inflammatory effect of anthocyanins via modulation of nuclear factor-κB and mitogen-activated protein kinase signaling cascades. Nutr Rev 73(6):348–358. https://doi.org/10.1093/nutrit/nuu066

Virruso C, Accardi G, Colonna-Romano G et al (2014) Nutraceutical properties of extra-virgin olive oil: a natural remedy for age-related disease? Rejuvenation Res 17:217–220. https://doi.org/10.1089/rej.2013.1532

Wang J, Chen W, Wang Y (2020) The relationship between gut microbiota and inflammatory diseases: the role of macrophages. Front Microbiol 11:1065. https://doi.org/10.3389/fmicb.2020.01065

Wang J, Liu Y, Xiao L et al (2014) Anti-inflammatory effects of apigenin in lipopolysaccharide-induced inflammatory in acute lung injury by suppressing COX-2 and NF-kB pathway. Inflammation 37:2085–2090. https://doi.org/10.1007/s10753-014-9942-x

Wu W, Li Y, Wu Y et al (2015) Lutein suppresses inflammatory responses through Nrf2 activation and NF-κB inactivation in lipopolysaccharide-stimulated BV-2 microglia. Mol Nutr Food Res 59:1663–1673. https://doi.org/10.1002/mnfr.201500109

Wu X, Schauss AG (2012) Mitigation of inflammation with foods. J Agric Food Chem 60:6703–6717. https://doi.org/10.1021/jf3007008

Xie Y, Liang D, Wu Q et al (2019) A system-level investigation into the mechanisms of apigenin against inflammation. Nat Prod Commun 14:1934578X1987860. https://doi.org/10.1177/1934578x19878600

Xiao S, Liu W, Bi J et al (2018) Anti-inflammatory effect of hesperidin enhances chondrogenesis of human mesenchymal stem cells for cartilage tissue repair. J Inflamm 15:14. https://doi.org/10.1186/s12950-018-0190-y

Xiao Y, Xia J, Ke Y et al (2018) Effects of nut consumption on selected inflammatory markers: a systematic review and meta-analysis of randomized controlled trials. Nutrition 54:129–143. https://doi.org/10.1016/j.nut.2018.02.017

Xu Y, Wan Q, Feng J et al (2018) Whole grain diet reduces systemic inflammation. Medicine 97:e12995. https://doi.org/10.1097/md.0000000000012995

Yang J, Han Y, Chen C et al (2013) EGCG attenuates high glucose-induced endothelial cell inflammation by suppression of PKC and NF-κB signaling in human umbilical vein endothelial cells. Life Sci 92:589–597. https://doi.org/10.1016/j.lfs.2013.01.025

Yi L, Ma S, Ren D (2017) Phytochemistry and bioactivity of Citrus flavonoids: a focus on antioxidant, anti-inflammatory, anticancer and cardiovascular protection activities. Phytochem Rev 16:479–511. https://doi.org/10.1007/s11101-017-9497-1

Zhang Y, Gan R, Li S et al (2015) Antioxidant phytochemicals for the prevention and treatment of chronic diseases. Molecules 20:21138–21156. https://doi.org/10.3390/molecules201219753

Zhang X, Wang G, Gurley EC, Zhou H (2014) Flavonoid apigenin inhibits lipopolysaccharide-induced inflammatory response through multiple mechanisms in macrophages. PLoS ONE 9(9):e107072. https://doi.org/10.1371/journal.pone.0107072

Zhu F, Du B, Xu B (2018) Anti-inflammatory effects of phytochemicals from fruits, vegetables, and food legumes: a review. Crit Rev Food Sci Nutr 58(8):1260–1270. https://doi.org/10.1080/10408398.2016.1251390

Wirth MD, Hébert JR, Shivappa N, Hand GA, Hurley TG, Drenowatz C, McMahon D, Shook RP, Blair SN (2016) Anti-inflammatory Dietary Inflammatory Index scores are associated with healthier scores on other dietary indices. Nutr Res 36(3):214–219. https://doi.org/10.1016/j.nutres.2015.11.009