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Review Article

Impact of Natural Functional Foods on Oxidative Stress in HIV-Infected Individuals: Implications for MAFLD

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Abstract

This review explores the impact of natural functional foods on oxidative stress in individuals infected with the human immunodeficiency virus (HIV), with a specific focus on their implications for metabolic-associated fatty liver disease (MAFLD). The global prevalence of HIV continues to pose significant public health challenges, with chronic liver disease, particularly MAFLD, being a common cause of mortality among HIV patients. The pathogenesis of MAFLD involves multiple hits, including insulin resistance, lipid accumulation, oxidative stress, and mitochondrial dysfunction. Oxidative stress, in particular, disrupts normal cellular metabolism, leading to inflammation, fibrosis, and hepatocellular carcinoma. Antioxidants, found in various functional foods such as fish, pitaya, and certain plant-based and microbial sources, have shown potential in reducing oxidative stress and improving liver health. However, the mechanisms of action and the specific therapeutic effects of these functional foods require further investigation. Despite the promising potential of antioxidant-active functional foods in managing MAFLD among people living with HIV (PLWH), current research remains limited, and more in-depth studies are necessary to validate their efficacy and understand their underlying mechanisms.

Keywords: Metabolic associated fatty liver disease; Oxidative Stress; Antioxidant; HIV; Functional Foods

Abbreviations

ART: Antiretroviral Therapy

Bio-A: Biochanin A

DNJ: 1-Deoxynojirimycin

EGCG: Epigallocatechin Gallate

EGW: Eriobotrya Japonica

GB: Glinkgolide B

Gp120: Glycoprotein 120

HIV: Human Immunedeficiency Virus

IL: Interleukin

LRP: Leucine-Arginine-Proline

LQP: Leucine-Glutamine-Proline

MAFLD: Metabolic-Associated Fatty Liver Disease

NAC: N-Acetyl-L-Cysteine

P3G: Peonidin 3-O-Glucoside

PLWH: People Living With HIV

PMF: Polymethoxyfalvone

PPC: Polyenylphosphosphatidylcholine

PUFA: Polyunsaturated Fatty Acid

MUFA: Monounsaturated Fatty Acd

ROS: Reacctive Oxygen Species

SCFA: Short Chain Fatty Acid

SG3: Sesquiterpene Glycoside 3

TFCH: Total Flavonoid

TXER: Troxerutin

TNF: Tumor Necrosis Factor

Vpr: Viral Protein

VTP: Vine Tea Polyphenol

WGHP: Walnut Green Husk Polysaccharide

WHO: World Health Organization

Introduction

First identified in 1981, human immunodeficiency virus (HIV) continues to represent one of the most significant global public health challenges, with approximately 39.9 million individuals living with the virus by the end of 2023, according to the World Health Organization (WHO) [1,2]. In addition to immunological decline, HIV infection predisposes individuals to a wide range of comorbidities, including chronic liver diseases. Among these, metabolic-associated fatty liver disease (MAFLD), a newly defined entity replacing the traditional concept of non-alcoholic fatty liver disease (NAFLD), has gained attention due to its high prevalence and associated risks in people living with HIV(PLWH) [3]. Unlike NAFLD, which excludes other etiologies of liver disease, MAFLD is diagnosed based on positive criteria that emphasize metabolic dysfunction, including obesity, type 2 diabetes, and metabolic dysregulation [4-6]. This shift toward a more inclusive definition reflects the complex pathophysiology underlying MAFLD and facilitates a more comprehensive understanding of its etiology, particularly in high-risk populations such as PLWH [7,8].

Oxidative stress, characterized by an imbalance between reactive oxygen species (ROS) production and antioxidant defenses, is a critical factor in the pathogenesis of MAFLD [9,10]. It contributes to lipid peroxidation, mitochondrial dysfunction, inflammation, and hepatic fibrosis, forming a vicious cycle that exacerbation liver damage [11-13]. In HIV-infected individuals, oxidative stress is further amplified due to viral proteins, chronic immune activation, and antiretroviral therapy, leading to an increased prevalence of MAFLD compared to the general population [14]. Consequently, addressing oxidative stress offers a promising therapeutic target for managing MAFLD in PLWH [15].

Functional foods, defined as foods that provide health benefits beyond basic nutrition, have emerged as a potential intervention [16-20]. These foods, which include plant-based products, animal-derived components, and microbial sources, are rich in bioactive compounds, such as polyphenols, omega-3 fatty acids, and carotenoids. Preliminary studies suggest these compounds can modulate oxidative stress, improve hepatic metabolism, and alleviate MAFLD-related liver damage [21,22]. However, the therapeutic potential of functional foods in PLWH remains underexplored, and their mechanisms of action are not fully understood.

This review aims to critically evaluate the current evidence on the role of functional foods in mitigating oxidative stress and improving MAFLD in HIV-infected populations. By synthesizing findings from experimental and clinical studies, this paper seeks to identify research gaps and propose future directions for developing effective dietary strategies to address this growing public health concern.

HIV and Oxidative stress

Studies have found that HIV infection significantly increases oxidative stress within the body and decreases antioxidant capacity, which leads to oxidative damage to proteins, lipids, and DNA, contributing to the pathogenesis of HIV-related comorbidities, including metabolic-associated fatty liver disease [14]. The envelope protein Gp120 and viral protein R (Vpr) have been implicated in the increased ROS production in HIV infected individuals. These viral components induce oxidative stress by activating NADPH oxidase and mitochondiral dysfunction, resulting in excessive ROS generation [23-26]. ROS, including superoxide anions, hydrogen peroxide, and hydroxyl radicals, are highly reactive intermediates that disrupt cellular homeostasis and amplify inflammatory pathways [27-30].

The oxidative stress in HIV infection is further compounded by the chronic immune activation and inflammation associated with the disease. Pro-inflammatory cytokines, such as tumor necrosis factor-alpha (TNFα) and interleukin-1 beta (IL-1β), are elevated in HIV-infected individuals, stimulating further ROS production through the activation of NFκB and other signaling pathways [31-34]. Studies have shown a positive correlation between oxidative stress markers and immune dysregulation, as evidenced by elevated malondialdehyde (MDA) levels and reduced antioxidant capacity in HIV patients [14,35]. However, conflicting findings, such as those reported by Halickoval et al., who found no significant difference in oxidative stress markers between HIV-infected individuals and healthy controls, highlight the complexity of this relationship and the need for further investigation [36].

Oxidative stress also impacts HIV-associated neurological dysfunctions, such as HIV-associated dementia. Lipid peroxidation products, including 4-hydroxynonenal (4-HNE), have been found at elevated levels in the brain tissues of affected individuals, contributing to neuronal apoptosis and mitochondrial dysfunction [37,38]. Some studies have used antioxidants to treat HIV-associated dementia, finding that antioxidant therapy can halt the progression of the disease. However, potential statistical significance was not observed between the experimental and control groups likely due to insufficient sample sizes [39]. Another study found that Selegiline may exert neuroprotective effects by reducing ROS production and thereby reducing neuronal apoptosis [40].

In addition to its direct effects on tissues, oxidative stress contributes to the suppression of the immune system in HIV infected individuals. It depletes key nutrients, such as tryptophan, which are critical for maintaining antiviral responses and enhances viral replications [41-46]. Antioxidant-rich interventions, including dietary supplements and functional foods, have shown promise in preclinical studies for mitigating these effects [47-50]. However, the clinical efficacy of such approaches in improving oxidative stress-related outcomes in HIV remains an area requiring robust investigation [51].

Oxidative Stress and MAFLD

Oxidative stress plays a central role in the development and progression of metabolic -associated fatty liver disease, particularly in high-risk populations, such as individuals living with HIV [52]. The pathogenesis of MAFLD involves the interplay of multiple factors, including insulin resistance, lipid accumulation, inflammation, and mitochondrial dysfunction. Among these, oxidative stress has emerged as a primary driver, contributing to hepatocellular injury, steatosis, and fibrosis [53].

ROS, produced during normal metabolic processes, are tightly regulated by antioxidant defense mechanisms, such as superoxide dismutase (SOD), catalase, and glutathione peroxidase [3]. However, when ROS production exceeds the capacity of these defenses, oxidative damage occurs, triggering lipid peroxidation and protein oxidation. In hepatocytes, excessive ROS activates signaling pathways, such as NFκB and MAPKs, leading to the production of pro-inflammatory cytokines, including TNFα, IL-6, and IL-1β [54]. This inflammatory response exacerbates liver injury and promotes fibrosis through the activation of hepatic stellate cells [55,56].

The Nrf2 pathway, a key regulator of cellular redox homeostasis, plays a protective role by inducing the expression of antioxidant enzymes [57]. However, chronic oxidative stress can impair the Nrf2 pathway, further tipping the balance between ROS accumulation [58]. Conversely, the NFκB pathway, which is activated by oxidative stress, perpetuates the inflammatory cycle by promoting the expression of pro-inflammatory genes [59]. The interplay between Nrf2 and NFκB signaling creates a feedback loop, amplifying oxidative damage and inflammation in MAFLD.

In individuals living with HIV, oxidative stress is further amplified by the combined effects of chronic viral infection, antiretroviral therapy (ART), and metabolic disturbances [60]. These factors synergistically exacerbate hepatic oxidative stress, creating a permissive environment for the onset and progression of MAFLD. Evidence suggests that the prevalence of MAFLD in people living with HIV ranges from 20% to 63% significantly higher than in the general population [61]. This underscores the need for targeted interventions to address oxidative stress as a therapeutic strategy for managing MAFLD in this vulnerable group.

Correcting oxidative stress has shown promise in improving liver health and mitigating MAFLD [9]. Preclinical studies have demonstrated that antioxidant compounds can reduce hepatic lipid accumulation, inhibit inflammation signaling, and restore mitochondrial function [62-64]. Functional foods rich in bioactive compounds, such as polyphenols, anthocyanins, and omega-3 fatty acids, represent a promising dietary approach for managing oxidative stress-related liver injury [9, 65-67]. However, more rigorous clinical studies are needed to validate their efficacy and establish standardized guidelines for their use.

Functional foods with anti-HIV activity

The concept of functional foods was first proposed by Japan in 1984 and subsequently recognized by countries around the world [68,69]. Over the past decade, research on functional foods has gained widespread attention. Functional foods offer additional health benefits beyond basic nutrition, providing an attractive new option for the prevention and treatment of certain diseases, which has led to their increasing popularity [69]. Functional foods exhibit a wide array of health benefits due to their diverse bioactive components, which commonly include anthocyanins, astaxanthin, lycopene, resveratrol, curcumin, and others [70-74]. These distinct bioactive compounds endow functional foods with varied health-promoting properties, such as reducing blood lipid levels, lowering blood pressure, protecting the heart, combating cancer, exhibiting anti-inflammatory and anti-diabetic effects [75]. Recent studies on HIV have found that certain functional foods possess anti-HIV effects. For instance, a longitudinal analysis of data from over 60 months of follow-up by Sung et al. revealed that long-term consumption of Korean red ginseng helped maintain CD4+ T-cell counts in HIV patients and delayed the development of drug resistance, thereby improving HIV treatment outcomes and prognosis [76].

Another study indicated that ajoene in garlic can inhibit HIV from attaching to host cells, thus exerting antiviral effects [77].

Furthermore, other antioxidant-rich foods, such as green tea and ganoderma lucidum (Reishi mushroom), have also been recognized for their potential to enhance immunity and combat HIV [78-81]. The anti-HIV effect of ganoderma lucidum is primarily achieved through the inhibition of HIV protease by its constituents, ganoderma B and ganoderic acid B, indicating the potential for use in the development of antiretroviral drugs [82-84]. Green tea, containing epigallocatechin gallate (EGCG), can block HIV-1 from adhering to CD4 molecules through the gp120 protein, significantly reducing the infectivity of HIV-1[85].

Additionally, certain functional foods possess immunomodulatory properties; for instance, sesamin, a polyphenolic compound derived from sesame, can regulate levels of immune cytokines such as IL-4, IL-5, IL-13, and inhibit the NFκB signaling pathway [86]. NFκB is a crucial molecule regulating HIV replication and is currently a significant potential target in HIV-1 chemotherapeutic research. One major research direction in targeting NFκB for HIV treatment involves the use of antioxidants, such as N-acetyl-L-cysteine (NAC) [87]. Consequently, it is plausible that moderate intake of antioxidant-functional foods could aid in the treatment of HIV.

Antioxidant Functional Foods with and MAFLD

The onset and progression of MAFLD are closely related to oxidative stress. Therefore, functional foods rich in antioxidant-active compounds may play an important role in the prevention and treatment of MAFLD. It has been confirmed that some functional foods can neutralize free radicals and reduce oxidative stress-induced liver damage, thereby inhibiting hepatic steatosis by providing a variety of active compounds, such as polyphenols and anthocyanins [88]. Based on their origin, these functional foods can be categorized into three major groups: plant-based, animal-based, and microorganism and algae-based, with most currently discovered functional foods being plant-derived [75]. The following section will elaborate on functional foods with antioxidant properties and protective effects against fatty liver disease, classified by their source.

Plant-based Functional Foods

Plant-based foods are rich in bioactive compounds such as polyphenols, flavonoids, and phytosterols, among others. Previous studies have also shown that certain phenolic compounds found in plants can prevent and treat hepatic steatosis by inhibiting lipogenesis and promoting fat breakdown [89]. These plant compounds not only protect the liver but also improve insulin resistance and inflammation [90]. A summary of plant-based functional foods that can antagonize oxidative stress is provided in Table 1. Since the classification of many plant foods is ambiguous, for example, bitter melon and avocado are considered both vegetables and fruits---have not been subdivided plant-based foods in the table. It should be noted that some of the research findings listed in the table are controversial. For instance, while some studies suggest that green tea can improve fatty liver disease, others have found that green tea may exacerbate it, whereas black tea effectively prevents and treats the condition [91, 92]. In such cases, we have marked the entries with a symbol (†). The specific details are summarized in (Table 1).

Foods	Bioactive ingredients	Primary Benefits	Mechanisms of Action	Ref.
SchisandraChinensis bee pollen	Naringenin, rutin, chrysin	anti-inflammatory, antioxidant, hypoglycemic, , inhibiting hepatic lipid accumulation	inhibit SREBP-1c, LXR-α, and FAS, balance gut microbiota	[93]
Black tea (Camellia sinensis)	Black tea extract (Tea flavonoids, theaflavin, troxerutin[TXER])	antioxidan, anti-tumor, anti-inflammatory, improving hepatic steatosis	downregulate iNOS, eliminate NO production, inhibit oxygen free radicals production	[91, 92, 94]
Coccinia grandis (ivy gourd) leaves	alkaloid, cardenolides, flavonoids, terpenoids, saponins, and polyprenols	antioxidant, anti-inflammatory, hypolipidemic, hypoglycemic, analgesic, antimicrobial, antipyretic, sedative, hepatoprotective, anticancer	upregulate PPAR-α & PPAR-γ, downregulate NF-κB, iNOS, TNF-α, upregulate eNOS, inhibit bcl-2 expression	[95]
Bitter gourd	charantins, polypeptide-p, momordin, oleanolic acid 3-o-monodesmoside	anti-inflammatory, antioxidant, anti-diabetic, blood hypolipidemic, improving insulin resistance, alleviating hepatic steatosis	regulate mtochondrial activity, inhibit lipid accumulation	[96]

Olive leaf	Oleuropein	anti-inflammatory,anti-oxidant, hypoglycemic, hypolipidemic, anti-hypertensive, antiviral	scavenging free radicals, inhibit chemical oxidation of LDL	[97]
Broccoli	vitamin C, flavonoids, glucosinolates, sulforaphane, phenethyl isothiocyanate, isothiocyanates	antioxidant, hypolipidemic, reducing hepatic lipid deposition	inhibit CYP2E1, cytochrome P450 1A, cytochrome P450 3A，downregulate TNF, CD68	[98]
Broccoli sprouts	Glucoraphanin	improving insulin resistance, inhibiting oxidative stress	induce Nrf2, protect mitochondria, inhibit the development of NASH	[99]
Asian white radish(Raphanus sativus L.)	4-methylthio-3-butenyl isothiocyanate (MTBITC), anthocyanins, polysaccharides, glucosinolates	anti-inflammatory, anti-tumor, antioxidant, improving insulin resistance, hypolipidemic	reduce hepatic lipid accumulation	[66]
Black radish (Raphanus sativus L. var. niger)	3-(E)-(methylthio)methylene-2-pyrrolidinethione, polyphenols, MTBITC, anthocyanins, polysaccharides, glucosinolates	antioxidant, liver protective, hypolipidemic	enhance Nrf2 expression, eliminate free radicals	[100]
Tomato juice	Lycopene	anti-inflammatory, anti-proliferation, antioxidant, hypolipidemic, reducing hepatic lipid accumulation	upregulate FXR and HNF4A，increase the abundance of intestinal lactobacilli, decrease acetate:propionate ratio	[101]
Spinach	β-carotene, flavonoids, phenolic compounds, lutlein, lycopene, linolenic acid, thylakoids	hypoglycemic, hypolipidemic , anti-obesity, antioxidant, anti-inflammatory	scavenge ROS, induce antioxidant enzymes (catalase, SOD, GPx, and glutathione reductase), upregulate PPAR-γ, downregulate TNF-α and PTX-3	[102]
Orange carrot	carotenoids	anti-inflammatory, antioxidant, improving fatty liver	upregulate PPAR-α, AMPK, and PGC-1α	[103]
Corn	Corn peptide	hypolipidemic, antioxidant, hepatoprotective, hypoglycemic, anti-hypertensive	upregulate SIRT1/PPARα and Nrf2/HO-1	[104]
Pueraria lobata	Puerarin(4',7-dihydroxy-8-β-D-glucosylisoflavone)	antioxidant, improving insulin resistance, hypolipidemic, hepatoprotective	activate JAK/STAT, upregulate Nrf2 and HO-1	[105]
Quinoa	Quinoa polyphenol	anti-oxidant, hypolipidemic, anti-inflammatory	upregulate AMPK，inhibit SREBP-1c activity, downregulate SREBP-2 , HMGCR, IL-1β, IL-6, and TNF-α	[106,107]

Oat	Beta-glucan	hypolipidemic, hypoglycemic, antioxidant, improving insulin resistance, immunomodulation, anti-infection, anti-tumor	inhibit NFκB, balance gut microbiota	[108,109]
Djulis(Chenopodium formosanum Koidz)	rutin, Phytochemicals (Polyphenols and catechins)	antioxidant, hepatoprotective, hypolipidemic,hypoglycemic , anti-tumor	activate PPAR-γ, upregulate SIRT1, LXR, pAMPK, PPAR-α, p-ACChe CPT1B	[65]
Mango, anemarrhena	Mangiferin (1,3,6,7-tetrahydroxy-xanthone-C2-β-D-gluoside)	anti-inflammatory, anti-tumor, anti-oxidative stress, hypolipidemic, anti-diabetic, anti-aging, anti-viral, anti-microbial, hepatoprotective	inhibit NFκB, enhance Nrf2 expression, blockTGF-β/Smad pathway, downregulate NLRP3 expression, activate AMPK	[110]
Sesame	Sesame lignans(sesamin, sesamolin, and sesamol)	anti-inflammatory, antioxidant, hypoglycemic, hypolipidemic, improving insulin resistance, improving hepatic steatosis	downregulate phospho-JNK1/2/3, phospho-NF-κB p65, phospho-IRS1 and phospho-IKK α/β, upregulate XBP1, CPT-1A, LXRα, CYP7A1, reductions of TNF-α and IL-6 levels, increasing GSH, 38 vitamin C and Nrf2 levels, decreasing MDA and NO levels, and enhancing SOD, CAT 39 and GSH-Px activities, activate AMPK and PPAR signaling pathways	[111-113]
Purple sweet potato	anthocyanins	antoxidant, anti-cancer, improving insulin resistance, anti-diabetic, inhibiting liver fat accumulation	inhibit Src/ERK/C/EBPβ	[114]
Purple corncob	peonidin 3-O-glucoside (P3G)	anti-inflammatory, antioxidant, anti-hypertensive, anti-cancer, inhibiting liver fat accumulation	upregulate the lysomal function mediated by transcription factor EB, activate PPARα	[115]
Onion	anthocyanins, flavanols (quercetin and its derivatives)	antioxidant, immunomodulation, antibacterial, hypolipidemic, hypoglycemic, anti-inflammatory, reducing hepatic steatosis	downregulate NFκB, iNOS, TNFα, balance gut microbiota, upregulate Sirt1	[116]
Red cabbage(Brassica oleracea L.)	anthocyanins, flavonoids, ascorbic acid, isothiocyanate (glucosinolates)	antioxidant, anti-inflammatory, hypolipidemic, hepatoprotective	scavenging ROS	[117,118]
Açaí (Euterpe oleracea Martius)	Anthocyanin(mainly polyphenols), polyunsaturated(PUFA) and monounsaturated (MUFA) fatty acids	antioxidant, improving hepatic steatosis	increase the expression of Gpx1, Gpx4, Sod1	[119]

tomatoes, watermelons, pink guavas, grapefruits, apricots, and papayas	Lycopene(lyco)	antioxidant, anti-inflammatory, anti-cancer, anti-hypertensive, hypolipidemic, anti-proliferation, inhibiting lilver fat accumulation	upregulate NR1H4 and HNF4A,activate SIRT1	[101, 120-122]
Tomato	Saponins (mainly Esculeoside A)	antioxidant, hypolipidemic, hypoglycemic, inhibiting liver fat accumulation	activate AMPK, upregulate Nrf2-Keap1	[123]
Vine tea	Vine tea polyphenol(VTP)	antioxidant, anti-inflammatory, improving insulin resistance, inhibiting liver fat accumulation	upregulate Nrf2,activate AMPKα/ PPARα，inhibit the expression of SREBP-1 and FAS	[124]
Green tea†	EGCG	anti-inflammatory, antioxidant, anti-HIV, improving hepatis steatosis	increase NADPH oxidase activity, inhibit TLR4/MyD88 mediated NFκB activation	[80, 81, 85, 125-127]
kombuchas	phenolic compounds, mainly catechins	anti-inflammatory, antioxidant, hypolipidemic, reversing hepatic steatosis, improving glucose tolerance	downregulate SREBP1c and NLR, upregulate CPT-1 and adipo-R2	[128]
Sophora japonica	Troxerutin(TXER)	anti-thrombotic, antioxidant, anti-inflammatory, anti-tumor, neuroprotective	scavenging ROS, inhibit NFκB	[94-129]
Gardenia jasminoides	Geniposide	anti-inflammatory, antioxidant, lipid-lower, inhibiting liver fat accumulation	upregulate Nrf2/HO-1 and AMPK signaling	[130]
citrus	flavonoids	antioxidant, hypolipidemic, anti-cancer, anti-cardiovascular disease, improving insulin resistance	activate SIRT1/PGC-1α signaling pathway	[131]
Pimpinella anisum L.	trans-anethole, γ-himachalene, methyl chavicol, cis-isoeugenol, linalool, pseudo-iso-eugenyl-2-methyl butyrate	antioxidant, lower blood lipid, anti-diabetic, hepatoprotective, reducing liver fat accumulation	inhibit TLR-4, decrease TNF-α, IL-6	[132]
Qu Zhi Qiao (Fruit of Citrus Paradisicv. Changshanhuyou)	total Flavonoids (TFCH)	anti-inflammatory, antioxidant, improving hepatic steatosis	upregulate Nrf2-ARE signaling pathway	[133]
Haw (Crataegus aronia)	total flavone of haw leaves (TFHL), polyphenolic antioxidants, flavonoids(luteolin-7 glucoside, hyperoside and rutin	antioxidant, hypolipidemic, improving hepatic steatosis	upregulate Nrf2	[134,135]
Vitis coignetiae Pulliat leaves	Polyphenols and anthocyanins	antioxidant, reducing liver fat deposition	inhibit CYP2E1	[136]

Crataegus oxyacantha L	flavonoids and triterpene acids	anti-nflammatory, hypolipidemic,, reducing hepatic fat accumulattion	increase the activity of GSH and FRAP	[137]
Dragon fruit (Red Pitaya)	betacyanins	antioxidant, anti-inflammatory, hypolipidemic, hypoglycemic, improving insulin resistance, reducing hepatic steatosis	scavenging ROS, downregulate TNF-α, IL-1β, IL-6, upregulate IL-10, balance gut microbiota	[138]
Grape seed extract	proanthocyanidins， resveratrol	anti-inflammatory, antioxidant, anti-cancer, improving hepatic steatosis	upregulate PPARβ/δ, SOD, GPx, inhibit MAPK	[139,140]
Grape fruit	resveratrol,ellagic acid, pterostibene	antioxidant, anti-inflammatory, anti-cancer, improving hepatic steatosis	inhibit NFκB, upregulate Gstp1,FABP1,Gpx4, Gpx8, Gss, Gps7, Sod1, Nrf2, PPARα, HO-1, downregulate mTORC1, SREBP-1c	[141,143]
Vitis vinifera L. skin	anthocyanidins	anti-inflammatory, antioxidant, improving insulin resistance, improving hepatic steatosis	downregulate lipogenic factor sterol regulatory-element binding protein-1c, upregulate lipolytic pathway (phosphorylated liver kinase B1/phosphorylated adenosine-monophosphate-activated protein kinase	[144]
Black soybean	Isoflavones	antixodiant, improving insulin resistance, hypolipidemic	downregulate SREBP2, HMG-CoA reductase, upregulate PPARα/γ, ABCA1,pAMPK，	[145]
Pea	Pea albumin	antioxidant, hypolipidemic, anti-inflammatory, improving insulin resistance, reducing liver fat accumulation	activate AMPKα and ACC, downregulate SREBF1 and FASN, upregulate ATGL and PPARα/γ	[146]
Loquat fruit	Polyphenols	anti-inflammatory, antioxidant, anti-cancer, anti-hypertensive, anti-diabetic	activate PI3K/Akt/GLUT-4, SREBP-1c, ChREBP, Nrf-2, inhibit TLR4/MyD88/TRIF pathway	[147]
Eriobotrya japonica seed	Polyphenols (caffeic and chlorogenic acids)	blood hypolipidemic, antioxidant, inhibiting liver fat accumulation	scavenging ROS	[148]
Eriobotrya japonica	hot water extract of Eriobotrya japonica(EJW)	antioxidant, reducing hepatic lipid accumulation	upregulate AMPK, CPT-1, PPARα	[149]
Loquat leaf	Sesquiterpene glycoside 3(SG3), total sesquiterpene glycosides, total flavonoids (quercetin and kaemferol)	anti-inflammatory, antioxidant, improving insulin resistance, hypolipidemic	downregulate CYP2E1, p-JNK and NLRP3， upregulate IRs-1and Akt phosphorylation	[151-152]

Coconut oil	polyphenols (ferulic acid, caffeic acid, coumaric acid)	antioxidant, hypolipidemic, improving hepatic steatosis	upregulate Nrf2	[153]
Olive oil	polyphenols, nitro-fatty acids (NO2-FA),oleic acid, monounsaturated fatty acid, tyrosol	anti-inflammatory, antioxidant, improving insulin sensivity, hypolipidemic, improving hepatic steatosis	upregulate Nrf2, AMPK, and PPARs, inhibit the activation of JNK, promote the expression of Bcl2 and Bax, activate CBS and CSE mediated H_2S synthesis	[154-162]
Pine nut	Pinolenic acid	anti-inflammatory, antioxidant, hypolipidemic	downregulate SREBP1c, FASN, SCD1, upregulate AMPK/SIRT1 signaling pathway	[163]
Avocado oil	oleic acid, linolenic acid	antioxidant, hypolipidemic	improve mitochondrial ETC function, upregulate PPAR-δ	[164]
Flaxseed oil	Alpha-lipoic acid	antioxidant, reducing hepatic lipid accumulation	activate PPARα, inhibit FAS and SREBP1	[165-167]
Berberis vulgaris	Berberine	antioxidant, blood hypolipidemic, improving glucose tolerance, reducing hepatic lipid accumulation	downregulate SREBP-1c, pERK, TNF-α, JNK	[168]
Sesame oil	sesamol, sesamolin, and sesamin	anti-inflammatory, antioxidant, reducing liver fat accumulation	downregulate TNF-α,TGF-β and leptin, inhibit the activation of NFκB	[169]
Rapeseeds oil	phenolic compounds(sinapic, salicylic, protocatechuic, phydroxybenzoic, gentisic, ferulic, p-coumaric, cinnamic, caffeic, syringic acids), tocopherol,phytosterols	antioxidant, inhibiting lipogenesis	inhibit FAS, ACC, SREBP1 and SREBP, upregulate PPAR-α/γ	[165,170]
Coffee	Caffeic acid, caffeine	anti-inflammatory, antioxidant, alleviating hepatic steatosis	activate Nrf2, PPARα and CPT1, inhibit FAS and ACC	[171,172]
Dark chocolate	Polyphenolsv(catechin, epicatechin)	antioxidant, slowing the progression of hepatic steatosis	downregulate Nox2	[173-175]
blackberry	anthocyanins(cyanidin-3-glucoside, total alkaloids), flavonoids， ellagic acid	anti-inflammatory, antioxidant, improving insulin resistance, and reducing hepatic lipid accumulation	inhibit NFκB, downregulate FAS, SREBP-1c and ACC, upregulate CPT-1, improve gut microbiota balance, increase SCFA levels	[176]
Coffeeberry	caffeine, chlorogenic acid, condensed proanthocyanidins, quinic acid, ferulic acid	anti-inflammatory, antioxidant, improving hepatic steatosis	activate CaMKII/CREB/BDNF pathway, upregulate Sirt1, inhibit NFκB,iNOS, COX-2， PARP-1, PI3K/Akt/mTOP/p70S6K signaling	[177]

Orange	quercetin, phytosterols, dietary fibers, mono and poly-unsaturated fatty acids, phenolic compounds	anti-inflammatory, antioxidant	downregulate TGF-β,CTGF,collagen-1α, inhibit NFκB	[178]
Citrus reticulate blanco peel	polymethoxyfalvones (PMFs)	antioxidant, anti-inflammatory, anti-cancer, improving hepatic steatosis, hypolipidemic, improving insulin resistance	activate Nrf2，upregulate CPT1α, ACOX1, PPARα, downregulate IL-6, TNF-α, IL-1β	[34]
Pu-erh tea	theabrownin	anti-inflammatory, antioxidant, improving insulin resistance	upregulate adenylate cyclase activity, increase cAMP levels, activate PKA/AMPK, upregulate PPARs, inhibit NFκB/JNK	[179-180]
Fuzhuan brick tea†	theabrownin, caffeine	anti-inflammatory, anti-oxidant, blood hypolipidemic, hypoglycemic, improving hepatic steatosis	upreguate PPARs, promote gut microbiota baance, lower ERK phosphorylation, downregulate TGFβ, α-SMA, Col1A1, Col3A1	[181-182]
Que Zui tea	6-O'-caffeoylarbutin	anti-inflammatory, antioxidant, hypolipidemic, hypoglycemic, reducing liver fat accumulating	upregulate Nrf2, adiponectin and adipoR2, activate AMPK/PPAR-α signaling pathway	[183]
Red wine	flavonoids, resveratrol	anti-inflammatory, antioxidant	inhibit NFκB, activate Nrf2, AP-1	[21-184]
Lycium barbarum	Lycium barbarum polysaccharides	anti-inflammatory, antioxidant, immunomodulation	downregulate NLRP3/6, NFκB	[185]
Phyllanthus emblica L fruit†	polyphenols(tannins, lignans, flavonoids, alkaloids, mucic acid, gallic acid, ellagic acid, quercetin, geraniin, chebulagic acid, corilagin, phyllanthin)	anti-inflammatory, antioxidant, hypolipidemic, hypoglycemic, anti-cancer, anti-bacterial, hepatoprotective	downregulate SREBP-1c, LXRα, upregulate PPARα and adiponectin	[186]
Mulberry	flavonoids, polyphenol compounds, 1-deoxynojirimycin (DNJ)	hypoglycemic, increasing insulin secretion	upregulate PPARs, inhibit FAS and HMGCoA reductase	[187-188]
Cherry	anthocyanins(cyanidin-3-rutinoside), flavones	anti-inflammatory, antioxidant, hypoglycemic, hypolipidemic	inhibit NFKB, upregulate PPAR-γ, Nrf2	[189]
Ginkgo biloba	Ginkgolide B(GB)	anti-inflammatory, antioxidant, inhibiting hepatic fat accumulation	upregulate Nrf2	[190]
Cranberry (Vaccinium oxycoccos L.)	Vit E, Vit C, phenolic polyphenols (proanthocyanidins, anthocyanins, resveratrol)	antioxidant, anti-inflammatory, hypolipidemic, inhibiting hepatic fat accumulation	inhibit SREBP-1c, TLR4/NFκB, downregulate TNFα and IL-6	[191-192]

Blueberry leaf	anthocyanins, flavonoids(D-catechin, L-epicatechink, rutin, isoquercitrin, iridin and quercetin), phenolic acid(chlorogenic acid), last anthocyanin(cyanidin-3-O-glucoside), catechol	anti-inflammatory, antioxidant, inhibiting hepatic fat accumulation	induce the expression of AMPK/PGC-1α/SIRT3, upregulate ERRα, Nrf1, Nrf2	[193]
blueberry	Flavonoids, polyphenols (anthocyanins), pterostibene	anti-inflammatory, antioxidant, anti-cancer, improving hepatic steatosis	activate SIRT1/PGC-1α, inhibit SREBP-1c and nTORC1, upregulate PPAR-α, Nrf2, HO-1	[143, 194, 195]
Mulberry leaf extracts	chorogenic acid derivative, flavonoid, rutin, quercetin	anti-inflammatory, antioxidant, anti-diabetic, hypolipidemic, reducing liver fat deposition	upregulate PPARα, inhibit FAS, HMGCoA reductase	[109,188]
Bayberry juice	phenolic acids (caffeic, ferulic, sinapic, salicylic acids), anthocyanins, vitamin C	anti-inflammatory, antioxidant	downregulate TNF-α, IL-8	[196]
White wine	tyrosol	anti-inflammatory, antioxidant, hepatoprotective	activate CBS and CSE mediated H2S biosynthesis	[162]
curcuma longa	curcumin	anti-inflammatory, antioxidant, anti-tumor, hypolipidemic, hepatoprotective	induce Nrf-2-FXR-LXR signaling pathway	[168, 197-200]
Lemon balm	Rosmarinic acid	anti-inflammatory, antioxidant, improving insulin resistance, reducing liver fat accumulation	upregulate Nrf2, AMPK, PGC-1α, PPARα and downregulate SREBP-1c	[201]
Maoberry(antidesma bunius)	polyphenol(anthocyanin, cyanidin, peonidin, ascorbic acid, gallic acid, (-)-epicatechin(+)-catechin, cyanidin-3-O-glucoside	anti-inflammatory, antioxidant, hypolipidemic, improving hepatic steatosis	downregulate ACC and GPAT-1, TNFα, and IL-6	[202]
Satsuma mandarin	β-Cryptoxanthin	anti-inflammatory, antioxidant, improving insulin resistance, hypolipidemic, reducing liver fat accumulation	inhibit JNK, p38 MAPK, and NFκB, upregulate PPARs	[203,204]
Beet (Beta vulgaris)	Betaine	anti-inflammatory, antioxidant, hypolipidemic, reducing hepatic steatosis	activate beclin 1, Atg4 and Atg5, induce autophagy, upregulate Akt/mTOR signaling	[205]
raspberry	Ellagic Acid, raspberry ketone, resveratrol	anti-inflammatory, antioxidant, reducing hepatic steatosis	downregulate p47phox, and HIF-α, activate Nrf2, and Akt, downregulate TNFα and IL-6, inhibit TLR4/NFκB	[7, 142, 192, 206]
Pomegranate	Polyphenols, anthocyanidins, tannic acid, gallic acid, and ellagic acid	anti-inflammatory, antioxidant	reduce the expression of TNFα, IL-1β, IL-6, and IL10	[207,208]

Thymbra spicata L.	Rosmarinic acid, carvacrol	anti-inflammatory, antioxidant, improving hepatic steatosis, hypolipidemic	reducing oxidative/nitrosative stress pathay, reducing the contents of intracellular NO and ROS, inhibit NFκB	[209]
Carob pod	polyphenols	anti-inflammatory, antioxidant, anti-diabetic, reducing liver fat accumulation	upregulate SIRT1, PCG-1α,CTP-1a	[210]
Soybean	Polyenylphosphatidylcholine (PPC), phytic acid, pinitol, soy protein	anti-inflammatory, antioxidant, hypolipidemic, improving insulin resistance	balance the gut microbiota, reducing TNFα, upregulate Cyp7b1, FXR, and FGFR4	[211-214]
Black bean	polyphenols (delphinidin 3-glucoside, petunidin 3-glucoside, and malvidin 3-glucoside), flavonoids (anthocyanins)	antioxidant, hypolipidemic, increasing insulin secretion, reducing hepatic lipid concentration	downregulate SREBP-2, Cyp7A1	[215]
Green coffee bean	chlorogenic acid	hypolipidemic, reducing hepatic fat accumulation	activate AMPK, upregulate CPT-1, GLUT4 and PPARγ, inhibit ACC	[216]
Chickpea (Cicer arietinum)	biochanin A(Bio-A)	hypolipidemic, hypoglycemic, anti-inflammatory, inhibiting hepatic steatosis	activate Sirt3/AMPK/ULK-1 signaling	[217]
Mung bean (Vigna radiata L.)	phenolic acids	hypocholesterolemic, anti-inflammatory, antioxidant, hepatoprotective, inhibiting hepatic steatosis	increase fecal excretion of cholesterol, upregulate CPT1, Bcl2a1a, downregulate SREBP-1, HMG-CoA reductase	[218]
White kidney bean (Phaseolus vulgaris L.)	phaseolin, polyphenols, resistant starch, oligosaccharides	antioxidant, anti-inflammatory, anti-cancer, anti-obesity, cardioprotective, hypolipidemic, hypoglycemic, improve insulin resistance, reducing hepatic fat accumulation	balance gut microbiota, inhibiting α-amylase	[219,220]
Pigeon pea (Cajanus cajan L)	stilbenes,phytosterol(β-sitosterol, stigmasterol),linoleic acid	hypolipidemic, hypoglycemic	upregulate PPARα, CPT-1, and CYP7A1	[221]
Walnut	Walnut green husk polysaccharide(WGHP), ellagic acid	anti-inflammatory, antioxidant, anti-bacterial, improving glucose intolerance	inhibit CYP2E1, JNK, and p38K, activate AMPK and SIRT1	[222, 223], [206]
Chestnut	tannin, ellagic acid, scoparone	anti-inflammatory, antioxidant, immunomodulation, hypolipidemic, inhibiting hepatic steatosis	inhibit SREBP-1c, downregulate FAS, ACC	[224]

Poria cocos	Poria cocos polysaccharides	anti-inflammatory, antioxidant, immunomodulation, hypolipidemic, balancing gut microbiota, reducing hepatic fat accumulation	inhibit NLRP3	[225]
Ganoderma mushroom	Triterpenoids(lucidenic acids, ganoderic acids)	antioxidant, anti-bacterial, anti-cancer, anti-HIV, anti-hypertensive, anti-diabetic, improving hepatic steatosis	increase the activity of ACC and AMPK, inhibit SREBP1, upregulate CPT-1	[79]
Cinnamon	Cinnamyl alcohol	anti-inflammatory, antioxidant	downregulate SREBP-1c and ACC1	[226]
Lycii (Goji berry, wolfberry)	LFP-a1(Lycii fructus polysaccharides)	antioxidant, immunomodulation, anti-aging, anti-cancer	inhibit the expression of Bax and C-Myc	[227]
Humulus japonicas	luteolin 7-O-β-D-glucoside(LU)	anti-inflammatory, antioxidant, alleviating hepatic steatosis	upregulate PPARα and SOD1, increase catalase activity	[228]
Korean Red Ginseng	Red ginseng extract	antioxidant, anti-HIV, inhibiting hepatic fat accumulation	upregulate PPAR-α, CPT-1,CYP7A1, AMPK, and ACC, inhibit C/EBPα,SREBP-1c, PPAR-γ, FAS, ACAT2, HMGCR, and ApoB	[76,229]
Ginger	6-gingerol, 6-shogao1, , alpinetin,citral, zingerone	anti-inflammatory, antioxidant, hypolipidemic, anti-cancer, anti-diabetic, reducing liver fat accumulation, anti-HIV, immune-enhancing	downregulate TNFα and IL-1β, downregulate SREBP-1c, SREBP-2, FAS, SCD1, LXR, ACC1, DGAT-2, and CYP2E1, inhibit NFκB, activate Nrf2, LKB1/AMPK signaling pathway, activate SIRT3, and Akt, upregulate CPT1α, PPARα/γ, PGC1α	[230-237]
Garlic (Allium sativum)	Garlic-derived S-allylmercaptoccysteine, N-trans-coumaroyloctopamine, N-trans-feruloyloctopamine, allicin ajoene, diallyl disulfide, SAC sulfoxide, S-methylcysteine sulfoxide, allicin	anti-inflammatory, antioxidant, immunomodulation, hypolipidemic, improving insulin resistance, anti-HIV	downregulate CYP2E1 , p38MAPK, downregulate TGF-β1 and α-SMA, activate MEK/ERK, inhibit AP-1,NFκB	[238-241]
black rice (Oryza sativa L.)	anthocyanin (Cyanidin-3-glucoside, C3G)	anti-inflammatory, antioxidant, hypolipidemic, hypoglycemic, improving fatty liver	upregulate AMPK, PPAR-α, CPT1A, ACO, and CYP4A10	[242]
Sintanur brown rice	phenolic acids (trans-ferulic, trans-p-coumaric acid), vitamin B3(niacin)	anti-inflammatory, antioxidant, reducing hepatic lipid accumulation	upregulate SCFAs, regulate FXR and reduce hepatic lipogenesis	[243]

Red rice	phenolic extract, anthocyanins, proanthocyanidins, protocatechuic acid,oryzanol, vitamin E,coenzyme Q10	anti-inflammatory, antioxidant, anti-diabetic, hypolipidemic, reducing hepatic steatosis	downregulate NFκB, Bax/ Bcl-2 ratio, iNOS, p47PHOX, ATGL, CD36, LXRα, SREBP-1c, SREBP-2, HMGCR, and hepatic lipase (HL), upregulate ApoA-1, LPL, and CPT1A	[244]
Brown sorghum (Sorghum bicolor L.)	phenolic acids, 3-deoxyanthocyanidins(3-DXA), proanthocyanidins(tannins)	antioxidant, anti-inflammatory, anti-diabetic, anti-cancer, anti-obesity, improving insulin resistance, improving hepatic steatosis	block lipogenic enzymes, increase β-oxidation, upregulate PPARα, downregulate SREBP-1c, increase adipo R2 sensitivity	[245]
whole wheat	leucine-arginine-proline(LRP), leucine-glutamine-proline(LQP)	antioxidant, improving fatty liver	upregulate AMPK, ACC	[246]
Buckwheat (Fagopyrum esculentum Moench)	fagopyrin polyphenols (flavonoids)	anti-inflammatory, antioxidant, hypolipidemic	upregulate ACOX1, PPARα, ACAT2, FXR, SCFAs, downregulate CEBPα,CD36, ACC1, SREBP-1c,	[247]
Tartary buckwheat (Fagopyrum tataricum (L.) Gaertn.)	flavone	anti-inflammatory, antioxidant, hypolipidemic, anti-hypertensive, hypoglycemic	inhibit iNOS, COX2, IL-6, IL-1β, TNF-α, downregulate SREBP1, acetyl-COA carboxylase protein levels, activate AMPK, downregulate MAPK and NFκB, balance gut microbiota	[248]
Khorasan bean	polyphenols, carotenoid, coumarin, and ferulic acid isomer	anti-inflammatory, antioxidant, improving hepatic steatosis, improving insulin resistance	downregulate NFκB, TNF-α and IL-1α	[249]
Purslane seeds (Portulaca oleraceae L.)	Omega-3, α-tocopherol, ascorbic acid, β-carotene,glutathione, phenolic and flavonoids compounds	anti-inflammatory, antioxidant, hepatotective, anti-diabetic	scavenging ROS, increase intracellular glutathione concentration	[67]
Garden cress seeds (Lepidium sativum Linn.)	phenolic compounds, alkaloids, falvonoids, ascorbic acid, tocopherol, polyunsaturated fatty acids	anti-inflammatory, antioxidant, hypolipidemic, hepatotective , anti-diabetic	scavenging ROS, increaseintracellular glutathione concentration	[67]
Adzuki bean (Phaseolus angularis)	anthocyanin, catechin, and adzukisaponin	anti-inflammatory, antioxidant, hypolipidemic	upregulate adiponectin, AMPKα, CPT-1, PPARα, downregulate SREBP-1c, FAS, TNFα and NFκB	[250]

Table 1: Functional Foods from Plants.

Animal-based Functional Foods

Although the number of animal-based functional foods discovered to have antioxidant activity is relatively limited, some have been proven to improve MAFLD significantly. These functional foods mainly include fish, krill, shellfish, dairy products, and honey products, among others. A detailed summary is provided in (Table 2).

Foods	Bioactive ingredients	Primary Benefits	Mechanisms of Action	Ref.
Salmon	Astaxanthin	anti-inflammatory, antioxidant, anti-cancer,immunomodulation, hypolipidemic, anti-diabetic	Block TGF-β/Smad3 signaling, inhibit MAPK and NFκB	[251,252]
Fish oil†	eicosapentaenoic(EPA), docosahexaenoic(DHA)	anti-inflammatory, antioxidant, improving hepatic steatosis	activate PPARs	[21,253,257]
Bluefin tuna	Selenoneine	anti-inflammatory, antioxidant, hepatoprotective	downregulate Gpx1, selenop	[258]
Menhaden	Menhaden oil(C20-22(n-3) PUFA)	anti-inflammatory, hypolipidemic, hepatoprotective	inhibit SREBP1, ACC1, Fasn, NFκB, inhibit hepatic lipogenesis	[259]
Antarctic Krill(Euphausia superba)	phospholipid-protein complex,carotenoid fucoxanthin, astaxanthin	antioxidant, hypolipidemic	downregulat SREBP1c inhibit the expression of IL-1β, IL-6, TNFα	[260]
Freshwater clam (corbicula fluminea)	Campesterol, stigmasterol, unsaturated fatty acids	anti-inflammatory, antioxidant, improving hepatic steatosis	inhibit NLRP3, downregulate CYP3A	[261]
Silkworm pupae	Silkworm pupae peptides,α-linolenic acids	antioxidant, improving fatty liver	upregulate PPARα, CPT-1	[262]
Yogurt	lactic acid, conjugated linoleic acid, folate, S. thermophiles, fructosan, galacto-oligosaccharides, galactose	ant-inflammatory, antioxidant, improving insulin resistance	inhibit NFκB, downregulate the expresson of TNFα and FGF21	[263]
Camel milk	α-Lactalbumin, L-carnitine	antioxidant, anti-inflammatory, antibacterial, immunomodulation, hypolipidemic, alleviating hepatic steatosis	scavenging ROS, inhibit lipid absorption, upregulate PPARα/SREBP1 ratio	[264,265]

Table 2: Functional Foods from Animals.

Microbial and Algal-based Functional Foods

Microbial-based functional foods with antioxidant properties and effects on improving fatty liver disease primarily include probiotics that regulate gut microbiota balance, postbiotics, and fungi used in the production of specific foods. Postbiotics are beneficial substances produced by microbial metabolism or structural components of microorganisms, such as short-chain fatty acids (SCFAs), polysaccharides, peptides, and phospholipids, among others [266]. These substances exert their antioxidant effects and improve fatty liver through various mechanisms. Similarly, algal-based functional foods also demonstrate significant antioxidant properties and can improve fatty liver disease. Common algal functional foods include Spirulina, brown algae, Chlorella, and astaxanthin-rich microalgae, such as Haematomatococcus pluvialis is rich in anthocyanins, which are potent natural antioxidants that protect liver cells from damage caused by free radicals. (Table 3) provides a summary of microbial and algal-based functional foods with antioxidant functions.

Foods	Primary Benefits	Classification	Mechanisms of Action	Ref.
Bifidobacteria	Antioxidant,improving hepatic steatosis	Probiotic	upregulate SIRT1 and PPARα, downregulate SREBP1c	[194]
Lactobacillus casei strain Shirota(LCS)	Anti-inflammatory, anti-oxidant, immunomodulation	Probiotic	downregulate TLR singaling pathway, inhibit SREBP1c and FAS	[267,268]
Lactobacillus coryniformis subsp. Torquens T3 (T3L)	Anti-inflammatory, anti-oxidant, hypolipidemic, inhibiting liver fat accumulation	Probiotic	upregulate NRF2-NQO-1 pathway, upregulate SCFAs concentration, inhibit the expression of TNF-α and IL-6	[269]
Lactobacillus casei	Anti-inflammatory, anti-oxidant, reducing hepatic steatosis	Probiotic	balance gut microbiota, downregulate NGAL and KIM-1, activate FOXO1/ pAMPK	[270]
Saccharomyces cerevisiae probiotic yeast	Anti-inflammatory, antioxidant, anti-diabetic(improving insuln sensitivity), inhibting fatty degeneration of liver	Probiotic	increase SCFAs concentration, immunemodulation, promote lipolysis	[271]
Sugary Kefir Strain Lactobacillus mali APS1	Anti-oxidant, reducing liver fat accumulation	Probiotic	activate AMPK, SIRT-1, PGC-1α and PPAR-γ, inhibit SREBP-1, upregulate Nrf-2/HO-1	[272]
Sodium butyrate	anti-inflammatory, antioxidant, hypolipidemic, improving hepatis steatosis	Postbiotic	upregulate miR-150, inhibit CXCR4, activate LKB1-AMPK-Insig, upregulate GLP-1	[273,274]
Monascus	anti-inflammatory, anti-oxidant, anti-diabetic, anti-hypertensive, immunomodulation, anti-tumor, hypolipidemic	Probiotic	activate PPAR-γ/Nrf-2, upregulate FXR, PGC1α and PPAR-α, downregulate TNFα and IL-6, enhance NO synthesis, inhibit JNK, ERK p38 kinase , NPC1L1, HR-LPL, C/EBPβ, and RAGE signalng pathways	[275]
Wakame	anti-inflammatory, antioxidant, hypolipidemic, hypoglycemic, reduing hepatic steatosis	Phaeophyta	upregulate CTP-1 and PPAR-α, downregulate SREBF-1	[210]
Sargassum serratifolium	anti-inflammatory, antioxidant	Brown algae	activate Nrf2, AMPK, PPARα, upregulate NQO1, HO-1, GST, and CPT-1, inhibit SREBP1c and C/EBPβ	[276,277]
Ulva prolifera	anti-inflammatory, antioxidant, hypolipidemic, improving insulin resistance, alleviating hepatic fat accumulation	green macroalgae	upregulate CPT-1a, ACOX1, and Acadm, inhibit DGAT1 and DGAT2	[278]

Brown seaweeds	anti-inflammatory, antioxidant, anti-cancer, reducing hepatic lipid accumulation	phaeophyta	activate PPARα/γ and Nrf2, downregulate TNFα,IL-1β, IL-6 and MCP-1	[279]
Spirulina	anti-inflammatory, antioxidant, immunomodulation, anti-cancer, anti-diabetic, hypolipidemic	blue-green algae	inhibit NFκB, downregulate TNFα, IL-6, and iNOS, upregulate adiponectin	[280-282]
Haematococcus pluvialis	anti-inflammatory, antioxidant, anti-cancer, immunomodulation, hypolipidemic, anti-diabetic	green microalga	block TGF-β/Smad3 signaling, inhibit MAPK and NFκB	[251]
Chlorella vulgaris	anti-inflammatory, antioxidant, hypolipidemic, immunomodulation, improve hepatic steatosis	microalgae	downregulate NGAL and KIM-1, activate FOXO1/pAMPK	[270]

Conclusion

In the absence of universally effective pharmacological treatments for MAFLD, functional foods have emerged as a promising, non-toxic alternative for managing this condition, particularly in HIV-infected populations. Functional foods rich in antioxidants offer multiple health benefits, including reducing oxidative stress, mitigating inflammation, and improving hepatic lipid metabolism. These advantages make them attractive as a dietary intervention for managing MAFLD. The findings summarized in this review highlight the therapeutic potential of functional foods, such as plant-based polyphenols, animal-derived omega-3 fatty acids, and probiotics. These bioactive compounds act through diverse molecular pathways, including the activation of Nrf2, suppression of NFκB, and modulation of lipid metabolism, to improve liver health. Notably, certain functional foods, such as EGCG, allicin, and ganoderma lucidum, have demonstrated dual benefits by both mitigating MAFLD and exhibiting anti-HIV activity [78,81,241]. For example, green tea's EGCG not only reduces hepatic steatosis but also inhibits HIV reverse transcriptase, providing a novel approach to addressing comorbidities in PLWH [81].

Despite these promising findings, the current evidence is limited by several factors. Most studies are preclinical or observational, with a paucity of high-quality randomized controlled trials validating the efficacy and safety of functional foods in clinical settings. Moreover, inconsistent results, as seen in studies on green tea and fish oil, suggest that individual variability, dosage differences, and complex metabolic interactions may influence outcomes. Further research is needed to clarify these discrepancies and establish standardized protocols for incorporating functional foods into dietary recommendations for MAFLD. Looking forward, the integration of functional foods into clinical practice for MAFLD management among PLWH requires a multidisciplinary approach. Collaboration among nutritionists, clinicians, and researchers is essential to design robust clinical trials that account for patient-specific factors, such as HIV status, antiretroviral therapy regimens, and coexisting metabolic disorders. Moreover, advances in nutrigenomics and metabolomics offer exciting opportunities to personalize dietary interventions based on individual genetic and metabolic profiles.

In conclusion, antioxidant-rich functional foods hold significant promise for addressing the dual challenges of oxidative stress and metabolic dysfunction in MAFLD among HIV-infected individuals. By bridging the gap between basic research and clinical application, these interventions could offer a sustainable and effective strategy for improving liver health and overall quality of life in this high-risk population. However, a concerted effort is needed to overcome current limitations, validate their benefits, and unlock their full therapeutic potential.

Declarations

Conflicts of interest

The author declares that he has no conflicts of interest.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publication

Not applicable.

Availability of data and materials

Not applicable.

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References

1. De Cock KM, Jaffe HW, Curran JW (2012) The evolving epidemiology of HIV/AIDS. Aids. 26: 1205-1213.
2. WHO (2024) HIV statistics, globally and by WHO region, 2024. Geneva, Switzerland: World Health Organization.
3. Delli Bovi AP, Marciano F, Mandato C, Siano MA, Savoia M, et al. (2021) Oxidative Stress in Non-alcoholic Fatty Liver Disease. An Updated Mini Review. Front Med (Lausanne) 8: 595371.
4. Eslam M, Newsome PN, Sarin SK, Anstee QM, Targher G,et al. (2020) A new definition for metabolic dysfunction-associated fatty liver disease: An international expert consensus statement. J Hepatol 73: 202-209.
5. Allende DS, Cummings O, Sternberg AL, Behling CA, Carpenter D, et al. (2024) MASLD in people with HIV exhibits higher fibrosis stage despite lower disease activity than in matched controls. Aliment Pharmacol Ther 60: 1351-1360.
6. Gofton C, Upendran Y, Zheng MH, George J (2023) MAFLD How is it different from NAFLD? Clin Mol Hepatol 29: S17-s31.
7. Panchal SK, Ward L, Brown L (2013) Ellagic acid attenuates high-carbohydrate, high-fat diet-induced metabolic syndrome in rats. Eur J Nutr 52: 559-568.
8. Michel M, Labenz C, Armandi A, Kaps L, Kremer WM, et al. (2023) Metabolic dysfunction-associated fatty liver disease in people living with HIV. Sci Rep 13: 9158.
9. Seidita A, Cusimano A, Giuliano A, Meli M, Carroccio A, et al. (2024) Oxidative Stress as a Target for Non-Pharmacological Intervention in MAFLD: Could There Be a Role for EVOO? Antioxidants (Basel). 13: 731.
10. Camini FC, da Silva Caetano CC, Almeida LT, de Brito Magalhães CL (2017) Implications of oxidative stress on viral pathogenesis. Arch Virol 162: 907-917.
11. Day CP, James OF (1998) Steatohepatitis: a tale of two “hits”? Gastroenterology 114: 842-845.
12. Tilg H, Moschen AR (2010) Evolution of inflammation in nonalcoholic fatty liver disease: the multiple parallel hits hypothesis. Hepatology 52: 1836-1846.
13. Ivanov AV, Bartosch B, Isaguliants MG (2017) Oxidative Stress in Infection and Consequent Disease. Oxid Med Cell Longev 2017: 3496043.
14. Ivanov AV, Valuev-Elliston VT, Ivanova ON, Kochetkov SN, Starodubova ES, et al. (2016) Oxidative Stress during HIV Infection: Mechanisms and Consequences. Oxid Med Cell Longev 2016: 8910396.
15. EASL-EASD-EASO (2016) Clinical Practice Guidelines for the management of non-alcoholic fatty liver disease. Diabetologia 59: 1121-1140.
16. Sies H (1985) Oxidative Stress. London:Academic Press 1-507.
17. Henry CJ (2010) Functional foods. Eur J Clin Nutr 64: 657-659.
18. Gautam R, Maurya K, Rai M, Singh R, Maurya R, et al. (2018) Consumer behavior towards functional food in eastern UP-A study of market drivers & challenges. IJAIR7: 15-30.
19. Topolska K, Florkiewicz A, Filipiak-Florkiewicz A (2021) Functional Food-Consumer Motivations and Expectations. Int J Environ Res Public Health 18: 5327.
20. Çakiroğlu FP, Uçar A (2018) Consumer attitudes towards purchasing functional products. Age 18: 494.
21. Da Silva MS, Rudkowska I (2016) Novel functional foods for optimal oxidative status in healthy ageing. Maturitas 93: 100-107.
22. Prabowo I, Utomo EP, Nurfaizy A, Widodo A, Widjajanto E, et al. (2019) Characteristics and antioxidant activities of anthocyanin fraction in red dragon fruit peels (Hylocereus polyrhizus) extract. Drug Invention Today 12: 670-678.
23. Ronaldson PT, Bendayan R (2008) HIV-1 viral envelope glycoprotein gp120 produces oxidative stress and regulates the functional expression of multidrug resistance protein-1 (Mrp1) in glial cells. J Neurochem 106: 1298-1313.
24. Shah A, Kumar S, Simon SD, Singh DP, Kumar A (2013) HIV gp120- and methamphetamine-mediated oxidative stress induces astrocyte apoptosis via cytochrome P450 2E1. Cell Death Dis 4: e850.
25. Deshmane SL, Mukerjee R, Fan S, Del Valle L, Michiels C, et al. (2009) Activation of the oxidative stress pathway by HIV-1 Vpr leads to induction of hypoxia-inducible factor 1alpha expression. J Biol Chem 284: 11364-11373.
26. Arunagiri C, Macreadie I, Hewish D, Azad A(1997) A C-terminal domain of HIV-1 accessory protein Vpr is involved in penetration, mitochondrial dysfunction and apoptosis of human CD4+ lymphocytes. Apoptosis 2: 69-76.
27. Gutowski M, Kowalczyk S (2013) A study of free radical chemistry: their role and pathophysiological significance. Acta Biochim Pol 60 : 1-16.
28. Augusto O, Miyamoto S (2011) Oxygen radicals and related species. Principles of free radical biomedicine 1: 19-42.
29. Halliwell B, Gutteridge J (1984) Oxygen toxicity, oxygen radicals, transition metals and disease. Biochemical journal 219: 1-14.
30. Ayala A, Muñoz M, Argüelles S (2014) Lipid peroxidation: production, metabolism, and signaling mechanisms of malondialdehyde and 4-hydroxy-2-nonenal. Oxid Med Cell Longev 2014: 360438.
31. Dattaroy D, Pourhoseini S, Das S, Alhasson F, Seth RK, et al. (2015) Micro-RNA 21 inhibition of SMAD7 enhances fibrogenesis via leptin-mediated NADPH oxidase in experimental and human nonalcoholic steatohepatitis. Am J Physiol Gastrointest Liver Physiol 308: G298-312.
32. Matsuzawa N, Takamura T, Kurita S, Misu H, Ota T, et al. (2007) Lipid-induced oxidative stress causes steatohepatitis in mice fed an atherogenic diet. Hepatology 46: 1392-1403.
33. Nan YM, Wu WJ, Fu N, Liang BL, Wang RQ, et al. (2009) Antioxidants vitamin E and 1-aminobenzotriazole prevent experimental non-alcoholic steatohepatitis in mice. Scand J Gastroenterol. 44: 1121-1131.
34. Ke Z, Zhao Y, Tan S, Chen H, Li Y, et al. (2020) Citrus reticulata Blanco peel extract ameliorates hepatic steatosis, oxidative stress and inflammation in HF and MCD diet-induced NASH C57BL/6 J mice. J Nutr Biochem. 83: 108426.
35. Biliaminu S, Hamza U, Okesina A, Abdulazeez I, Yusuff J, et al. (2024) Correlation between oxidative DNA damage and CD4 count in HIV

patients at University of Ilorin Teaching Hospital. Clinica Chimica Acta. 558: 118473.

36. Havlickova K, Snopkova S, Pohanka M, Svacinka R, Vydrar D, et al. (2024) Oxidative stress, microparticles, and E-selectin do not depend on HIV suppression. Biomedical Papers-Olomouc.

37. Turchan J, Pocernich CB, Gairola C, Chauhan A, Schifitto G, et al. (2003) Oxidative stress in HIV demented patients and protection ex vivo with novel antioxidants. Neurology 60: 307-314.

38. Colovic M, Caccia S (2003) Liquid chromatographic determination of minocycline in brain-to-plasma distribution studies in the rat. J Chromatogr B Analyt Technol Biomed Life Sci 791:337-343.

39. Di Rocco A (1999) A randomized, double-blind, placebo-controlled trial of deprenyl and thiotic acid in HIV-associated cognitive impairment. Neurology 52: 1920.

40. Carrillo MC, Ivy GO, Milgram NW, Head E, Wu P, et al. (1994) Deprenyl increases activities of superoxide dismutase (SOD) in striatum of dog brain. Life Sci 54: 1483-1489.

41. Soliman H, Mediavilla-Varela M, Antonia S (2010) Indoleamine 2, 3-dioxygenase: is it an immune suppressor? The Cancer Journal 16: 354-359.

42. Mellor AL, Munn DH (2004) IDO expression by dendritic cells: tolerance and tryptophan catabolism. Nature Reviews Immunology 4: 762-774.

43. Boasso A, Vaccari M, Hryniewicz A, Fuchs D, Nacsa J, et al. (2007) Regulatory T-cell markers, indoleamine 2, 3-dioxygenase, and virus levels in spleen and gut during progressive simian immunodeficiency virus infection. Journal of virology81: 11593-11603.

44. Favre D, Mold J, Hunt PW, Kanwar B, Loke Pn, et al. (2010) Tryptophan catabolism by indoleamine 2, 3-dioxygenase 1 alters the balance of TH17 to regulatory T cells in HIV disease. Science translational medicine 2: 32ra6-ra6.

45. Boasso A, Vaccari M, Nilsson J, Shearer GM, Andersson J, et al. (2006) Do regulatory T-cells play a role in AIDS pathogenesis. AIDS Rev 8: 141-147.

46. Nzowa L, Teponno R, Tapondjou L, Verotta L, Liao Z, et al .(2013) Two new tryptophan derivatives from the seed kernels of Entada rheedei: effects on cell viability and HIV infectivity. Fitoterapia 87: 37-42.

47. Steiner J, Haughey N, Li W, Venkatesan A, Anderson C, et al. (2006) Oxidative stress and therapeutic approaches in HIV dementia. Antioxid Redox Signal 8: 2089-2100.

48. Gélinas S, Martinoli MG (2002) Neuroprotective effect of estradiol and phytoestrogens on MPP+-induced cytotoxicity in neuronal PC12 cells. J Neurosci Res. 70: 90-96.

49. Calabrese V, Butterfield DA, Stella AM (2003) Nutritional antioxidants and the heme oxygenase pathway of stress tolerance: novel targets for neuroprotection in Alzheimer's disease. Ital J Biochem 52: 177-181.

50. Scapagnini G, Butterfield DA, Colombrita C, Sultana R, Pascale A, et al. (2004) Ethyl ferulate, a lipophilic polyphenol, induces HO-1 and protects rat neurons against oxidative stress. Antioxid Redox Signal 6: 811-818.

51. Becker K, Gromer S, Schirmer RH, Müller S (2000) Thioredoxin reductase as a pathophysiological factor and drug target. European journal of biochemistry 267: 6118-6125.

52. Spahis S, Delvin E, Borys JM, Levy E (2017) Oxidative Stress as a Critical Factor in Nonalcoholic Fatty Liver Disease Pathogenesis. Antioxid Redox Signal 26: 519-541.

53. Chen Z, Tian R, She Z, Cai J, Li H (2020) Role of oxidative stress in the pathogenesis of nonalcoholic fatty liver disease. Free Radic Biol Med 152: 116-14k1.

54. Pan H, Wang H, Wang X, Zhu L, Mao (2012) The absence of Nrf2 enhances NF-κB-dependent inflammation following scratch injury in mouse primary cultured astrocytes. Mediators Inflamm 2012: 217580.

55. Wiering L, Subramanian P, Hammerich L (2023) Hepatic Stellate Cells: Dictating Outcome in Nonalcoholic Fatty Liver Disease. Cell Mol Gastroenterol Hepatol 15: 1277-1292.

56. Jiang JX, Török NJ (2013) Liver Injury and the Activation of the Hepatic Myofibroblasts. Curr Pathobiol Rep 1: 215-223.

57. Zhang YK, Yeager RL, Tanaka Y, Klaassen CD (2010) Enhanced expression of Nrf2 in mice attenuates the fatty liver produced by a methionine- and choline-deficient diet. Toxicol Appl Pharmacol 245: 326-334.

58. Chen B, Lu Y, Chen Y, Cheng J (2015) The role of Nrf2 in oxidative stress-induced endothelial injuries. J Endocrinol 225: R83-99.

59. Liu GH, Qu J, Shen X (2008) NF-kappaB/p65 antagonizes Nrf2-ARE pathway by depriving CBP from Nrf2 and facilitating recruitment of HDAC3 to MafK. Biochim Biophys Acta 1783: 713-727.

60. Biały M, Czarnecki M, Inglot M (2023) Impact of Combination Antiretroviral Treatment on Liver Metabolic Health in HIV-Infected Persons. Viruses 15: 2432.

61. Lake JE, Overton T, Naggie S, Sulkowski M, Loomba R, et al. (2022) Expert Panel Review on Nonalcoholic Fatty Liver Disease in Persons With Human Immunodeficiency Virus. Clin Gastroenterol Hepatol 20: 256-268.

62. D'Andrea G (2015) Quercetin: A flavonol with multifaceted therapeutic applications? Fitoterapia. 106: 256-271.

63. Kim T, Mijan MA, Lee J, Yun J, Chung JH, et al. (2024) Essential Oils for the Treatment and Management of Nonalcoholic Fatty Liver Disease (NAFLD). Natural Product Communications. 19:1934578X241250248.

64. Al-Busafi SA, Bhat M, Wong P, Ghali P, Deschenes M (2012) Antioxidant therapy in nonalcoholic steatohepatitis. Hepatitis Research and Treatment 2012: 947575.

65. Tung YT, Zeng JL, Ho ST, Xu JW, Li S, et al. (2021) Anti-NAFLD Effect of Djulis Hull and Its Major Compound, Rutin, in Mice with High-Fat Diet (HFD)-Induced Obesity. Antioxidants (Basel) 2021: 10.

66. You H, Hao R, Li R, Zhang L, Zhu Y, et al. (2015) The effect of radish sourced 4-(Methylthio)-3-butenyl isothiocyanate on ameliorating the severity of high fat diet inducted nonalcoholic fatty liver disease in rats. Int J Clin Exp Med 8: 15910-15919.

67. D AM, S SA, H AE, R SM (2018) Preparation and Evaluation of Functional Foods for Prevention of Non-alcoholic Fatty Liver Disease. Pak J Biol Sci 21: 454-462.

68. Mellentin J, Heasman M (2014) The functional foods revolution: Healthy people, healthy profits: Routledge.

69. Ballini A, Charitos IA, Cantore S, Topi S, Bottalico L, et al. (2023) About Functional Foods: The Probiotics and Prebiotics State of Art. Antibiotics (Basel) 12: 635.

70. Chaplin A, Carpéné C, Mercader J (2018) Resveratrol, Metabolic Syndrome, and Gut Microbiota. Nutrients 10: 1651.

71. Sneharani AH (2019) Curcumin-sunflower protein nanoparticles-A potential antiinflammatory agent. J Food Biochem 43: e12909.

72. Tang L, Jin T, Zeng X, Wang JS (2005) Lycopene inhibits the growth of human androgen-independent prostate cancer cells in vitro and in BALB/c nude mice. J Nutr 135: 287-290.

73. Lila MA, Burton-Freeman B, Grace M, Kalt W (2016) Unraveling Anthocyanin Bioavailability for Human Health. Annu Rev Food Sci Technol 7: 375-393.

74. Kumar S, Kumar R, Kumari A, Panwar A (2022) Astaxanthin: A super antioxidant from microalgae and its therapeutic potential. J Basic Microbiol 62: 1064-1082.

75. Essa MM, Bishir M, Bhat A, Chidambaram SB, Al-Balushi B, et al. (2023) Functional foods and their impact on health. J Food Sci Technol 60: 820-834.

76. Sung H, Kang SM, Lee MS, Kim TG, Cho YK (2005) Korean red ginseng slows depletion of CD4 T cells in human immunodeficiency virus type 1-infected patients. Clin Diagn Lab Immunol 12: 497-501.

77. Walder R, Kalvatchev Z, Garzaro D, Barrios M, Apitz-Castro R (1997) In vitro suppression of HIV-1 replication by ajoene [(e)-(z)-4,5,9-trithiadodeca-1,6,11-triene-9 oxide]. Biomedicine & Pharmacotherapy 51: 397-403.

78. el-Mekkawy S, Meselhy MR, Nakamura N, Tezuka Y, Hattori M, et al. (1998) Anti-HIV-1 and anti-HIV-1-protease substances from Ganoderma lucidum. Phytochemistry 49:1651-1657.

79. Hsu CL, Yen GC (2014) Ganoderic Acid and Lucidenic Acid (Triterpenoid). Enzymes 36: 33-56.

80. Yamaguchi K, Honda M, Ikigai H, Hara Y, Shimamura T (2002) Inhibitory effects of (-)-epigallocatechin gallate on the life cycle of human immunodeficiency virus type 1 (HIV-1). Antiviral Res 53: 19-34.

81. Li S, Hattori T, Kodama EN (2011) Epigallocatechin gallate inhibits the HIV reverse transcription step. Antivir Chem Chemother 21: 239-243.

82. Sharma C, Bhardwaj N, Sharma A, Tuli HS, Batra P, et al. (2019) Bioactive metabolites of Ganoderma lucidum: Factors, mechanism and broad spectrum therapeutic potential. Journal of Herbal Medicine 18:100268.

83. Akbar R, Yam WK (2011)Interaction of ganoderic acid on HIV related target: molecular docking studies. Bioinformation 7: 413-417.

84. Kang D, Mutakin M, Levita J (2015) Computational study of triterpenoids of Ganoderma lucidum with aspartic protease enzymes for discovering HIV-1 and plasmepsin inhibitors. Int J Chem 7: 62.

85. Nance CL, Siwak EB, Shearer WT (2009) Preclinical development of the green tea catechin, epigallocatechin gallate, as an HIV-1 therapy. J Allergy Clin Immunol 123:459-465.

86. Lin CH, Shen ML, Zhou N, Lee CC, Kao ST,et al. (2014) Protective effects of the polyphenol sesamin on allergen-induced TH2 responses and airway inflammation in mice. PloS one 9: e96091.

87. Pande V, Ramos M (2003) Nuclear factor kappa B: a potential target for anti-HIV chemotherapy. Current medicinal chemistry 10: 1603-1615.

88. Mittal RK, Mishra R, Sharma V, Purohit P (2024) Bioactive Exploration in Functional Foods: Unlocking Nature's Treasures. Curr Pharm Biotechnol 25: 1419-1435.

89. Li S, Tan HY, Wang N, Zhang ZJ, Lao L, et al. (2015) The Role of Oxidative Stress and Antioxidants in Liver Diseases. Int J Mol Sci 16: 26087-26124.

90. Saha P, Talukdar AD, Nath R, Sarker SD, Nahar L, et al. (2019) Role of Natural Phenolics in Hepatoprotection: A Mechanistic Review and Analysis of Regulatory Network of Associated Genes. Front Pharmacol 10: 509.

91. Sarkar A, Bhaduri A (2001) Black tea is a powerful chemopreventor of reactive oxygen and nitrogen species: comparison with its individual catechin constituents and green tea. Biochem Biophys Res Commun 284: 173-178.

92. Karmakar S, Das D, Maiti A, Majumdar S, Mukherjee P, et al. (2011) Black tea prevents high fat diet-induced non-alcoholic steatohepatitis. Phytother Res 25: 1073-1081.

93. Cheng N, Chen S, Liu X, Zhao H, Cao W (2019) Impact of SchisandraChinensis Bee Pollen on Nonalcoholic Fatty Liver Disease and Gut Microbiota in High Fat Diet Induced Obese Mice. Nutrients. 11: 346.

94. Thomas NS, George K, Arivalagan S, Mani V, Siddique AI, et al. (2017) The in vivo antineoplastic and therapeutic efficacy of troxerutin on rat preneoplastic liver: biochemical, histological and cellular aspects. Eur J Nutr 56: 2353-2366.

95. Banerjee A, Das D, Paul R, Roy S, Das U, et al. (2020) Mechanistic study of attenuation of monosodium glutamate mixed high lipid diet induced systemic damage in rats by Coccinia grandis. Sci Rep 10: 15443.

96. Xu J, Cao K, Li Y, Zou X, Chen C, et al. (2014) Bitter gourd inhibits the development of obesity-associated fatty liver in C57BL/6 mice fed a high-fat diet. J Nutr 144: 475-483.

97. Omagari K, Kato S, Tsuneyama K, Hatta H, Sato M, et al. (2010) Olive leaf extract prevents spontaneous occurrence of non-alcoholic steatohepatitis in SHR/NDmcr-cp rats. Pathology 42 : 66-72.

98. Chen YJ, Wallig MA, Jeffery EH (2016) Dietary Broccoli Lessens Development of Fatty Liver and Liver Cancer in Mice Given Diethylnitrosamine and Fed a Western or Control Diet. J Nutr 146: 542-550.

99. Xu L, Nagata N, Ota T (2019) Impact of Glucoraphanin-Mediated Activation of Nrf2 on Non-Alcoholic Fatty Liver Disease with a Focus on Mitochondrial Dysfunction. Int J Mol Sci 20: 5920.

100. Ahn M, Kim J, Hong S, Kim J, Ko H, et al. (2018) Black Radish (Raphanus sativus L. var. niger) Extract Mediates Its Hepatoprotective Effect on Carbon Tetrachloride-Induced Hepatic Injury by Attenuating Oxidative Stress. J Med Food 21: 866-875.

101. Elvira-Torales LI, Navarro-González I, González-Barrio R, Martín-Pozuelo G, Doménech G, et al. (2018) Tomato Juice Supplementation Influences the Gene Expression Related to Steatosis in Rats. Nutrients 10: 1215.

102. Amirinejad A, Totmaj AS, Mardali F, Hekmatdoost A, Emamat H, et al. (2021) Administration of hydro-alcoholic extract of spinach improves oxidative stress and inflammation in high-fat diet-induced NAFLD rats. BMC Complement Med Ther 21: 221.

103. Balbuena E, Cheng J, Eroglu A (2022) Carotenoids in orange carrots

mitigate non-alcoholic fatty liver disease progression. Front Nutr 9: 987103.

104. Wei K, Wei Y, Xu W, Lu F, Ma H (2022) Corn peptides improved obesity-induced non-alcoholic fatty liver disease through relieving lipid metabolism, insulin resistance and oxidative stress. Food Funct. 13: 5782-5793.

105. Zheng P, Ji G, Ma Z, Liu T, Xin L, et al. (2009) Therapeutic effect of puerarin on non-alcoholic rat fatty liver by improving leptin signal transduction through JAK2/STAT3 pathways. Am J Chin Med 37: 69-83.

106. Yao W, Fan M, Qian H, Li Y, Wang L (2024) Quinoa Polyphenol Extract Alleviates Non-Alcoholic Fatty Liver Disease via Inhibiting Lipid Accumulation, Inflammation and Oxidative Stress. Nutrients 16: 2276.

107. Dong H, Zhao Y, Teng H, Jiang T, Yue Y, et al. (2024) Pueraria lobata antioxidant extract ameliorates non-alcoholic fatty liver by altering hepatic fat accumulation and oxidative stress. J Ethnopharmacol. 333: 118468.

108. You S, Hu X, Zhao Q, Chen X, Xu C (2013) Oat β-glucan inhibits lipopolysaccharide-induced nonalcoholic steatohepatitis in mice. Food Funct 4: 1360-1368.

109. Xu J, Wang X, Cao K, Dong Z, Feng Z, et al. (2017) Combination of β-glucan and Morus alba L. Leaf Extract Promotes Metabolic Benefits in Mice Fed a High-Fat Diet. Nutrients 9: 1110.

110. Li L, Dong Y, Liu X, Wang M (2023) Mangiferin for the Management of Liver Diseases: A Review. Foods 12: 2469.

111. Shi L, Karrar E, Liu R, Chang M, Wang X (2022) Comparative effects of sesame lignans (sesamin, sesamolin, and sesamol) on oxidative stress and lipid metabolism in steatosis HepG2 cells. J Food Biochem 46: e14180.

112. Shi L, Karrar E, Wang X (2021) Sesamol ameliorates hepatic lipid accumulation and oxidative stress in steatosis HepG2 cells via the PPAR signaling pathway. J Food Biochem 45: e13976.

113. Yang Y, Wang J, Zhang Y, Li J, Sun W (2018) Black Sesame Seeds Ethanol Extract Ameliorates Hepatic Lipid Accumulation, Oxidative Stress, and Insulin Resistance in Fructose-Induced Nonalcoholic Fatty Liver Disease. J Agric Food Chem 66: 10458-10469.

114. Wang X, Zhang ZF, Zheng GH, Wang AM, Sun CH, et al. (2017) Attenuation of hepatic steatosis by purple sweet potato colour is associated with blocking Src/ERK/C/EBPβ signalling in high-fat-diet-treated mice. Appl Physiol Nutr Metab 42: 1082-1091.

115. Hao R, Shan S, Yang D, Zhang H, Sun Y, et al. (2023) Peonidin-3-O-Glucoside from Purple Corncob Ameliorates Nonalcoholic Fatty Liver Disease by Regulating Mitochondrial and Lysosome Functions to Reduce Oxidative Stress and Inflammation. Nutrients 15: 372.

116. Emamat H, Foroughi F, Eini-Zinab H, Hekmatdoost A (2018) The Effects of Onion Consumption on Prevention of Nonalcoholic Fatty Liver Disease. Indian J Clin Biochem 33: 75-80.

117. Huang H, Jiang X, Xiao Z, Yu L, Pham Q, et al. (2016) Red Cabbage Microgreens Lower Circulating Low-Density Lipoprotein (LDL), Liver Cholesterol, and Inflammatory Cytokines in Mice Fed a High-Fat Diet. J Agric Food Chem 64: 9161-9171.

118. Al-Dosari MS (2014) Red cabbage (Brassica oleracea L.) mediates redox-sensitive amelioration of dyslipidemia and hepatic injury induced by exogenous cholesterol administration. Am J Chin Med 42: 189-206.

119. Barbosa PO, Souza MO, Silva MPS, Santos GT, Silva ME, et al. (2021) Açaí (Euterpe oleracea Martius) supplementation improves oxidative stress biomarkers in liver tissue of dams fed a high-fat diet and increases antioxidant enzymes' gene expression in offspring. Biomed Pharmacother 139: 111627.

120. Wadie W, Mohamed AH, Masoud MA, Rizk HA, Sayed HM (2021) Protective impact of lycopene on ethinylestradiol-induced cholestasis in rats. Naunyn Schmiedebergs Arch Pharmacol 394: 447-455.

121. Khan M, Gul S, Rehman I, Leghari QA, Badar R, et al. (2024) Protective effect of lycopene against celecoxib induced fat deposition and glycogen reduction in liver cells. J Taibah Univ Med Sci. 19: 856-866.

122. Martín-Pozuelo G, Navarro-González I, González-Barrio R, Santaella M, García-Alonso J, et al. (2015) The effect of tomato juice supplementation on biomarkers and gene expression related to lipid metabolism in rats with induced hepatic steatosis. Eur J Nutr 54: 933-944.

123. Yang Z, Zhang L, Liu J, Chan ASC, Li D (2023) Saponins of Tomato Extract Improve Non-Alcoholic Fatty Liver Disease by Regulating Oxidative Stress and Lipid Homeostasis. Antioxidants (Basel) 12: 1848.

124. Xie K, He X, Chen K, Sakao K, Hou DX (2020) Ameliorative effects and molecular mechanisms of vine tea on western diet-induced NAFLD. Food Funct 11: 5976-5991.

125. Li J, Sasaki GY, Dey P, Chitchumroonchokchai C, Labyk AN, et al. (2018) Green tea extract protects against hepatic NFκB activation along the gut-liver axis in diet-induced obese mice with nonalcoholic steatohepatitis by reducing endotoxin and TLR4/MyD88 signaling. J Nutr Biochem 53: 58-65.

126. Chung MY, Park HJ, Manautou JE, Koo SI, Bruno RS (2012) Green tea extract protects against nonalcoholic steatohepatitis in ob/ob mice by decreasing oxidative and nitrative stress responses induced by proinflammatory enzymes. J Nutr Biochem 23: 361-367.

127. Hirsch N, Konstantinov A, Anavi S, Aronis A, Hagay Z, et al. (2016) Prolonged feeding with green tea polyphenols exacerbates cholesterol-induced fatty liver disease in mice. Mol Nutr Food Res 60: 2542-2553.

128. Cardoso RR, Moreira LPD, de Campos Costa MA, Toledo RCL, Grancieri M, et al. (2021) Kombuchas from green and black teas reduce oxidative stress, liver steatosis and inflammation, and improve glucose metabolism in Wistar rats fed a high-fat high-fructose diet. Food Funct 12: 10813-10827.

129. Lee KS, Cha HJ, Lee GT, Lee KK, Hong JT, et al. (2014) Troxerutin induces protective effects against ultraviolet B radiation through the alteration of microRNA expression in human HaCaT keratinocyte cells. Int J Mol Med 33: 934-942.

130. Shen B, Feng H, Cheng J, Li Z, Jin M, et al. (2020) Geniposide alleviates non-alcohol fatty liver disease via regulating Nrf2/AMPK/mTOR signalling pathways. J Cell Mol Med 24: 5097-5108.

131. Chen ZY, Li JS, Jiang JP, Yan MX, He BH (2014) Effect of pure total flavonoids from citrus on hepatic SIRT1/PGC-1alpha pathway in mice with NASH] 39: 100-105.

132. Asadollahpoor A, Abdollahi M, Rahimi R. Pimpinella anisum L (2017) fruit: Chemical composition and effect on rat model of nonalcoholic fatty liver disease. J Res Med Sci 22: 37.

133. Shi Z, Li T, Liu Y, Cai T, Yao W, et al. (2020) Hepatoprotective and Anti-Oxidative Effects of Total Flavonoids From Qu Zhi Qiao (Fruit of Citrus Paradisi cv.Changshanhuyou) on Nonalcoholic Steatohepatitis In Vivo and In Vitro Through Nrf2-ARE Signaling Pathway. Front Pharmacol 11: 483.

134. Wang DJ, Cai YQ, Pan SZ, Zhang LZ, Chen YX, et al.(2018) Effect of Total Flavone of Haw Leaves on Nuclear Factor Erythroid-2 Related Factor and Other Related Factors in Nonalcoholic Steatohepatitis Rats. Chin J Integr Med 24: 265-271.

135. Al Humayed S (2017) Protective and therapeutic effects of Crataegus aronia in non-alcoholic fatty liver disease. Arch Physiol Biochem 123: 23-30.

136. Takayama F, Nakamoto K, Kawasaki H, Mankura M, Egashira T, et al.(2009) Beneficial effects of Vitis coignetiae Pulliat leaves on nonalcoholic steatohepatitis in a rat model. Acta Med Okayama 63: 105-111.

137. Saeedi G, Jeivad F, Goharbari M, Gheshlaghi GH, Sabzevari O (2018) Ethanol Extract of Crataegus Oxyacantha L. Ameliorate Dietary Non-Alcoholic Fatty Liver Disease in Rat. Drug Res (Stuttg) 68: 553-559.

138. Song H, Chu Q, Yan F, Yang Y, Han W, et al. (2016) Red pitaya betacyanins protects from diet-induced obesity, liver steatosis and insulin resistance in association with modulation of gut microbiota in mice. J Gastroenterol Hepatol 31: 1462-1469.

139. Ghanbari P, Alboebadi R, Bazyar H, Raiesi D, ZareJavid A, et al. (2024) Grape seed extract supplementation in non-alcoholic fatty liver disease. Int J Vitam Nutr Res 94:365-376.

140. Khoshbaten M, Aliasgarzadeh A, Masnadi K, Farhang S, Tarzamani MK, et al. (2010) Grape seed extract to improve liver function in patients with nonalcoholic fatty liver change. Saudi J Gastroenterol 16: 194-197.

141. Dave A, Park EJ, Kumar A, Parande F, Beyoğlu D, et al. (2022) Consumption of Grapes Modulates Gene Expression, Reduces Non-Alcoholic Fatty Liver Disease, and Extends Longevity in Female C57BL/6J Mice Provided with a High-Fat Western-Pattern Diet. Foods 11: 1984.

142. Polce SA, Burke C, França LM, Kramer B, de Andrade Paes AM, et al. (2018) Ellagic Acid Alleviates Hepatic Oxidative Stress and Insulin Resistance in Diabetic Female Rats. Nutrients 10 : 53.

143. Shen B, Wang Y, Cheng J, Peng Y, Zhang Q, et al. (2023) Pterostilbene alleviated NAFLD via AMPK/mTOR signaling pathways and autophagy by promoting Nrf2. Phytomedicine. 109: 154561.

144. Santos IB, de Bem GF, Cordeiro VSC, da Costa CA, de Carvalho L, et al. (2017) Supplementation with Vitis vinifera L. skin extract improves insulin resistance and prevents hepatic lipid accumulation and steatosis in high-fat diet-fed mice. Nutr Res 43: 69-81.

145. Jung JH, Kim HS (2013) The inhibitory effect of black soybean on hepatic cholesterol accumulation in high cholesterol and high fat diet-induced non-alcoholic fatty liver disease. Food Chem Toxicol 60: 404-412.

146. Zhang S, Cui Z, Zhang H, Wang P, Wang F, et al. (2024) Pea Albumin Extracted from Pea (Pisum sativum L.) Seeds Ameliorates High-Fat-Diet-Induced Non-Alcoholic Fatty Liver Disease by Regulating Lipogenesis and Lipolysis Pathways. Nutrients 16: 2232.

147. Li W, Yang H, Zhao Q, Wang X, Zhang J, et al. (2019) Polyphenol-Rich Loquat Fruit Extract Prevents Fructose-Induced Nonalcoholic Fatty Liver Disease by Modulating Glycometabolism, Lipometabolism, Oxidative Stress, Inflammation, Intestinal Barrier, and Gut Microbiota in Mice. J Agric Food Chem 67: 7726-7737.

148. Yoshioka S, Hamada A, Jobu K, Yokota J, Onogawa M, et al. (2010) Effects of Eriobotrya japonica seed extract on oxidative stress in rats with non-alcoholic steatohepatitis. J Pharm Pharmacol 62: 241-246.

149. Mun J, Park J, Yoon HG, You Y, Choi KC, et al. (2019) Effects of Eriobotrya japonica Water Extract on Alcoholic and Nonalcoholic Fatty Liver Impairment. J Med Food 22: 1262-1270.

150. Chen J, Ding X, Wu R, Tong B, Zhao L, et al. (2021) Novel Sesquiterpene Glycoside from Loquat Leaf Alleviates Type 2 Diabetes Mellitus Combined with Nonalcoholic Fatty Liver Disease by Improving Insulin Resistance, Oxidative Stress, Inflammation, and Gut Microbiota Composition. J Agric Food Chem 69: 14176-14191.

151. Jian T, Ding X, Wu Y, Ren B, Li W, et al. (2018) Hepatoprotective Effect of Loquat Leaf Flavonoids in PM(2.5)-Induced Non-Alcoholic Fatty Liver Disease via Regulation of IRs-1/Akt and CYP2E1/JNK Pathways. Int J Mol Sci 19: 3005.

152. Jian T, Ao X, Wu Y, Lv H, Ma L, et al. (2017) Total sesquiterpene glycosides from Loquat (Eriobotrya japonica) leaf alleviate high-fat diet induced non-alcoholic fatty liver disease through cytochrome P450 2E1 inhibition. Biomed Pharmacother 91: 229-237.

153. Narayanankutty A, Palliyil DM, Kuruvilla K, Raghavamenon AC (2018) Virgin coconut oil reverses hepatic steatosis by restoring redox homeostasis and lipid metabolism in male Wistar rats. J Sci Food Agric 98: 1757-1764.

154. Sánchez-Calvo B, Cassina A, Mastrogiovanni M, Santos M, Trias E, et al. (2021) Olive oil-derived nitro-fatty acids: protection of mitochondrial function in non-alcoholic fatty liver disease. J Nutr Biochem 94: 108646.

155. Lama A, Pirozzi C, Mollica MP, Trinchese G, Di Guida F, et al.(2017) Polyphenol-rich virgin olive oil reduces insulin resistance and liver inflammation and improves mitochondrial dysfunction in high-fat diet fed rats. Mol Nutr Food Res 61.

156. Vergani L, Vecchione G, Baldini F, Grasselli E, Voci A, et al. (2018) Polyphenolic extract attenuates fatty acid-induced steatosis and oxidative stress in hepatic and endothelial cells. Eur J Nutr 57: 1793-1805.

157. Chen X, Li L, Liu X, Luo R, Liao G, et al. (2018) Oleic acid protects saturated fatty acid mediated lipotoxicity in hepatocytes and rat of non-alcoholic steatohepatitis. Life Sci 203: 291-304.

158. Hussein O, Grosovski M, Lasri E, Svalb S, Ravid U, et al. (2007) Monounsaturated fat decreases hepatic lipid content in non-alcoholic fatty liver disease in rats. World J Gastroenterol 13: 361-368.

159. Valenzuela R, Espinosa A, Llanos P, Hernandez-Rodas MC, Barrera C, et al. (2016) Anti-steatotic effects of an n-3 LCPUFA and extra virgin olive oil mixture in the liver of mice subjected to high-fat diet. Food Funct. 7: 140-150.

160. Hernández-Rodas MC, Valenzuela R, Echeverría F, Rincón-Cervera M, Espinosa A, et al. (2017) Supplementation with Docosahexaenoic Acid and Extra Virgin Olive Oil Prevents Liver Steatosis Induced by a High-Fat Diet in Mice through PPAR-α and Nrf2 Upregulation with Concomitant SREBP-1c and NF-kB Downregulation. Mol Nutr Food Res: 61.

161. Trovato FM, Castrogiovanni P, Szychlinska MA, Purrello F, Musumeci G (2018) Early effects of high-fat diet, extra-virgin olive oil and vitamin D in a sedentary rat model of non-alcoholic fatty liver disease. Histol Histopathol 33: 1201-1213.

162. Sarna LK, Sid V, Wang P, Siow YL, House JD (2016)Tyrosol Attenuates High Fat Diet-Induced Hepatic Oxidative Stress: Potential Involvement of Cystathionine β-Synthase and Cystathionine γ-Lyase. Lipids. 51: 583-590.

163. Zhang J, Zhang SD, Wang P, Guo N, Wang W, et al.(2019) Pinolenic acid ameliorates oleic acid-induced lipogenesis and oxidative stress via AMPK/SIRT1 signaling pathway in HepG2 cells. Eur J Pharmacol. 861: 172618.

164. Ortiz-Avila O, Gallegos-Corona MA, Sánchez-Briones LA, Calderón-Cortés E, Montoya-Pérez R, et al. (2015) Protective effects of dietary avocado oil on impaired electron transport chain function and exacerbated oxidative stress in liver mitochondria from diabetic rats. J Bioenerg Biomembr 47: 337-353.

165. Xu J, Zhou X, Gao H, Chen C, Deng Q, et al. (2013) Micronutrients-fortified rapeseed oil improves hepatic lipid accumulation and oxidative stress in rats fed a high-fat diet. Lipids Health Dis 12: 28.

166. Xu J, Rong S, Gao H, Chen C, Yang W, et al. (2017) A Combination of Flaxseed Oil and Astaxanthin Improves Hepatic Lipid Accumulation and Reduces Oxidative Stress in High Fat-Diet Fed Rats. Nutrients 9: 271.

167. Nogueira MS, Kessuane MC, Lobo Ladd AA, Lobo Ladd FV, Cogliati B, et al.(2016) Effect of long-term ingestion of weakly oxidised flaxseed oil on biomarkers of oxidative stress in LDL-receptor knockout mice. Br J Nutr 116: 258-269.

168. Feng WW, Kuang SY, Tu C, Ma ZJ, Pang JY, et al. (2018) Natural products berberine and curcumin exhibited better ameliorative effects on rats with non-alcohol fatty liver disease than lovastatin. Biomed Pharmacother 99: 325-333.

169. Periasamy S, Chien SP, Chang PC, Hsu DZ, Liu MY (2014) Sesame oil mitigates nutritional steatohepatitis via attenuation of oxidative stress and inflammation: a tale of two-hit hypothesis. J Nutr Biochem 25: 232-240.

170. Xu J, Liu X, Gao H, Chen C, Deng Q, et al. (2015) Optimized Rapeseed Oils Rich in Endogenous Micronutrients Protect High Fat Diet Fed Rats from Hepatic Lipid Accumulation and Oxidative Stress. Nutrients 7: 8491-8502.

171. Zhang J, Ouyang H, Gu X, Dong S, Lu B, et al. (2024) Caffeic acid ameliorates metabolic dysfunction-associated steatotic liver disease via alleviating oxidative damage and lipid accumulation in hepatocytes through activating Nrf2 via targeting Keap1. Free Radic Biol Med 224: 352-365.

172. Helal MG, Ayoub SE, Elkashefand WF, Ibrahim TM (2018) Caffeine affects HFD-induced hepatic steatosis by multifactorial intervention. Hum Exp Toxicol 37: 983-990.

173. Loffredo L, Baratta F, Ludovica P, Battaglia S, Carnevale R, et al. (2017) Effects of dark chocolate on endothelial function in patients with non-alcoholic steatohepatitis. Nutr Metab Cardiovasc Dis 28: 143-149.

174. Malhi H, Loomba R (2016) Editorial: dark chocolate may improve NAFLD and metabolic syndrome by reducing oxidative stress. Aliment Pharmacol Ther 44: 533-534.

175. Loffredo L, Del Ben M, Perri L, Carnevale R, Nocella C, et al. (2016) Effects of dark chocolate on NOX-2-generated oxidative stress in patients with non-alcoholic steatohepatitis. Aliment Pharmacol Ther 44: 279-286.

176. Park S, Cho SM, Jin BR, Yang HJ, Yi QJ (2019) Mixture of blackberry leaf and fruit extracts alleviates non-alcoholic steatosis, enhances intestinal integrity, and increases Lactobacillus and Akkermansia in rats. Exp Biol Med (Maywood) 244: 1629-1641.

177. Lu MC, Lee IT, Hong LZ, Ben-Arie E, Lin YH, et al. (2021) Coffeeberry Activates the CaMKII/CREB/BDNF Pathway, Normalizes Autophagy and Apoptosis Signaling in Nonalcoholic Fatty Liver Rodent Model. Nutrients 13: 3652.

178. S YA-O, Mohamed DA, Abd-Elhady EE, Hussein AMS, Al-Siedy ESK (2018) Comparative Study of Orange and its Main Bioactive Constituents as Remedy for Non-alcoholic Fatty Liver in Rats. Pak J Biol Sci 21: 359-368.

179. Wu E, Zhang T, Tan C, Peng C, Chisti Y, et al. (2020) Theabrownin from Pu-erh tea together with swinging exercise synergistically ameliorates obesity and insulin resistance in rats. Eur J Nutr 59: 1937-1950.

180. Hernández-Aquino E, Muriel P (2018) Beneficial effects of naringenin in liver diseases: Molecular mechanisms. World J Gastroenterol 24: 1679-1707.

181. Zhen Q, Liang Q, Wang H, Zheng Y, Lu Z, et al. (2023) Theabrownin ameliorates liver inflammation, oxidative stress, and fibrosis in MCD diet-fed C57BL/6J mice. Front Endocrinol (Lausanne). 14: 1118925.

182. Jing N, Liu X, Jin M, Yang X, Hu X, et al. (2020) Fubrick tea attenuates high-fat diet induced fat deposition and metabolic disorder by regulating gut microbiota and caffeine metabolism. Food Funct. 11: 6971-6986.

183. Zhang JK, Zhou XL, Wang XQ, Zhang JX, Yang ML, et al. (2022) Que Zui tea ameliorates hepatic lipid accumulation and oxidative stress in high fat diet induced nonalcoholic fatty liver disease. Food Res Int. 156: 111196.

184. Peluso I, Manafikhi H, Reggi R, Palmery M (2015) Effects of red wine on postprandial stress: potential implication in non-alcoholic fatty liver disease development. Eur J Nutr 54: 497-507.

185. Xiao J, Wang F, Liong EC, So KF, Tipoe GL (2018) Lycium barbarum polysaccharides improve hepatic injury through NFkappa-B and NLRP3/6 pathways in a methionine choline deficient diet steatohepatitis mouse model. Int J Biol Macromol 120: 1480-1489.

186. Huang CZ, Tung YT, Hsia SM, Wu CH, Yen GC (2017)The hepatoprotective effect of Phyllanthus emblica L. fruit on high fat diet-induced non-alcoholic fatty liver disease (NAFLD) in SD rats. Food Funct 8: 842-850.

187. Hu D, Xu Y, Xie J, Sun C, Zheng X, et al. (2018) Systematic evaluation of phenolic compounds and protective capacity of a new mulberry cultivar J33 against palmitic acid-induced lipotoxicity using a simulated digestion method. Food Chem 258: 43-50.

188. Peng CH, Lin HT, Chung DJ, Huang CN, Wang CJ (2018) Mulberry Leaf Extracts prevent obesity-induced NAFLD with regulating adipocytokines, inflammation and oxidative stress. J Food Drug Anal 26: 778-787.

189. Van der Werf R, Walter C, Bietiger W, Seyfritz E, Mura C, et al. (2018) Beneficial effects of cherry consumption as a dietary intervention for metabolic, hepatic and vascular complications in type 2 diabetic rats. Cardiovasc Diabetol 17: 104.

190. Yang Y, Chen J, Gao Q, Shan X, Wang J, et al. (2020) Study on the attenuated effect of Ginkgolide B on ferroptosis in high fat diet induced nonalcoholic fatty liver disease. Toxicology 445: 152599.

191. Shimizu K, Ono M, Imoto A, Nagayama H, Tetsumura N, et al. (2019) Cranberry Attenuates Progression of Non-alcoholic Fatty Liver Disease Induced by High-Fat Diet in Mice. Biol Pharm Bull 42: 1295-1302.

192. Verma S, Goand UK, Rathaur S, Garg R, Katekar R, et al.(2023) The combined effect of Raspberry Ketone with Resveratrol against oxidative stress and steatohepatitis in rats: Pharmacokinetic and pharmacodynamic studies. J Biochem Mol Toxicol 37: e23336.

193. Li Z, Zhang H, Li Y, Chen H, Wang C, et al. (2020) Phytotherapy using blueberry leaf polyphenols to alleviate non-alcoholic fatty liver disease through improving mitochondrial function and oxidative defense. Phytomedicine 69: 153209.

194. Ren T, Huang C, Cheng M (2014) Dietary blueberry and bifidobacteria attenuate nonalcoholic fatty liver disease in rats by affecting SIRT1-mediated signaling pathway. Oxid Med Cell Longev 2014: 469059.

195. Ren T, Zhu L, Shen Y, Mou Q, Lin T, et al. (2019) Protection of hepatocyte mitochondrial function by blueberry juice and probiotics via SIRT1 regulation in non-alcoholic fatty liver disease. Food Funct 10: 1540-1551.

196. Guo H, Zhong R, Liu Y, Jiang X, Tang X, et al. (2014) Effects of bayberry juice on inflammatory and apoptotic markers in young adults with features of non-alcoholic fatty liver disease. Nutrition 30: 198-203.

197. Bae M, Park YK, Lee JY (2018) Food components with antifibrotic activity and implications in prevention of liver disease. J Nutr Biochem 55: 1-11.

198. Vizzutti F, Provenzano A, Galastri S, Milani S, Delogu W, et al. (2010) Curcumin limits the fibrogenic evolution of experimental steatohepatitis. Lab Invest 90: 104-115.

199. Yan C, Zhang Y, Zhang X, Aa J, Wang G, et al. (2018) Curcumin regulates endogenous and exogenous metabolism via Nrf2-FXR-LXR pathway in NAFLD mice. Biomed Pharmacother 105: 274-281.

200. Khan H, Ullah H, Nabavi SM (2019) Mechanistic insights of hepatoprotective effects of curcumin: Therapeutic updates and future prospects. Food Chem Toxicol 124: 182-191.

201. Kim M, Yoo G, Randy A, Son YJ, Hong CR, et al. (2020) Lemon Balm and Its Constituent, Rosmarinic Acid, Alleviate Liver Damage in an Animal Model of Nonalcoholic Steatohepatitis. Nutrients 12: 1166.

202. Ngamlerst C, Udomkasemsab A, Kongkachuichai R, Kwanbunjan K, Chupeerach C, et al. (2019) The potential of antioxidant-rich Maoberry (Antidesma bunius) extract on fat metabolism in liver tissues of rats fed a high-fat diet. BMC Complement Altern Med 19: 294.

203. Ota T (2021) Prevention of NAFLD/NASH by Astaxanthin and β-Cryptoxanthin. In: editor^editors, editor. Carotenoids: Biosynthetic and Biofunctional Approaches. Singapore: Springer Singapore 231-238.

204. Nishino A, Maoka T, Yasui H (2022) Preventive Effects of β-Cryptoxanthin, a Potent Antioxidant and Provitamin A Carotenoid, on Lifestyle-Related Diseases—A Central Focus on Its Effects on Non-Alcoholic Fatty Liver Disease (NAFLD). Antioxidants 11: 43.

205. Veskovic M, Mladenovic D, Milenkovic M, Tosic J, Borozan S, et al. (2019) Betaine modulates oxidative stress, inflammation, apoptosis, autophagy, and Akt/mTOR signaling in methionine-choline deficiency-induced fatty liver disease. Eur J Pharmacol 848: 39-48.

206. Kang I, Buckner T, Shay NF, Gu L, Chung S (2016) Improvements in Metabolic Health with Consumption of Ellagic Acid and Subsequent Conversion into Urolithins: Evidence and Mechanisms. Adv Nutr 7: 961-972.

207. Al-Shaaibi SN, Waly MI, Al-Subhi L, Tageldin MH, Al-Balushi NM, et al.(2016) Ameliorative Effects of Pomegranate Peel Extract against Dietary-Induced Nonalcoholic Fatty Liver in Rats. Prev Nutr Food Sci 21: 14-23.

208. Noori M, Jafari B, Hekmatdoost A (2017) Pomegranate juice prevents development of non-alcoholic fatty liver disease in rats by attenuating oxidative stress and inflammation. J Sci Food Agric 97: 2327-2332.

209. Khalil M, Khalifeh H, Baldini F, Salis A, Damonte G, et al. (2019) Antisteatotic and antioxidant activities of Thymbra spicata L. extracts in hepatic and endothelial cells as in vitro models of non-alcoholic fatty liver disease. J Ethnopharmacol 239: 111919.

210. Rico D, Martin-Diana AB, Lasa A, Aguirre L, Milton-Laskibar I, et al. (2019) Effect of Wakame and Carob Pod Snacks on Non-Alcoholic Fatty Liver Disease. Nutrients 11: 86.

211. Mak KM, Shekhar AC (2024) Soybean polyenylphosphatidylcholine (PPC) is beneficial in liver and extrahepatic tissue injury: An update in experimental research. Anat Rec (Hoboken) 307: 2162-2186.

212. Ran X, Hu G, He F, Li K, Li F, et al. (2022) Phytic Acid Improves Hepatic Steatosis, Inflammation, and Oxidative Stress in High-Fat Diet (HFD)-Fed Mice by Modulating the Gut-Liver Axis. J Agric Food Chem 70:11401-11411.

213. Lee E, Lim Y, Kwon SW, Kwon O (2019) Pinitol consumption improves liver health status by reducing oxidative stress and fatty acid accumulation in subjects with non-alcoholic fatty liver disease: A randomized, double-blind, placebo-controlled trial. J Nutr Biochem 68: 33-41.

214. Panasevich MR, Schuster CM, Phillips KE, Meers GM, Chintapalli SV, et al. (2017) Soy compared with milk protein in a Western diet changes fecal microbiota and decreases hepatic steatosis in obese OLETF rats. J Nutr Biochem 46: 125-136.

215. Hernandez-Velazquez I, Sanchez-Tapia M, Ordaz-Nava G, Torres N, Tovar AR, et al. (2020) Black bean protein concentrate ameliorates hepatic steatosis by decreasing lipogenesis and increasing fatty acid oxidation in rats fed a high fat-sucrose diet. Food Funct 11: 10341-10350.

216. H VS, K V, Patel D (2016) Biomechanism of chlorogenic acid complex mediated plasma free fatty acid metabolism in rat liver. BMC Complement Altern Med 16: 274.

217. Wang GE, Liu XT, Yang F, Wang RH, Liu XY, et al. (2022) Biochanin A ameliorated oleate-induced steatosis in HepG2 cells by activating the SIRT3/AMPK/ULK-1 signaling pathway. J Food Biochem 46: e14428.

218. Lopes LAR, Martins M, Farias LM, Brito A, Lima GM, et al. (2018) Cholesterol-Lowering and Liver-Protective Effects of Cooked and Germinated Mung Beans (Vigna radiata L.). Nutrients 10: 821.

219. Wang S, Chen L, Yang H, Gu J, Wang J, et al. (2020) Regular intake of white kidney beans extract (Phaseolus vulgaris L.) induces weight loss compared to placebo in obese human subjects. Food Sci Nutr 8: 1315-1324.

220. Feng Q, Niu Z, Zhang S, Wang L, Dong L, et al. (2023) Protective Effects of White Kidney Bean (Phaseolus vulgaris L.) against Diet-Induced Hepatic Steatosis in Mice Are Linked to Modification of Gut Microbiota and Its Metabolites. Nutrients 15: 3033.

221. Dai FJ, Hsu WH, Huang JJ, Wu SC (2013) Effect of pigeon pea (Cajanus cajan L.) on high-fat diet-induced hypercholesterolemia in hamsters. Food Chem Toxicol 53: 384-391.

222. Choi Y, Abdelmegeed MA, Song BJ (2016) Preventive effects of dietary walnuts on high-fat-induced hepatic fat accumulation, oxidative stress and apoptosis in mice. J Nutr Biochem 38: 70-80.

223. Wang G, Zhang Y, Zhang R, Pan J, Qi D, et al. (2020) The protective effects of walnut green husk polysaccharide on liver injury, vascular endothelial dysfunction and disorder of gut microbiota in high fructose-induced mice. Int J Biol Macromol 162: 92-106.

224. Noh JR, Kim YH, Gang GT, Yang KJ, Lee HS, et al. (2010) Chestnut (Castanea crenata) inner shell extract inhibits development of hepatic steatosis in C57BL/6 mice fed a high-fat diet. Food Chemistry 121: 437-442.

225. Ye H, Ma S, Qiu Z, Huang S, Deng G, et al. (2022) Poria cocos polysaccharides rescue pyroptosis-driven gut vascular barrier disruption in order to alleviates non-alcoholic steatohepatitis. J Ethnopharmacol 296: 115457.

226. Dai Y, Zhang X, Xu Y, Wu Y, Yang L (2023) The Protective Effects of Cinnamyl Alcohol Against Hepatic Steatosis, Oxidative and Inflammatory Stress in Nonalcoholic Fatty Liver Disease Induced by Childhood Obesity. Immunol Invest 52: 1008-1022.

227. Zhang F, Zhang X, Gu Y, Wang M, Guo S, et al. (2021) Hepatoprotection of Lycii Fructus Polysaccharide against Oxidative Stress in Hepatocytes and Larval Zebrafish. Oxid Med Cell Longev 2021: 3923625.

228. Cho W, Park SY, Oh H, Abd El-Aty AM, Hacimüftüoğlu A, et al. (2023) Humulus japonicus Extract Ameliorates Hepatic Steatosis Through the PPARα-Mediated Suppression of Alcohol-Induced Oxidative Stress. J Med Food 26: 193-200.

229. Zheng M, Li Y, Dong Z, Zhang Y, Xi Z, et al. (2023) Korean red ginseng formula attenuates non-alcoholic fatty liver disease in oleic acid-induced HepG2 cells and high-fat diet-induced rats. Heliyon. 9: e21846.

230. Liu Y, Li D, Wang S, Peng Z, Tan Q, et al. (2023) 6-Gingerol Ameliorates Hepatic Steatosis, Inflammation and Oxidative Stress in High-Fat Diet-Fed Mice through Activating LKB1/AMPK Signaling. Int J Mol Sci 24: 6285.

231. Yang AY, Kim K, Kwon HH, Leem J, Song JE (2024) 6-Shogaol Ameliorates Liver Inflammation and Fibrosis in Mice on a Methionine- and Choline-Deficient Diet by Inhibiting Oxidative Stress, Cell Death, and Endoplasmic Reticulum Stress. Molecules 29: 419.

232. Sahebkar A (2011) Potential efficacy of ginger as a natural supplement for nonalcoholic fatty liver disease. World J Gastroenterol 17: 271-272.

233. Li J, Wang S, Yao L, Ma P, Chen Z, et al. (2019) 6-gingerol ameliorates age-related hepatic steatosis: Association with regulating lipogenesis, fatty acid oxidation, oxidative stress and mitochondrial dysfunction. Toxicol Appl Pharmacol 362: 125-135.

234. Lai YS, Lee WC, Lin YE, Ho CT, Lu KH, et al. (2016) Ginger Essential Oil Ameliorates Hepatic Injury and Lipid Accumulation in High Fat Diet-Induced Nonalcoholic Fatty Liver Disease. J Agric Food Chem 64: 2062-2071.

235. Mohammed HM (2022) Zingerone ameliorates non-alcoholic fatty liver disease in rats by activating AMPK. J Food Biochem 46: e14149.

236. Tejasari D (2007) Evaluation of Ginger (Zingiber officinale Roscoe) Bioactive Compounds in Increasing the Ratio of T-cell Surface Molecules of CD3+CD4+:CD3+CD8+ In-Vitro. Malays J Nutr 13: 161-170.

237. Zhou Y, Ding YL, Zhang JL, Zhang P, Wang JQ, et al. (2018) Alpinetin improved high fat diet-induced non-alcoholic fatty liver disease (NAFLD) through improving oxidative stress, inflammatory response and lipid metabolism. Biomed Pharmacother 97: 1397-1408.

238. Xiao J, Ching YP, Liong EC, Nanji AA, Fung ML, et al. (2013) Garlic-derived S-allylmercaptocysteine is a hepato-protective agent in non-alcoholic fatty liver disease in vivo animal model. Eur J Nutr 52: 179-191.

239. Wu ZR, Peng C, Yang L, Li JY, Xin W, et al. (2015) Two cinnamoyloctopamine antioxidants from garlic skin attenuates oxidative stress and liver pathology in rats with non-alcoholic steatohepatitis. Phytomedicine 22: 178-182.

240. Sangouni AA, Mohammad Hosseini Azar MR, Alizadeh M (2020) Effects of garlic powder supplementation on insulin resistance, oxidative stress, and body composition in patients with non-alcoholic fatty liver disease: A randomized controlled clinical trial. Complement Ther Med 51: 102428.

241. Rouf R, Uddin SJ, Sarker DK, Islam MT, Ali ES, et al. (2020) Antiviral potential of garlic (Allium sativum) and its organosulfur compounds: A systematic update of pre-clinical and clinical data. Trends Food Sci Technol 104: 219-234.

242. Jang HH, Park MY, Kim HW, Lee YM, Hwang KA, et al. (2012) Black rice (Oryza sativa L.) extract attenuates hepatic steatosis in C57BL/6 J mice fed a high-fat diet via fatty acid oxidation. Nutr Metab (Lond) 9: 27.

243. Kusumastuty I, Handayani D, Hanifa S, Lisan M, Sulistyowati E (2020) The Effect of Brown Rice on Superoxide Dismutase Level and Non-alcoholic Fatty Liver in an Sprague–Dawley Rat Model of High-fat High-fructose Diet-induced Obesity. Open Access Macedonian Journal of Medical Sciences. 2020.

244. Munkong N, Somnuk S, Jantarach N, Ruxsanawet K, Nuntaboon P, et al. (2023) Red Rice Bran Extract Alleviates High-Fat Diet-Induced Non-Alcoholic Fatty Liver Disease and Dyslipidemia in Mice. Nutrients 15: 246.

245. de Sousa AR, de Castro Moreira ME, Toledo RCL, Dos Anjos Benjamin L, Queiroz VAV, et al. (2018) Extruded sorghum (Sorghum bicolor L.) reduces metabolic risk of hepatic steatosis in obese rats consuming a high fat diet. Food Res Int 112: 48-55.

246. Kawaguchi T, Ueno T, Nogata Y, Hayakawa M, Koga H (2017) Wheat-bran autolytic peptides containing a branched-chain amino acid attenuate non-alcoholic steatohepatitis via the suppression of oxidative stress and the upregulation of AMPK/ACC in high-fat diet-fed mice. Int J Mol Med 39: 407-414.

247. Huang ZR, Deng JC, Li QY, Cao YJ, Lin YC, et al. (2020) Protective Mechanism of Common Buckwheat (Fagopyrum esculentum Moench.) against Nonalcoholic Fatty Liver Disease Associated with Dyslipidemia in Mice Fed a High-Fat and High-Cholesterol Diet. J Agric Food Chem 68: 6530-6543.

248. Xu P, Liu J, Li Z, Kan X, Hu G, et al. (2023) Tartary Buckwheat Flavonoids Relieve Non-alcoholic Fatty Liver Disease by Inhibiting Lipid Accumulation, Inflammation, and Regulating Intestinal Flora. Revista Brasileira de Farmacognosia 33: 965-979.

249. Dinu M, Whittaker A, Pagliai G, Giangrandi I, Colombini B, et al. (2018) A Khorasan Wheat-Based Replacement Diet Improves Risk Profile of Patients With Nonalcoholic Fatty Liver Disease (NAFLD): A Randomized Clinical Trial. J Am Coll Nutr 37: 508-514.

250. Kim S, Hong J, Jeon R, Kim HS (2016) Adzuki bean ameliorates hepatic lipogenesis and proinflammatory mediator expression in mice fed a high-cholesterol and high-fat diet to induce nonalcoholic fatty liver disease. Nutr Res 36: 90-100.

251. Ambati RR, Phang SM, Ravi S, Aswathanarayana RG (2014) Astaxanthin: sources, extraction, stability, biological activities and its commercial applications--a review. Mar Drugs 12: 128-152.

252. Yang Y, Kim B, Park YK, Koo SI, Lee JY (2015) Astaxanthin prevents TGFβ1-induced pro-fibrogenic gene expression by inhibiting Smad3 activation in hepatic stellate cells. Biochim Biophys Acta. 1850: 178-185.

253. Lima Rocha J, Mendes Furtado M, Mello Neto RS, da Silva Mendes AV, Brito A, et al. (2022) Effects of Fish Oil Supplementation on Oxidative Stress Biomarkers and Liver Damage in Hypercholesterolemic Rats. Nutrients 14: 426.

254. Kobori M, Akimoto Y, Takahashi Y, Kimura T (2020) Combined Effect of Quercetin and Fish Oil on Oxidative Stress in the Liver of Mice Fed a Western-Style Diet. J Agric Food Chem 68: 13267-13275.

255. Al-Gayyar MM, Shams ME, Barakat EA (2012) Fish oil improves lipid metabolism and ameliorates inflammation in patients with metabolic syndrome: impact of nonalcoholic fatty liver disease. Pharm Biol 50: 297-303.

256. Espinosa A, Valenzuela R, González-Mañán D, D'Espessailles A, Guillermo Gormaz J, et al. (2013) Prevention of liver steatosis through fish oil supplementation: correlation of oxidative stress with insulin resistance and liver fatty acid content. Arch Latinoam Nutr 63: 29-36.

257. Parker HM, Cohn JS, O'Connor HT, Garg ML, Caterson ID, et al. (2019) Effect of Fish Oil Supplementation on Hepatic and Visceral Fat in Overweight Men: A Randomized Controlled Trial. Nutrients 11: 475.

258. Miyata M, Matsushita K, Shindo R, Shimokawa Y, Sugiura Y, et al.(2020) Selenoneine Ameliorates Hepatocellular Injury and Hepatic Steatosis in a Mouse Model of NAFLD. Nutrients 12-1898.

259. Depner CM, Torres-Gonzalez M, Tripathy S, Milne G, Jump DB (2012) Menhaden oil decreases high-fat diet-induced markers of hepatic damage, steatosis, inflammation, and fibrosis in obese Ldlr-/- mice. J Nutr 142: 1495-1503.

260. Ramsvik MS, Bjørndal B, Bruheim I, Bohov P, Berge RK (2015) A Phospholipid-Protein Complex from Krill with Antioxidative and Immunomodulating Properties Reduced Plasma Triacylglycerol and Hepatic Lipogenesis in Rats. Mar Drugs 13: 4375-4397.

261. Yao HT, Lee PF, Lii CK, Liu YT, Chen SH (2018) Freshwater clam extract reduces liver injury by lowering cholesterol accumulation, improving dysregulated cholesterol synthesis and alleviating inflammation in high-fat, high-cholesterol and cholic acid diet-induced steatohepatitis in mice. Food Funct 9: 4876-4887.

262. Ryu SP (2014) Silkworm pupae powder ingestion increases fat metabolism in swim-trained rats. J Exerc Nutrition Biochem 18: 141-149.

263. Chen Y, Feng R, Yang X, Dai J, Huang M, et al. (2019) Yogurt improves insulin resistance and liver fat in obese women with nonalcoholic fatty liver disease and metabolic syndrome: a randomized controlled trial. Am J Clin Nutr 109: 1611-1619.

264. Korish AA, Arafah MM (2013) Camel milk ameliorates steatohepatitis, insulin resistance and lipid peroxidation in experimental non-alcoholic fatty liver disease. BMC Complement Altern Med 13: 264.

265. Salami M, Moosavi-Movahedi AA, Ehsani MR, Yousefi R, Haertlé T, et al. (2010) Improvement of the antimicrobial and antioxidant activities of camel and bovine whey proteins by limited proteolysis. J Agric Food Chem 58: 3297-3302.

266. Hernández-Granados MJ, Franco-Robles E (2020) Postbiotics in human health: Possible new functional ingredients? Food Res Int 137: 109660.

267. Okubo H, Sakoda H, Kushiyama A, Fujishiro M, Nakatsu Y, et al. (2013) Lactobacillus casei strain Shirota protects against nonalcoholic steatohepatitis development in a rodent model. Am J Physiol Gastrointest Liver Physiol 305: G911-G918.

268. El-Baz AM, Shata A, Nouh NA, Jamil L, Hafez MM, et al. (2014) Vinpocetine and Lactobacillus improve fatty liver in rats: role of adiponectin and gut microbiome. AMB Express 14: 89.

269. Song W, Wang T, Cui X, Li L, Chen B, et al. (2023) Lactobacillus coryniformis subsp. torquens T3 alleviates non-alcoholic fatty liver disease via reconstruction of the gut microbiota and redox system. J Sci Food Agric 103: 6814-6825.

270. Keyghobadi H, Bozorgpoursavadjani H, Koohpeyma F, Mohammadipoor N, Nemati M, et al. (2024) Therapeutic potential of Lactobacillus casei and Chlorella vulgaris in high-fat diet-induced non-alcoholic fatty liver disease (NAFLD)-associated kidney damages: a stereological study. Mol Biol Rep 51: 613.

271. Konda PY, Poondla V, Jaiswal KK, Dasari S, Uyyala R, et al. (2020) Pathophysiology of high fat diet induced obesity: impact of probiotic banana juice on obesity associated complications and hepatosteatosis. Sci Rep 10: 16894.

272. Chen YT, Lin YC, Lin JS, Yang NS, Chen MJ (2018) Sugary Kefir Strain Lactobacillus mali APS1 Ameliorated Hepatic Steatosis by Regulation of SIRT-1/Nrf-2 and Gut Microbiota in Rats. Mol Nutr Food Res 62: e1700903.

273. Zhang N, Qu Y, Qin B (2021) Sodium butyrate ameliorates non-alcoholic fatty liver disease by upregulating miR-150 to suppress CXCR4 expression. Clin Exp Pharmacol Physiol 48: 1125-1136.

274. Zhao ZH, Wang ZX, Zhou D, Han Y, Ma F, et al. (2021) Sodium Butyrate Supplementation Inhibits Hepatic Steatosis by Stimulating Liver Kinase B1 and Insulin-Induced Gene. Cell Mol Gastroenterol Hepatol 12: 857-871.

275. Lin CH, Lin TH, Pan TM (2017) Alleviation of metabolic syndrome by monascin and ankaflavin: the perspective of Monascus functional foods. Food Funct 8: 2102-2109.

276. Lim S, Kwon M, Joung EJ, Shin T, Oh CW, et al. (2018) Meroterpenoid-Rich Fraction of the Ethanolic Extract from Sargassum serratifolium Suppressed Oxidative Stress Induced by Tert-Butyl Hydroperoxide in HepG2 Cells. Mar Drugs 16: 374.

277. Kwon, Misung, Lim, Su-Jin, Joung (2018) Meroterpenoid-rich fraction of an ethanolic extract from Sargassum serratifolium alleviates obesity and non-alcoholic fatty liver disease in high fat-fed C57BL/6J mice. Journal of Functional Foods 47:288-298.

278. Song W, Wang Z, Zhang X, Li Y (2018) Ethanol Extract from Ulva prolifera Prevents High-Fat Diet-Induced Insulin Resistance, Oxidative Stress, and Inflammation Response in Mice. Biomed Res Int 2018: 1374565.

279. Takatani N, Kono Y, Beppu F, Okamatsu-Ogura Y, Yamano Y, et al. (2020) Fucoxanthin inhibits hepatic oxidative stress, inflammation, and fibrosis in diet-induced nonalcoholic steatohepatitis model mice. Biochem Biophys Res Commun 528: 305-310.

280. Pak W, Takayama F, Mine M, Nakamoto K, Kodo Y, et al. (2012) Anti-oxidative and anti-inflammatory effects of spirulina on rat model of non-alcoholic steatohepatitis. J Clin Biochem Nutr 51: 227-234.

281. Neyrinck AM, Taminiau B, Walgrave H, Daube G, Cani PD, et al. (2017) Spirulina Protects against Hepatic Inflammation in Aging: An Effect Related to the Modulation of the Gut Microbiota? Nutrients 9; 633.

282. Mazloomi SM, Samadi M, Davarpanah H, Babajafari S, Clark CCT, et al. (2022) The effect of Spirulina sauce, as a functional food, on cardiometabolic risk factors, oxidative stress biomarkers, glycemic profile, and liver enzymes in nonalcoholic fatty liver disease patients: A randomized double-blinded clinical trial. Food Sci Nutr 10: 317-328.