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NATURAL BIOACTIVE COMPOUNDS BY VITAL ROLE ON DETOXIFICATION AND PROMOTING LIVER FUNCTION

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Abstract. Natural bioactive compounds found in foods and as nutraceuticals show promise for supporting liver detoxification and health through their antioxidant, anti-inflammatory and anti-fibrotic. Compounds like curcumin, silymarin and resveratrol, along with flavonoids, triterpenoids and others, exhibit hepatoprotective effects by acting as antioxidants, anti-inflammatories and anti-fibrotics. These compounds can help mitigate liver damage caused by various factors, including drug-induced toxicity, alcohol consumption and metabolic disorders. A healthy diet is crucial for managing and improving liver disease. It involves focusing on nutrient-rich foods, limiting harmful substances and maintaining a healthy weight. A balanced diet with plenty of fruits, vegetables, whole grains, lean protein and healthy fats is recommended. Limiting alcohol, processed foods and foods high in sugar, salt and saturated fats is essential. Several bioactive compounds and nutraceuticals show promise in supporting liver health and potentially treating liver conditions like non-alcoholic fatty liver disease (NAFLD). These include silymarin (from milk thistle), curcumin, omega-3 fatty acids, resveratrol and anthocyanins. Additionally, certain foods like coffee, green tea and cruciferous vegetables are linked to liver health benefits, with their respective compounds being studied for their protective effects.

Keywords: *Detoxification, natural compounds, nutraceuticals, fatty liver disease, holistic approach.*

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1. Introduction

Nutraceuticals are products derived from food sources that provide health benefits beyond basic nutrition, often used to prevent or treat diseases and support overall health. They are derived from food sources and provide health or medicinal benefits beyond basic nutrition, categorized as functional foods (such as fortified cereals), dietary supplements (fish oil capsules) or medical foods for specific health conditions. This diverse group of products includes vitamins, minerals, probiotics and plant-derived compounds like antioxidants and fatty acids, serving as therapeutic and preventive options alongside conventional medicine (Ziarati & Farokhi Soofi, 2025). Unlike regular dietary supplements, nutraceuticals often have scientific evidence supporting their efficacy in preventing or managing chronic diseases. They may come in various forms such as pills, powders, capsules or fortified foods and beverages (Sawicka *et al*., 2019; Puri *et al*., 2022; Ziarati *et al*., 2023). Nutraceuticals are a class of products that bridge the gap between nutrition and pharmaceuticals, offering health benefits that go beyond basic nutritional value. Coined by Dr. Stephen De Felice in 1989, the term combines “nutrition” and “pharmaceutical” to describe foods or parts of foods that provide medical or health benefits, including the prevention and treatment of disease (Rahmanpoor, 2019). Nutraceuticals have gained prominence due to their potential in preventing chronic diseases, improving health outcomes and supporting therapeutic interventions. They are often specially designed to fulfill particular dietary requirements or to serve as preventive healthcare measures. While their efficacy and safety are increasingly emphasized in scientific literature, the regulatory distinction between nutraceuticals and other food supplements remains blurred in many regions. Nonetheless, the growing body of research and consumer interest continues to drive the development and use of nutraceuticals in modern healthcare (Puri *et al*., 2022; Rahmanpoor, 2019).

The liver cancer is the world's third most common malignancy in the world. Hepatocellular carcinoma (HCC) is accounting for about 90% of all primary liver cancer cases (Cruz-Rodriguez *et al*., 2021). Hepatocellular Carcinoma (HCC), a form of liver cancer, is a major health issue, but there are no proved recognized “remedies” involving bioactive compounds for its treatment. The key is managing underlying risk factors like hepatitis B or C, alcohol abuse and non-alcoholic fatty liver disease and seeking treatment from medical professionals, not self-medicating with natural products, as effective treatments are available. Bioactive compounds may play a role in prevention or as an adjunct to traditional therapies, but they are not cures. Several studies suggest that natural extracts and bioactive compounds hold promise for preventing and treating liver disorders, as well as other diseases. These compounds, found in plants and other natural sources, are known for their antioxidant and anti-inflammatory properties. Research indicates they can help protect the liver from damage and improve its function (Zhao *et al*., 2022; Hossen *et al*., 2020). Current estimates indicate that fatty liver disease impacts about 30-40% of the worldwide adult population (Amini-Salehi *et al*., 2024; Teng *et al*., 2023). Estimates for the global prevalence of Metabolic Dysfunction-Associated Steatotic Liver Disease (MASLD), formerly known as MAFLD or NAFLD, vary but are consistently high in recent analyses, with estimates around 30-38% in 2025, not the 25-30% stated in the query. This prevalence reflects the globally increasing rates of obesity and type 2 diabetes (Younossi *et al*., 2023). This condition, previously called NAFLD, is strongly linked to obesity, type 2 diabetes and other metabolic risk factors, according to Feng et al. (2025), El-Kassas et al. (2025). MASLD can progress from simple steatosis to more severe forms like MASH (metabolic dysfunction-associated steatohepatitis), potentially leading to cirrhosis and liver cancer. Prevalence varies by region, with higher rates typically found in Western countries and regions with higher rates of obesity and metabolic syndrome.

The study by Younossi et al. (2023) found a prevalence of 32.16% for NAFLD, with a 95% confidence interval ranging from 18.40% to 50.14% and highlighted significant regional variations. The wide confidence interval suggests a large amount of uncertainty in the prevalence estimate, potentially due to regional variations or other factors not fully accounted for in the study (Younossi *et al*., 2023). The study also pointed out that these variations exist, meaning that the prevalence of NAFLD is not the same across different geographic areas, which is shown in Figure 1.

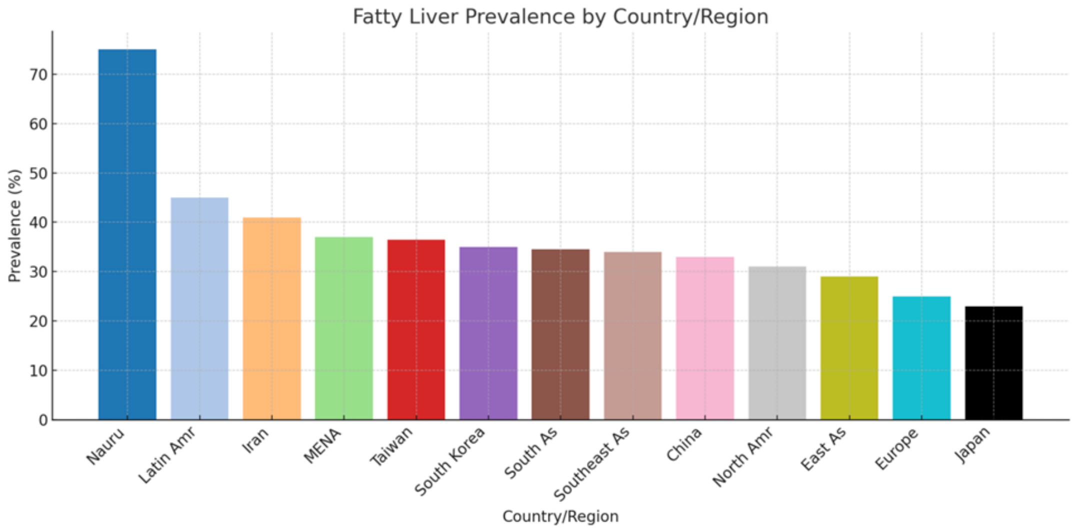

Figure 1. Prevalence of Fatty Liver Disease in Top Countries and Regions, emphasizing the urgent need for prevention and lifestyle change programs to address fatty liver disease in top-impacted areas
Source: Dong et al. (2024), Teng et al. (2023), Younossi et al. (2023)

Factors like obesity rates, genetic predispositions, socioeconomic conditions and diagnostic methods contribute to these regional differences (Sahu *et al*., 2023). Among adults with obesity, prevalence is as high as 57.5%; in type 2 diabetes, up to 75% may have fatty liver (El-Kassas *et al*., 2023a). By 2040-2050, over half of all adults worldwide could have nonalcoholic fatty liver disease (NAFLD) (Le *et al*., 2022). Many individuals are unaware they have fatty liver, as early disease is often silent. Top Countries and Regions with the NAFLD is a growing global health issue, with significant differences in prevalence across countries and regions. Figure 1, describes a scenario where Nauru, in the Pacific Islands, has a very high rate of obesity among its male population, with over 75% of adult men classified as obese. Latin America also shows a significantly high prevalence, exceeding 40%, while the Middle East and North Africa (MENA) region, along with Iran specifically and also report some of the highest rates, typically between 35% and 41%. East and Southeast Asia: Countries such as Taiwan, South Korea, China and regions of Southeast Asia display substantial prevalence rates, generally around one-third of the adult population. North America: Rates are over 30% in countries like the United States and Canada. Europe and Japan: Europe shows moderate prevalence (about 25%), while Japan reports some of the lowest rates among the listed countries (22-25%) (Younossi *et al*., 2016).

Fatty liver disease now increasingly called metabolic dysfunction-associated steatotic liver disease (MASLD) develops predominantly due to obesity and Metabolic Syndrome. Fat accumulation, especially in the abdomen, is the strongest factor. Insulin Resistance & Type 2 Diabetes are another example. These impair fat metabolism, promoting storage in the liver (El-Kassas *et al*., 2023b; Huh *et al*., 2022b; Rong *et al*., 2023). High intake of processed foods, sugars and saturated/trans fats increases fat buildup can cause fatty liver (Rong *et al*., 2023). Sedentary lifestyles contribute to fat gain and metabolic dysfunction (Roeb, 2021) DNA variations can increase individual risk and also Sleep deprivation, altered gut microbiota and chronic systemic inflammation are newly recognized contributors (Huh *et al*., 2022b; Rong *et al*., 2023). Heavy drinking directly causes alcoholic steatotic liver disease.

Major Factors Impacting Liver Health

Recent studies highlighted multiple factors underlying liver health and the risk of fatty liver disease, major factors impacting liver health include metabolic conditions like obesity, insulin resistance, high cholesterol and high triglycerides, which increase the risk of fatty liver disease (NAFLD). Viral infections, particularly hepatitis B and C, are also significant causes of chronic liver injury. Additionally, excessive alcohol consumption and environmental factors such as air pollution and exposure to specific chemicals contribute to liver damage. Genetics, epigenetics, alongside the gut-liver axis and its microbial metabolites, influencing further liver disease development (Ha *et al*., 2024).

Excessive Alcohol Intake: Chronic overconsumption directly damages liver cells and accelerates fat accumulation. **Obesity & Overweight:** Excess body weight, especially abdominal fat, is the leading risk factor. Up to 57.5% of obese adults have fatty liver disease. **Type 2 Diabetes & Insulin Resistance:** These metabolic disorders strongly drive fat buildup in the liver and significantly raise risk (El-Kassas *et al*., 2023). **Unhealthy Diet:** Regular consumption of saturated fats, added sugars and ultra-processed foods is closely tied to fatty liver development (Rong *et al*., 2023). **Physical Inactivity:** Lack of exercise contributes to obesity, metabolic dysfunction and fat deposition in the liver (Roeb, 2021). **Genetics & Ethnic Risk Factors:** Genetic predisposition and ethnic background can impact susceptibility (Rong *et al*., 2023). **Viral Hepatitis & Toxins:** Infections and environmental toxins can also compromise liver health (Roeb, 2021). **Other Metabolic Syndrome Components:** Dyslipidemia (high cholesterol/triglycerides) and high blood pressure play supporting roles (Le *et al*., 2022). **Gut Microbiome, Sleep and Inflammation:** Research points to gut-liver axis dysregulation and chronic low-grade inflammation as contributors (Huh *et al*., 2022).

There are multiple scientific evidences and guidelines recommend some dietary strategies. Increase fruits & vegetables, especially those rich in antioxidants (e.g., berries, citrus) to counter oxidative stress. Adopt the Mediterranean Diet like fruits, vegetables, whole grains, olive oil, fish, legumes and nuts shown to reduce liver fat and inflammation (Huh *et al*., 2022). Favor Unsaturated Fats: From sources like avocados, olives and fatty fish; limit saturated and Trans fats. Lean Proteins like Fish, poultry, eggs and plant proteins aid liver repair. Whole Grains & Fiber like Oats, brown rice and legumes improve metabolic health and support the liver. Coffee & Green Tea (in moderation): Both have been linked to lower liver disease risk due to antioxidant properties. Reduce Processed Foods & Added Sugars, limiting these lowers the risk of fat buildup in the liver (Rong *et al*., 2023). Losing just 5-10% of body weight can significantly reduce liver fat and even reverse early-stage disease.

Mechanisms by Which Unhealthy Diets Damage the Liver

Fat Accumulation: Excess calories, fat and sugar lead to triglyceride buildup in liver cells, causing steatosis (fatty liver). Consumption of refined carbs and sugars reduces insulin sensitivity, leading to higher blood sugar, more liver fat and inflammation. Diets elevate levels of pro-inflammatory molecules and reactive oxygen species, which damage liver cells. Low-fiber, high-sugar/fat diets harm gut bacteria balance, which can lead to leaky gut and further liver inflammation and damage.

Table 1. The role of major nutraceuticals in supporting liver health and recovery

Nutraceutical	Immune System Effects	Liver Health Effects	Researches
Vitamin C	Enhances immune cell function, increases antibody production, supports defense against infections	Antioxidant protection, supports detoxification, reduces oxidative stress	(Del Ben *et al*., 2017; Hegazi *et al*., 2023)
Vitamin E	Increases lymphocyte proliferation, boosts NK cell activity, reduces infection rates	Lowers liver inflammation, improves liver function in NAFLD/NASH, antioxidant protection	(Del Ben *et al*., 2017; Hegazi *et al*., 2023)
Vitamin D	modulate both innate and adaptive immune responses	reducing inflammation, improving insulin sensitivity and potentially having anti-fibrotic effects	(Aggeletopoulou *et al*., 2024)
Zinc	Essential for immune cell development, boosts T and B cell function	Supports liver enzyme function, may protect against liver injury	(Del Ben *et al*., 2017)
β-glucans (mushrooms)	Stimulates NK cell and T cell activity, increases sIgA, enhances immune response	May reduce liver inflammation, supports hepatic immune modulation	(Medoro *et al*., 2023b)
Garlic	Increases macrophage and NK cell activity, reduces duration/severity of respiratory infections	May protect against liver injury, modulates inflammatory pathways	(Medoro *et al*., 2023b)
Silymarin (milk thistle)	Mild immune modulation, anti-inflammatory, antioxidant	Reduces oxidative stress and inflammation, improves liver function and histology in NAFLD/NASH	(Del Ben *et al*., 2017; Hegazi *et al*., 2023)
Glutathione	Supports immune cell function, antioxidant defense	Detoxifies liver, reduces oxidative stress, supports tissue repair	(Del Ben *et al*., 2017; Hegazi *et al*., 2023)
Omega-3 fatty acids	Modulates inflammation, supports immune cell membrane integrity	Reduces hepatic fat, inflammation and oxidative stress	(Del Ben *et al*., 2017; Hegazi *et al*., 2023 ; Santamarina *et al*., 2024)
Polyphenols	Antioxidant, anti-inflammatory, supports immune regulation	Inhibits liver fat accumulation, reduces inflammation, improves metabolic function	(Del Ben *et al*., 2017; Hegazi *et al*., 2023)
Resveratrol	Modulates immune response, antioxidant	Improves insulin sensitivity, reduces liver enzymes and steatosis in NAFLD	(Del Ben *et al*., 2017)
Carnitine	Modulates inflammatory response, supports energy metabolism in immune cells	Improves liver function and histology in NAFLD/NASH, reduces inflammation	(Del Ben *et al*., 2017)
Probiotics	Modulate gut-immune axis, enhance mucosal immunity	Support gut-liver axis, may reduce liver inflammation and improve liver function	(Hegazi *et al*., 2023)

Nutraceuticals also play a significant role in supporting liver health and aiding recovery from liver-related conditions: **Antioxidant and Detoxification Support:** Compounds like silymarin (from milk thistle), glutathione and vitamin E protect liver cells from oxidative damage and support detoxification pathways (Chiurazzi *et al*., 2022; Del Ben *et al*., 2017). **Reduction of Liver Enzymes and Inflammation**: Silymarin, vitamin E and glutathione supplementation have been shown to lower liver enzyme levels and reduce liver inflammation, particularly in non-alcoholic fatty liver disease (NAFLD) (Chiurazzi *et al*., 2022; Del Ben *et al*., 2017; Rizzo *et al*., 2023). **Improvement of Liver Steatosis:** Nutraceutical combinations (silymarin, vitamin E, glutathione and hepatoactive compounds) in conjunction with a healthy diet can significantly improve liver fat content and function in NAFLD patients (Chiurazzi *et al*., 2022; Rizzo *et al*., 2023). **Polyphenols and Flavonoids:** These compounds, found in foods like berries and myricetin-rich sources, reduce liver fat accumulation and promote overall liver health (Del Ben *et al*., 2017; Grangeiro Neto *et al*., 2024). **Epigenetic Regulation:** Certain nutraceutical blends can regulate genes involved in liver cell function and protection (Davis *et al*., 2025). Table 1 summarizes the key nutraceuticals in dietary strategies.

Bioactive Compounds and Nutraceuticals

Nutraceuticals, which are bioactive compounds found in foods and plants, can enhance immune function through various mechanisms. Substances impacting the immune system are shown to weaken, over-activate or dysregulate immune responses, as described in a Table 2, that is not provided but implied by the prompt. For example, heavy metals, some chemicals (like BPA, phthalates) and certain illicit drugs can suppress the immune system, making the body more vulnerable to disease. In contrast, harmful pathogens or toxins in general can trigger an immune response and substances that trigger a false positive response can cause autoimmune diseases or allergies. These substances can modulate immune responses, act as antioxidants or have antimicrobial properties. These functions collectively contribute to a healthier immune system and potentially prevent disease.

Table 2. Mechanisms of specific compounds and their effects, which can either stimulate or suppress the immune system, protect against oxidative stress or directly fight off pathogens

Compound Type	Main Actions on Liver	Examples / Sources	Researches
Polysaccharides	↓ Fat accumulation, ↓ inflammation, ↑ antioxidant enzymes	Seaweed, algae, plants	Ferro et al. (2022)
Polyphenols/Flavonoids	↓ Oxidative stress, mitochondrial boost, ↓ cholesterol	Grapes, berries, cocoa	Badolati et al. (2020)
Omega-3 fatty acids	↓ Steatosis, ↓ fibrosis	Fish oil, chia, flax	Parker et al. (2019)
Carotenoids	↓ Oxidative stress	Vegetables (carrots, etc.)	Cardenas-Toro et al. (2015)
Terpenes/Glycosides	↑ Detox pathways, hepatoprotection	Citrus, artichoke, licorice	Makiso et al. (2023)
Micronutrients	↓ LDL cholesterol, ↑ bile flow	Stearic acid, artichoke	Mahdavi et al. (2025)

decrease↓, increase=↑

To understand the role of bioactive compounds in fatty liver disease (FLD), it's necessary to review their chemical structures and how they function, such as polyphenols, terpenoids and alkaloids. These compounds, found in plant-based foods, exert beneficial effects primarily through their antioxidant and anti-inflammatory properties, modulating pathways like hepatic steatosis, oxidative stress and apoptosis to potentially treat or prevent FLD. Reviewing their specific molecular actions, like epigallocatechin-3-gallate's (EGCG) iron-chelating properties, provides insight into their therapeutic potential.

Silymarin/Silybin: Often used in liver conditions like NAFLD due to its anti-inflammatory, antioxidant and insulin-sensitizing properties. Can improve liver function markers and reduce liver fat. The molecular formula $C_{25}H_{22}O_{10}$ belongs to the compound silydianin. It is a flavonolignan, a type of flavonoid found in milk thistle (Cogorno *et al*., 2023). Figure 2 shows the chemical structure of silydianin, a flavonolignan found in milk thistle, with the molecular formula $C_{25}H_{22}O_{10}$. It is one of the main components of silymarin and possesses antioxidant and anti-inflammatory properties. The image likely depicts its complex structure, which consists of a flavone unit linked to a phenylpropanoid unit via a carbon-carbon bond.

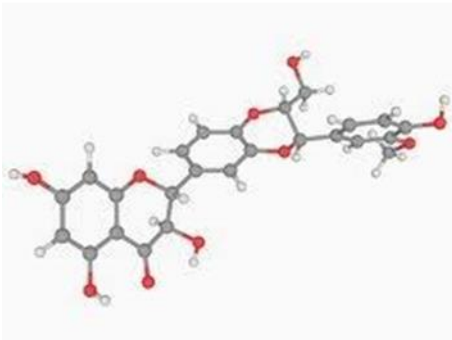

Figure 2. Chemical structure of Silydianin, Molecular formula: $C_{25}H_{22}O_{10}$

Curcumin: In a study by Patel et al. (2025) underscored the potential of Curcumin and silymarin, as the natural products derived from turmeric and milk thistle respectively, have demonstrated hepatoprotective effects by exerting antioxidant, anti-inflammatory and detoxifying effects on the liver. They achieve this by reducing oxidative stress, modulating inflammatory pathways and aiding in the liver's detoxification processes (Patel *et al*., 2025).

The active compound in turmeric is recognized for its anti-inflammatory and antioxidant properties and research suggests it may help improve liver steatosis (fatty liver). Studies indicate that curcumin can reduce liver inflammation, potentially by suppressing inflammatory cells and pro-inflammatory cytokine production. Additionally, its antioxidant properties may protect the liver from damage caused by oxidative stress (Obrzut *et al*., 2025).

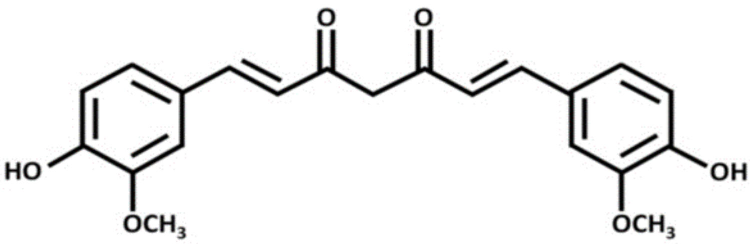

Figure 3. Chemical structure of Curcumin

Turmeric's primary chemical component is curcumin is shown in Figure 3, a polyphenol also known as diferuloylmethane. It's the main bioactive compound responsible for turmeric's yellow color and many of its purported health benefits. Curcumin is a natural antioxidant and it exists in the form of a yellow-orange solid with a molecular weight of 368 g/mol and a melting point of 183°C.

Omega-3 Fatty Acids: Omega-3 fatty acids, particularly those found in fish oil (EPA and DHA), have been shown to help reduce liver fat and inflammation. They play a role in improving liver health by reducing inflammation, preventing fat accumulation, supporting detoxification and promoting liver regeneration (Parker *et al*., 2019). In the study by Parker et al. (2019) Omega-3 polyunsaturated fatty acid (PUFA) supplementation was recommended for prevention of chronic disease and thought to reduce raised liver fat, although, had been few randomized controlled trials with accurate measurement of liver fat and Omega-3 PUFA did not appear to be an effective agent for reducing liver fat in overweight men.

Resveratrol: Resveratrol, a potent antioxidant, has been shown to reduce oxidative stress in the liver. Studies indicate that it can protect against liver damage by mitigating the effects of oxidative stress and inflammation, as well as improving liver function markers. Resveratrol's protective effects are linked to its ability to enhance antioxidant enzyme activity and potentially modulate fat metabolism in the liver. Resveratrol is a substance or process that can interfere with cellular signaling pathways. It does so by increasing the production of antioxidant enzymes like catalase (CAT) and superoxide dismutase (SOD), inhibiting the formation of new blood vessels (angiogenesis), regulating the cell cycle and triggering programmed cell death (apoptosis) in a targeted way. This suggests a potential role in cancer treatment or other conditions where these mechanisms are relevant (Rojo *et al*., 2022). Resveratrol is a stilbenoid, a type of polyphenol, with a chemical structure composed of two phenolic rings connected by a double bond. Specifically, it's known as trans-3,5,4′-trihydroxystilbene. There are two geometric isomers: cis- and trans-resveratrol, with the trans-isomer being the more prevalent and biologically active form. However, exposure to solar or ultraviolet (UV) light can cause the less stable cis-form to isomerize into the more stable trans-form. The general structure of this component is shown in Figure 4.

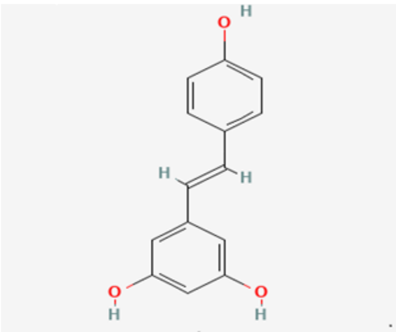

Figure 4. The chemical structure of Resveratrol

Anthocyanins: Found in berries and other colorful fruits and vegetables, these can improve liver function markers and potentially reduce liver fat.

These pigments, known for their antioxidant and anti-inflammatory properties, may offer protective benefits for liver health when incorporated into a diet. Anthocyanins, a type of flavonoid, are primarily found in red and purple fruits and vegetables (Fidiyawati *et al*., 2024). Common dietary sources include berries (like blueberries, raspberries and strawberries), grapes, apples, plums and red cabbage. Foods with high levels of natural colorants, such as those with red, purple or blue hues, are also good sources.

Anthocyanins can promote mitochondrial biogenesis and improve mitochondrial function in skeletal muscle by activating the SIRT1/PGC-1α/AMPK pathway. This pathway is crucial for regulating mitochondrial number and function and its activation can lead to enhanced energy metabolism and improved cellular health (Price *et al*., 2012; Yong & Liu, 2020).

Anthocyanins are widely distributed in fruits, vegetables, flowers and cereals and are responsible for a wide array of colors such as red, orange, blue and purple (Yong & Liu, 2020).

Anthocyanin molecules are the largest group of water-soluble pigments in the plant kingdom, composed of an aglycone (anthocyanidin), a sugar group (glycosylation) and often organic acids, which contribute to the red, blue and purple colors in plants and possess antioxidant properties. The six key food anthocyanidin aglycones - pelargonidin, cyanidin, delphinidin, peonidine, petunidine and malvidin - are flavonoid compounds responsible for red, blue and violet colors in plants, with their colors varying from red to orange or blue depending on their chemical structure and pH. These aglycones possess significant antioxidant properties, acting as strong antioxidants in emulsions and LDL (low-density lipoprotein), though their effectiveness can vary depending on whether they are in their aglycone (sugar-free) or glycosidic (sugar-attached) form (Cardenas-Toro *et al*., 2015; Khoo *et al*., 2017; Wang *et al*., 2022).

Anthocyanins, pigments responsible for red, purple and blue hues in plants, share a basic C6-C3-C6 structure, derived from the flavylium ion (a type of pyrylium cation). This structure consists of two aromatic rings (A and B) connected by a three-carbon chain that forms a heterocyclic ring (C) containing oxygen. The specific anthocyanin's color and properties are influenced by the number and position of hydroxyl and methoxyl groups, as well as the attached sugars. Hydroxyl (OH) and methoxyl (OCH3) groups are commonly found on the aromatic rings, influencing the color and stability of the anthocyanin. The aglycone (non-sugar) part of an anthocyanin is called an anthocyanidin (Khoo *et al*., 2017; Sabou *et al*., 2021). Six common anthocyanidins are pelargonidin, cyanidin, delphinidin, peonidin, petunidin and malvidin are all found in various edible fruits and vegetables (Castañeda-Ovando *et al*., 2009; Khoo *et al*., 2017; Kang *et al*., 2021; Poiana *et al*., 2020; Flores-Verastegui *et al*., 2025).

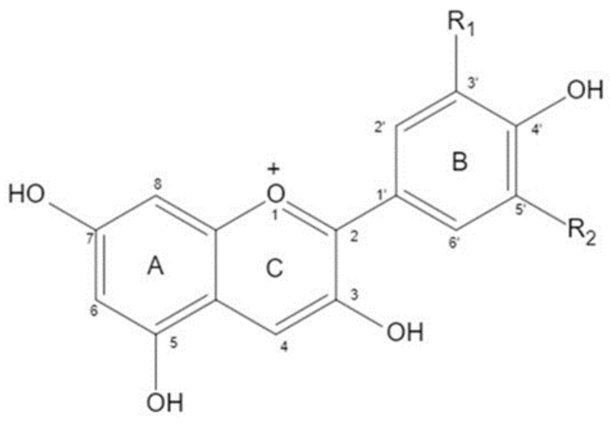

Figure 5. Chemical structure of Cyanidin-3-glucoside

Cyanidin-3-glucoside is the most common anthocyanin pigment found in plants and has been traditionally used as a natural food colorant. The color of anthocyanins is influenced by pH, with red hues appearing in acidic conditions and turning blue as the pH increases (Le *et al*., 2019).

Cyanidin-3-glucoside (C3G) is a prevalent anthocyanin pigment found in various foods, particularly berries, black rice and purple potatoes. Berries like blackberries, red raspberries and strawberries are excellent sources of C3G. Other foods containing C3G include black beans and certain cultivars of purple corn (López-Angulo *et al*., 2018).

Vitamin D: Vitamin D deficiency is common in chronic liver disease (CLD) and is linked to greater severity and progression. Vitamin D plays a role in immune regulation, which may explain its connection to CLD, a group of conditions including Non-Alcoholic Fatty Liver Disease (NAFLD) and Hepatitis C. While some smaller studies suggest vitamin D supplementation may improve outcomes such as viral response and fibrosis, larger, randomized studies are needed to confirm these benefits and establish the exact role of vitamin D supplementation in treating CLD. Vitamin D plays a role in both immune system regulation and liver health. Deficiency in Vitamin D is common in chronic liver disease and may be associated with disease progression and severity. Supplementation may offer benefits, but further research is ongoing (Aggeletopoulou *et al*., 2024; Sahu *et al*., 2023).

Myricetin: Myricetin is a critical nutritive component of diet providing immunological protection and beneficial for maintaining good health. Preclinical studies show it can improve fatty liver by reducing lipid synthesis and inflammation and protecting against other liver injuries by combating oxidative stress and apoptosis. While human studies are limited, it holds promise as a nutraceutical for liver health, with research also exploring its effects on conditions like diabetes, cardiovascular disease and neurodegenerative diseas (Grangeiro Neto *et al*., 2024). Myricetin is a hexahydroxyflavone that is flavone substituted by hydroxy groups at positions 3, 3', 4', 5, 5' and 7. It has been isolated from the leaves of Myrica rubra and other plants. This bioactive flavonoid with antioxidant properties is found in a variety of fruits, vegetables, nuts, berries, tea and red wine. Common dietary sources include berries like blueberries and cranberries, grapes (especially red and purple), walnuts, kale and onions. Tea, especially green tea, is also a good source. With a chemical formula of $C_{15}H_{10}O_8$, myricetin is made up of three rings on its flavonol backbone: two benzene rings and one heterocyclic ring. Six hydroxyl groups (-OH) linked to the rings at certain positions set myricetin distinct (Imran *et al*., 2021).

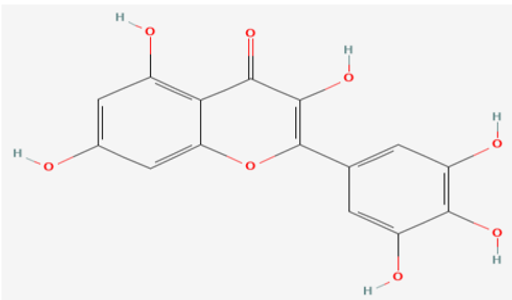

Figure 6. Chemical Structure of myricetin

The appropriate dosage of myricetin can vary based on factors such as the specific health condition being addressed, individual health status and the concentration of the supplement, but the appropriate dosage of myricetin can vary based on factors such as the specific health condition being addressed, individual health status and the concentration of the supplement (Semwal *et al*., 2016; Fan *et al*., 2024).

Milk Thistle

Milk thistle is a plant known for containing silymarin, a group of compounds with liver-protective properties. Silymarin is a mixture of flavonolignans, including silybin, silydianin and silychristin. Silybin is considered the most active component (Abenavoli *et al*., 2010; Xu *et al*., 2022). Silymarin, particularly silybin, has been studied for its potential to protect the liver from damage and promote its health, including in cases of chronic liver disease (Alali *et al*., 2024). In the study by Kim and his team in 2020, formulation containing milk thistle extract was designed to protect the liver and prevent liver fibrosis. Milk thistle is used to reduce the production of free radicals. It has anti-lipid peroxidation and anti-fibrosis properties (Kim *et al*., 2020). The other described invention is a liver-protective compound composed of milk thistle, Lathyrus palustris, Chinese globeflower, licorice roots and Melicope patulinervia with stalks. This compound is intended for the treatment of acute and chronic hepatitis, liver fibrosis and the prevention of liver cancer (Li *et al*., 2012; Emadi *et al*., 2022). Identification of novel Silymarin is known to act as a free radical scavenger and modulate enzymes involved in cellular damage, fibrosis and cirrhosis. It's a key component of milk thistle extract and is used to protect the liver from various insults. Silybin and silymarin are related compounds derived from milk thistle (Silybum marianum), but they are not synonymous. Silymarin is a complex mixture of flavonolignans and silybin is a major active component of silymarin. Silybin, in turn, can be further broken down into silybin A and silybin B (Gillessen & Schmidt, 2020).

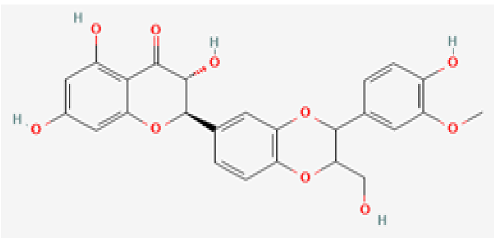

Figure 7. Chemical structure of Silybin (mixture of Silybin A and Silybin B), IUPAC name: (2R,3R)-3,5,7-trihydroxy-2-[3-(4-hydroxy-3-methoxyphenyl)-2-(hydroxymethyl)-2,3-dihydro-1,4-benzodioxin-6-yl]-2,3-dihydrochromen-4-one

The compounds mentioned; curcumin from turmeric, omega-3 fatty acids from fish oil, anthocyanins from berries and catechins from green tea - have all been the subject of liver-focused research, though some evidences for routine clinical use is still lacking. Curcumin shows potential for liver protection and reducing inflammation, omega-3s can help lower liver fat and inflammation and berries and green tea offer antioxidant and anti-inflammatory benefits that can support liver health. More human clinical trials are needed to confirm these compounds' efficacy and safety for liver conditions.

- **Turmeric:** Contains curcumin, which has shown promise in treating liver conditions.
- **Fish Oil:** Provides omega-3 fatty acids, which can help reduce liver fat and inflammation.

- **Berries:** Rich in anthocyanins, which have antioxidant and anti-inflammatory properties.
- **Green Tea:** Contains catechins, which may have beneficial effects on liver health. Green tea's health benefits are largely attributed to catechins, a type of flavonoid known for their antioxidant properties. A typical cup of green tea contains 50-100 mg of catechins (Nain *et al*., 2022). Catechins neutralize free radicals, protecting cells from damage. Green tea is indeed known for its high catechin content, which are a type of flavonoid. The main catechins in green tea are EGCG, EGC, ECG and EC. These catechins are found in much higher concentrations in green tea compared to black or oolong tea. The primary catechins in green tea are epigallocatechin gallate (EGCG), epigallocatechin (EGC), epicatechin gallate (ECG) and epicatechin (EC).

EC:
(–)-epicatechin
ECG:
(–)-epicatechin-3-gallate
EGC:
(–)-epigallocatechin
EGCG:
(–)-epigallocatechin-3-gallate

EGCG is typically the most abundant and potent of these catechins (Kim *et al*., 2014; Mokra *et al*., 2022). The chemical structures of epigallocatechin gallate (EGCG), epigallocatechin (EGC), epicatechin gallate (ECG) and epicatechin (EC) differ primarily in the number of hydroxyl groups and the presence or absence of a gallate group. All four are flavan-3-ols, characterized by a B-ring with either a catechol (two hydroxyl groups) or pyrogallol (three hydroxyl groups) structure and a meta-5,7-dihydroxy-substituted A-ring (Jin *et al*., 2006; Oh *et al*., 2023). **Epigallocatechin** is a flavan-3,3',4',5,5',7-hexol having (2R,3R)-configuration. It has a role as an antioxidant, a plant metabolite and a food component.

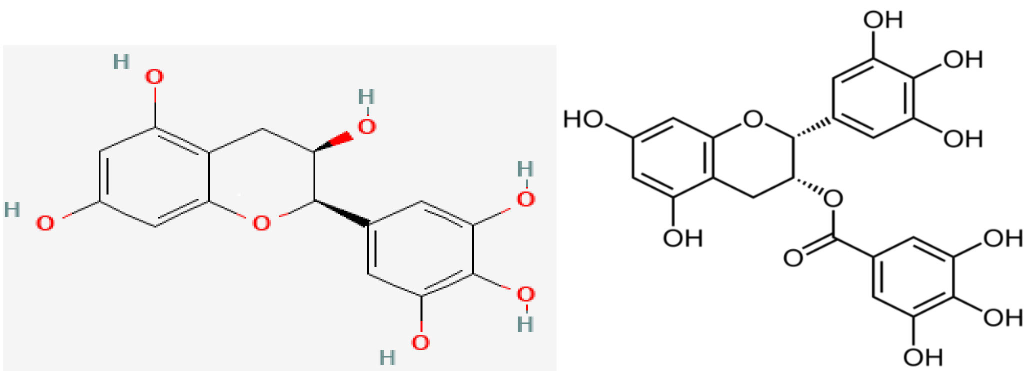

Figure 8. Chemical Epigallocatechin & Epigallocatechin_gallate structures

- **Coffee:** Coffee contains bioactive compounds like caffeine ($C_8H_{10}N_4O_2$), chlorogenic acids (CGA), diterpenes (cafestol and kahweol) and trigonelline ($C_7H_7NO_2$). Coffee Arabica and Robusta are the two most widely consumed coffee species for their pleasant aroma and flavor (Tajik *et al*., 2020). They contain different mixtures of aroma-impact compounds, such as caffeine, CGA, trigonelline, melanoidins and diterpenes that significantly determine the perceived quality of coffee. Study findings show that these bioactive compounds are associated with a low risk of type-2 diabetes, cardiovascular disease, neurodegenerative diseases and various types of cance (Makiso *et al*., 2023).

These compounds contribute to coffee's aroma, taste and potential health benefits which may offer protection against liver damage. These compounds exhibit antioxidant and anti-inflammatory properties, potentially reducing liver inflammation and fibrosis. Coffee's antioxidant capacity, primarily from chlorogenic acids and caffeine, is thought to protect liver cells (hepatocytes) by reducing the formation of reactive oxygen species (ROS) and thereby mitigating potential damage (Rebollo-Hernanz *et al*., 2022; Rasheed & Rasheed, 2025). Several studies suggest that coffee consumption, including both caffeinated and decaffeinated varieties, may reduce the risk of developing liver diseases, including cirrhosis and hepatocellular carcinoma (HCC). The protective effect appears to be dose-dependent, with increased consumption potentially leading to a greater reduction in risk. Consumption of coffee ≥2 cups/day protects against progression of almost all forms of liver disease (Wadhawan & Anand, 2020).

Bioactive compounds in coffee inhibit pro-inflammatory pathways, including nuclear factor-kappa B and cytokine production can suppress the NF-κB pathway, a key regulator of inflammation, by interfering with its activation and subsequent translocation to the nucleus, thus preventing the expression of pro-inflammatory genes (Kim *et al*., 2014; Xie *et al*., 2024).

Probiotics/Prebiotics/Synbiotics: Recent evidence suggests a strong link between intestinal microbiota and the development of NAFLD (Nonalcoholic Fatty Liver Disease). The modulation of gut microbiota through probiotics, prebiotics or synbiotics is being explored as a potential therapeutic approach for NAFLD (Li *et al*., 2022). Supplementation with probiotics, prebiotics or synbiotics has been shown to have a positive impact on reducing liver enzymes, improving lipid profiles and decreasing inflammatory cytokines in patients with non-alcoholic fatty liver disease (NAFLD). Pan et al. (2024) found that probiotics have a positive effect on liver health, particularly in the context of cirrhosis. Their systematic review and meta-analysis indicated that probiotics can reduce ammonia levels, improve neuropsychometric status and improve liver function by lowering MELD scores in patients with cirrhosis. Furthermore, probiotics were shown to be safe and well-tolerated, with a lower incidence of serious adverse events compared to control treatments. These microbial therapies can help improve liver function, lipid metabolism and reduce inflammation associated with NAFLD (Pan *et al*., 2024). Synbiotics, a combination of probiotics and prebiotics, have shown a positive impact on liver health, particularly in the context of non-alcoholic fatty liver disease (NAFLD). Studies indicate that synbiotics can help improve liver enzyme levels, lipid profiles and inflammatory markers in NAFLD patients. Specifically, synbiotic supplementation has been linked to a reduction in AST, ALT and GGT levels, as well as decreased levels of cholesterol, triglycerides and inflammatory cytokines like CRP and TNF-α (Pan *et al*., 2024). On the whole it can be said that Synbiotics improve non-alcoholic fatty liver disease (NAFLD) by promoting a healthy gut microbiome, which can reduce liver damage, lower liver enzyme levels (AST, ALT, GGT), improve lipid profiles (cholesterol, triglycerides) and decrease inflammation. Studies and meta-analyses confirm that synbiotic supplementation can be an effective adjunct therapy, improving markers of liver injury, metabolic dysfunction and inflammation in NAFLD patients. Probiotics and synbiotics may have a positive effect on liver aminotransferase levels in patients with non-alcoholic fatty liver disease (NAFLD). Studies have shown that these interventions can lead to reductions in alanine aminotransferase (ALT) and aspartate aminotransferase (AST), two key liver enzymes used as biomarkers for liver damage (Saha & Hartmann, 2025).

Other Compounds: Research also indicates potential benefits from soy isoflavones, licorice and even Fusarium oxysporum bioactive compounds. Many other foods offer health benefits and potential advantages. However, specific studies are needed to confirm these benefits and understand their mechanisms. While fruits and vegetables are generally recognized as healthy, this discussion highlights the potential of less conventional sources like soy and licorice, while acknowledging the need for further research.

4. Conclusion

Bioactive natural compounds, particularly those with antioxidant, anti-inflammatory and anti-fibrotic properties, can play a significant role in supporting liver detoxification within a holistic approach. Many clinical trials and studies have explored the potential of these compounds, including nutraceuticals, in improving liver health and function. Several bioactive natural compounds, particularly antioxidants, can support liver detoxification, especially in the context of an industrial lifestyle. These include curcumin, berberine and various polyphenols like those found in green tea and certain fruits. These compounds help protect the liver from damage by reducing inflammation, promoting antioxidant defenses and aiding in the elimination of toxins. While nutraceuticals are often marketed for liver detoxification, more rigorous clinical trials are needed to assess their efficacy and safety, especially given the potential for liver injury. Many existing studies lack sufficient quality and large sample sizes, making it difficult to draw firm conclusions.

Data Availability Statement

Data are contained within the article.

Conflicts of Interest

The authors declare no conflict of interest.

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