

Chapter 3: Cardio Nutraceuticals: Bioactive Compounds, Mechanism and Clinical Potential

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Abstract

The global spread of cardiovascular disorders serves as the leading cause of human illnesses and deaths which requires doctors to use multiple treatment methods that extend beyond traditional medication. Nutraceuticals which include various bioactive plant compounds and healthful dietary components function as supplementary treatments which provide strong heart protection benefits. The metabolic pathways of omega-3 fatty acids (EPA, DHA) lead to lower triglyceride levels through their ability to block the liver's production of VLDL particles while they also control heart rhythm through their effects on heart muscle ion channels and increase blood vessel relaxation through their interaction with nitric oxide. Coenzyme Q10 functions as an essential mitochondrial element which boosts ATP production while protecting against oxidative damage and garlic-derived organosulfur compounds stop cholesterol production while they block thromboxane A2-induced platelet clumping and they improve blood vessel function through hydrogen sulfide and nitric oxide release. The polyphenolic compounds epigallocatechin gallate which exists in green tea and resveratrol which comes from grapes execute antioxidant and anti-inflammatory activities through their ability to increase eNOS production and activate SIRT1 and block NF-κB activity which helps them protect endothelial cells and blood vessel function.2. Plant sterols block the body from absorbing cholesterol through the intestines while soy isoflavones produce phytoestrogen effects which change endothelial function and curcumin reduces the effects of proteins that promote hypertrophy and fibrosis. Vitamin E protects blood vessel membranes from damage by stopping LDL oxidation while L-arginine restores nitric oxide production because it provides the necessary materials for endothelial cell function. The bioactive compounds from this study show their ability to serve as complementary heart protection solutions through their impact on fat metabolism and cellular defense mechanisms and blood flow regulation which supports their use in personalized heart disease prevention and holistic medical approaches.

Keyword: Cardiovascular health, Nutraceuticals, Bioactive compounds, Clinical Potential

1. INTRODUCTION

Nutraceuticals are bioactive compounds which exist in ordinary foods and they can also be obtained through extraction from plant materials. The products function as dietary supplements and functional foods which deliver benefits that surpass their basic nutritional content. Nutraceuticals include multiple bioactive compounds which people can obtain from food products that contain antioxidants and phytochemicals and fatty acids and amino acids and probiotics. The established health advantages of nutraceuticals together with their potential health effects enable their use to treat diseases and prevent diseases and they support anti-aging processes and they promote cancer prevention. Probiotics should become a part of daily meals because they serve as an essential component for treating and preventing all types of stomach problems. Garlic now serves as an additional treatment option which helps people manage their high blood pressure and cholesterol levels. Nutraceuticals have become popular because they provide a budget-friendly solution to medical needs while offering effective alternatives to pharmaceutical drugs which bring severe negative effects and cause people to worry about growing antimicrobial resistance. The immune system shows positive responses to nutraceutical ingredients because multiple studies have demonstrated that these ingredients help people fight infections and improve their immune functions and lessen the symptoms of autoimmune diseases and allergies. Nutraceuticals provide benefits which include reduced lipid levels and decreased inflammation and anti-cancer effects and antioxidant protection.

The immune system functions as a complex defense network which consists of various specialized cells and proteins that collaborate to protect the body. The term "nutraceutical" is derived from the combination of "nutrition" and "pharmaceutical." The term was first introduced by Stephen Defelice who established the Foundation for Innovation in Medicine to support American medical research as its current chairman. The definition was restated in a 1994 press release which explained that "any substance that can be quantified as food or a component of food that offers medical or health benefits, including the prevention and treatment of disease." The term "nutraceutical" combines two concepts which the term "nutrient" describes as nourishing food and food components and "pharmaceutical" describes as a medical drug.

People work together to fight against illnesses. The system consists of two primary elements which are the innate immune system and the adaptive immune system. Each part of the system functions through both humoral and cellular mechanisms. The innate immune system uses general defence mechanisms which include all elements that exist from birth. The body protects itself through skin and mucous membranes as its primary defense system while granulocytes and macrophages and dendritic cells and cytokines and complements function as its secondary defense system. The adaptive immune system uses previous antigen encounters to create immune memory which enables it to recognize future threats. The process leads to a particular immune response which depends on multiple cell-mediated processes. T lymphocytes identify pathogens and proceed to eliminate them from the body. B lymphocytes produce specific antibodies that correspond to antigens or pathogens, providing a neutralizing effect and protection against potential threats to the body.

The recognition of nutraceutical science is increasing throughout society. People show growing interest to identify new treatment options by using present-day scientific research and technological advancements. The immune system benefits from numerous recognized nutraceuticals which scientific research has confirmed. We need to conduct additional clinical trials which meet high standards because these studies will help us understand how long-term treatment impacts people and their safety to society. Research into these compounds needs to examine their medicinal properties together with their nutritional advantages because this requirement has become apparent. Many individuals still perceive nutraceuticals as ambiguous some question whether they should be utilized as medicine or if they merely fulfil basic nutritional requirements. A more thorough investigation into their safety, efficacy, and accessibility is essential. This process will enable us to convert natural nutraceuticals which have potential benefits into validated and controlled and authorized medicinal products. The primary aim of this review is to present the latest research findings about how nutraceutical compounds enhance immune function and their potential therapeutic applications. The document will provide an overview of different nutraceutical categories together with their distinct mechanisms which affect immune system functioning. The research will investigate the safety of nutraceuticals together with their potential uses and future development.

2. CLASSIFICATION OF BIOACTIVE COMPOUNDS BASED ON SOURCE

Nutraceuticals have been classified based on their applications in traditional, nontraditional, fortified, recombinant, phytochemical, herbal, and functional foods; dietary supplements; probiotics; and prebiotics. The different categories of nutraceuticals serve a variety of purposes and applications depending on their characteristics. The following subsections will discuss the various categories of nutraceuticals. The table establishes different nutraceutical categories together with their associated health advantages. The chemical similarities between nutraceuticals create challenges for their classification because they share common elements which produce health benefits. The Institute of Food Technologists (IFT) describes functional foods as "foods and food components that offer a health benefit beyond basic nutrition." The term functional foods includes traditional foods and fortified foods and enriched foods and dietary supplements.

2.1 BIOACTIVE COMPOUNDS SOURCE

- 2.1.1 Plant based:** Incorporates phytochemicals such as flavonoids, carotenoids, curcuminoids, and polyphenols found in fruits, vegetables, spices (like turmeric and garlic), and herbs (like ginseng and fenugreek).
- 2.1.2 Animal based:** Supplies nutrients like omega-3 fatty acids from fish (like salmon), dairy products with probiotics, and marine algae.
- 2.1.3 Microbial based:** Contains probiotics such as *Lactobacillus* and *Bifidobacterium* species.
- 2.1.4 Mineral based:** Comprises inorganic mineral supplements including calcium, magnesium, zinc, iron, and phosphorus.

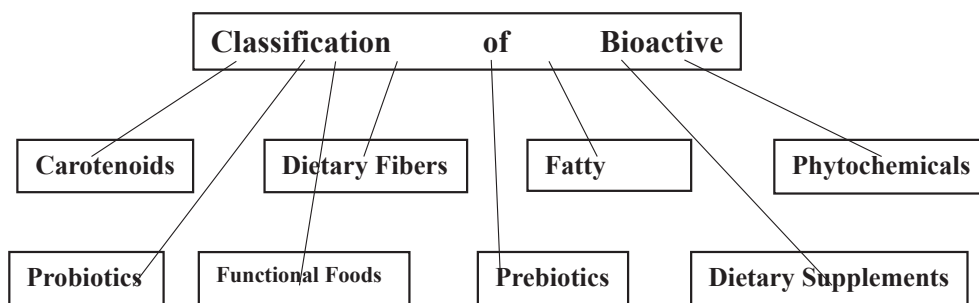


Figure 1: Classification of Bioactive compounds

2.2.1 Functional Foods

Functional foods provide health benefits that go beyond their basic nutritional content because these foods help people avoid diseases and improve their health. The foods contain elements which strengthen their ability to fight oxidative stress and reduce inflammation thus helping to protect against type 2 diabetes. The specific group of people who need these foods for their daily meals can access them because these foods meet the same standards as typical market products. Functional foods include rice wheat soybeans kidney beans lentils chocolate citrus fruits almonds and fermented milk as their food items. Whole-grain wheat stands as the second most commonly eaten staple grain worldwide because it can be processed into both wheat bran and wheat germ. Whole-grain wheat consists of three parts which include bran and endosperm and germ. The substance contains lycopene and sulforaphane as its two active components. The current research shows that functional foods contain multiple active ingredients which deliver various health benefits yet scientific proof remains insufficient for health claims to become available for these products. The active components of functional foods include carotenoids collagen hydrolysate dietary fibres and fatty acids. The substances provide multiple health benefits because they help lower inflammation levels and strengthen immune system function. The upcoming subsections will describe how functional ingredients work together with their distinct health benefits.

2.2.2 Carotenoids

Natural pigments known as carotenoids exist in high amounts within plants as well as fruits and vegetables and algae. The human diet includes various carotenoid derivatives such as α -carotene and β -carotene and β -cryptoxanthin and lutein and lycopene and zeaxanthin and crocetin and fucoxanthin and astaxanthin. The compounds exist as well-established substances which provide different health advantages through their ability to reduce inflammation and protect against oxidative damage. Carotenoids support human vision development while they maintain heart health and boost cognitive abilities and help fight cancer and improve immune system strength. The two specific carotenoids astaxanthin and β -carotene exhibit anti-

inflammatory effects. The treatment can reduce *Helicobacter pylori*-induced inflammation by decreasing the levels of inflammatory mediators and stopping the creation of reactive oxygen species.

Example: Natural sources include carrots, tomatoes (lycopene), and leafy greens (lutein, zeaxanthin).

2.2.3 Dietary Fibers

People who conduct research have discovered that dietary fibers which come from plants and function as non-digestible starches provide multiple health advantages to humans. The compounds exist in natural form throughout various foods that include fruits vegetables wheat bran oats and ispaghula husk. People can classify dietary fibers into two or more categories based on their water retention capacity and ability to dissolve in hot water and their viscosity. Soluble fibers consist of two components which include viscous substances such as fructus and β -glucans and non-viscous fibers which include hemicellulose. The body processes insoluble fibers which do not dissolve in water by eliminating their thickening properties thus making them suitable for combating constipation while their effect on stomach emptying process is opposite to that. Research shows that high-fiber diets bring about beneficial effects on inflammatory bowel diseases because they decrease the likelihood of developing Crohn's disease and ulcerative colitis.

Example: Naturally found in oats, legumes, fruits, and vegetables; or added to foods (e.g., inulin, polydextrose-fortified yogurt or bread).

2.2.4 Fatty Acids

The main elements that make up the oils and fats from seeds and coconuts and fish oil supplements and animal fats and olive oil are classified as fatty acids. Numerous research studies have demonstrated that these acids possess both anti-inflammatory effects and immunomodulatory capabilities together with their role in energy storage. The study found that rheumatoid arthritis patients who consumed more than 2.7 grams of omega-3 polyunsaturated fatty acids per day for three months experienced reduced RA symptoms.

Example: Rich in fish (Omega-3), nuts, seeds, and oils; or incorporated into foods (e.g., DHA-enriched eggs).

2.2.5 Phytochemicals

The health advantages of probiotics exist because they are beneficial microorganisms found in food, especially dairy products, which provide people with digestive and immune system protection. The living microorganisms work to restore microbial balance in the intestines. The human gut contains *Lactobacillus* as its most common probiotic which consists of multiple species. Currently, people use probiotic strains which belong to both *Streptococcus* and *Bifidobacterium* species.

Example: Tomatoes, pumpkins, apples, onions, fruits, vegetables, soybeans and dark chocolate etc.

2.2.6 Probiotics:

Phytochemicals exist as active plant-based compounds which scientists extract from plants to create concentrated or purified forms. The compounds show neuroprotective effects because they assist in

maintaining the brain's chemical equilibrium. A diet which contains high amounts of fruits and vegetables that contain phytochemicals will decrease the risk of developing both cancer and heart and neurological diseases.

Example: Curd, kefir, kimchi, kombucha, yogurt, and natto etc.

2.2.7 Prebiotics

Prebiotic carbohydrate components known as prebiotics enhance the activity of probiotics. The prebiotics function as probiotic fertilizers because they maintain their effectiveness against stomach acids and different pH conditions. The substances function as indigestible materials which transform gut microbiota composition and functioning while they support the growth of advantageous bacteria. Functional foods incorporate prebiotics like fructo-oligosaccharides and inulin to improve digestive health.

Example: Chicory root, Garlic, Onions, Bananas, Barley, Oats, Apples, and Cocoa etc.

2.2.8 Dietary Supplements

Dietary supplements are products that people can take as dietary ingredients to maintain and improve their health rather than to cure diseases, even though they are not strictly traditional. These supplements come in a variety of forms, including tablets, liquids, capsules, powders, and concentrated forms with precise dosages.

Example: Dietary supplements that a person can take with or without a prescription include omega-3, vitamins A, B, C, D, and E, iron, folic acid, minerals, calcium, magnesium, etc.

Additionally, these supplements can be taken to prevent deficiencies and make sure a diet provides the body with enough nutrients. In the early 1900s, food extracts containing essential nutrients like vitamins.

3. THE MECHANISMS OF ACTION OF CARDIOVASCULAR NUTRACEUTICALS

3.1 INHIBITION OF HEPATIC VLDL SYNTHESIS

The liver is crucial for fat metabolism, with one of its primary roles being the synthesis of very low-density lipoproteins (VLDL). These particles serve as carriers that move triglycerides and cholesterol from the liver into the bloodstream. Although this transport is essential for normal bodily functions, an overproduction of VLDL can be detrimental as it inundates the blood with triglycerides. Eventually, these VLDL particles transform into low-density lipoproteins (LDL), which are infamous for depositing cholesterol in arterial walls and instigating atherosclerosis. Consequently, elevated levels of circulating VLDL are strongly associated with cardiovascular conditions such as coronary artery disease, heart attacks, and strokes.

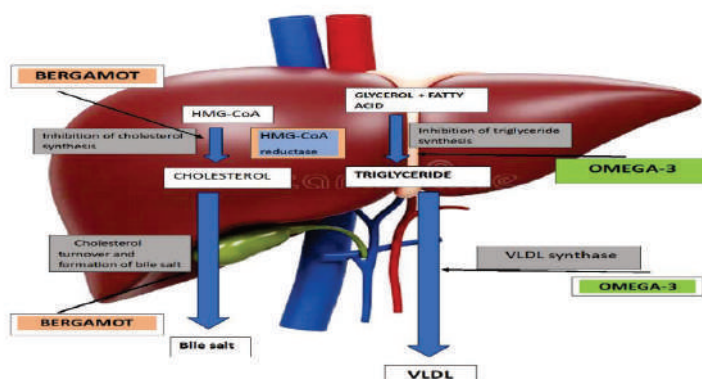


Figure 2: Inhibition of Hepatic VLDL Synthesis

Nutraceuticals, especially omega-3 fatty acids which come from fish oil through EPA and DHA, prove their ability to reduce hepatic VLDL production directly. The effect happens because different pathways produce the results. The first function of omega-3 fatty acids prevents the production of triglycerides through their effect on key triglyceride production enzymes which include diacylglycerol acyltransferase DGAT. The body produces fewer lipoprotein particles because VLDL assembly requires specific building blocks which have been reduced. The body uses omega-3s to improve fatty acid oxidation that takes place in the liver mitochondria and peroxisomes, which leads to fat "burning" before VLDL production begins. Omega-3s decrease the gene expression which SREBP-1c transcription factor controls because it drives lipogenesis. The combined effects of these modifications lead to two outcomes which include decreased plasma triglyceride levels and reduced production of LDL particles from VLDL remnants. Clinical trials have consistently shown that omega-3 fatty acid supplementation can decrease triglyceride levels by 20–50%, depending on the dosage. The lipid-lowering effect brings two benefits which include better overall cardiovascular risk assessment and protection against pancreatitis complications for patients who experience severe hypertriglyceridemia. Nutraceuticals which include omega-3 fatty acids work as natural brakes on blood lipid production because they stop the liver from making excess VLDL, which results in less fat accumulation in bloodstreams and better protection against heart and artery damage.

3.2 ENHANCEMENT OF MITOCHONDRIAL ELECTRON TRANSPORT CHAIN ACTIVITY

Cardiovascular nutraceuticals boost the activity of the mitochondrial electron transport chain (ETC) by enhancing energy production and minimizing oxidative stress in heart cells. The ETC plays a crucial role in ATP generation, which is the energy currency of the cell and essential for the heart's continuous operation. In cases of heart disease, the activity of the ETC frequently diminishes, resulting in fatigue and reduced cardiac output. Nutraceuticals such as Coenzyme Q10, L-carnitine, omega-3 fatty acids, and resveratrol aid the ETC

by improving electron flow, safeguarding mitochondria from damage, and enhancing overall energy efficiency. These substances contribute to the restoration of mitochondrial function, boost heart muscle performance, and may help slow the advancement of cardiovascular diseases.

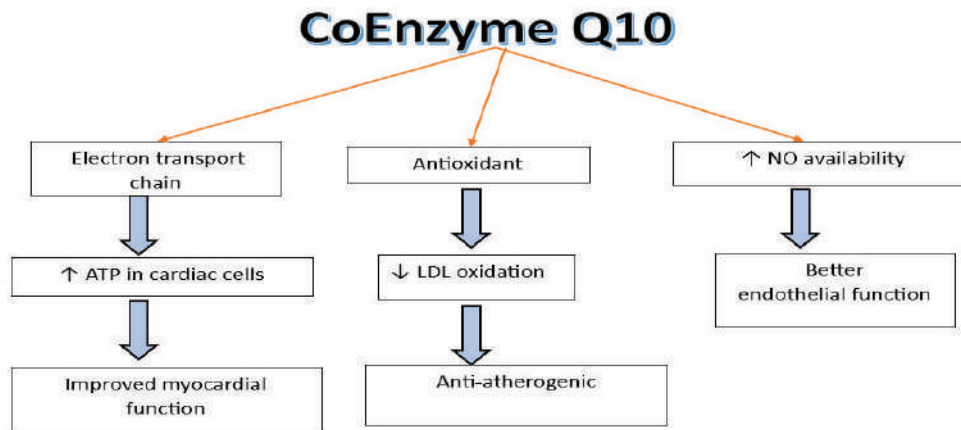


Figure 3: Enhancement of Mitochondrial Electron Transport Chain Activity

Cardiovascular nutraceuticals help maintain mitochondrial membrane integrity while they reduce the generation of dangerous reactive oxygen species which occur due to faulty electron transport. The nutrients alpha-lipoic acid and magnesium and B vitamins function as cofactors which enable mitochondrial enzymes to operate the electron transport chain (ETC) correctly. D-ribose accelerates ATP production while taurine helps control calcium levels in cells which assists heart muscle function. The nutraceuticals enhance mitochondrial function which results in better heart performance and increased endurance while decreasing symptoms of heart failure and ischemia and hypertension.

3.3 ENDOTHELIAL NITRIC OXIDE ACTIVATION

Cardiovascular nutraceuticals improve cardiovascular health by activating eNOS which creates nitric oxide for vascular system enhancement. Nitric oxide is an important molecule that aids in relaxing blood vessels together with improving blood flow and lowering blood pressure. Heart disease patients experience decreased eNOS activity which leads to blood circulation. The essential elements which eNOS requires to produce nitric oxide are found in the nutraceuticals L-arginine and L-citrulline. The eNOS function improves when omega-3 fatty acids resveratrol quercetin and vitamins C and E reduce oxidative stress and improve endothelial performance. The nutraceuticals increase eNOS activity which results in healthy blood vessels and decreased atherosclerosis risk and better cardiovascular health.

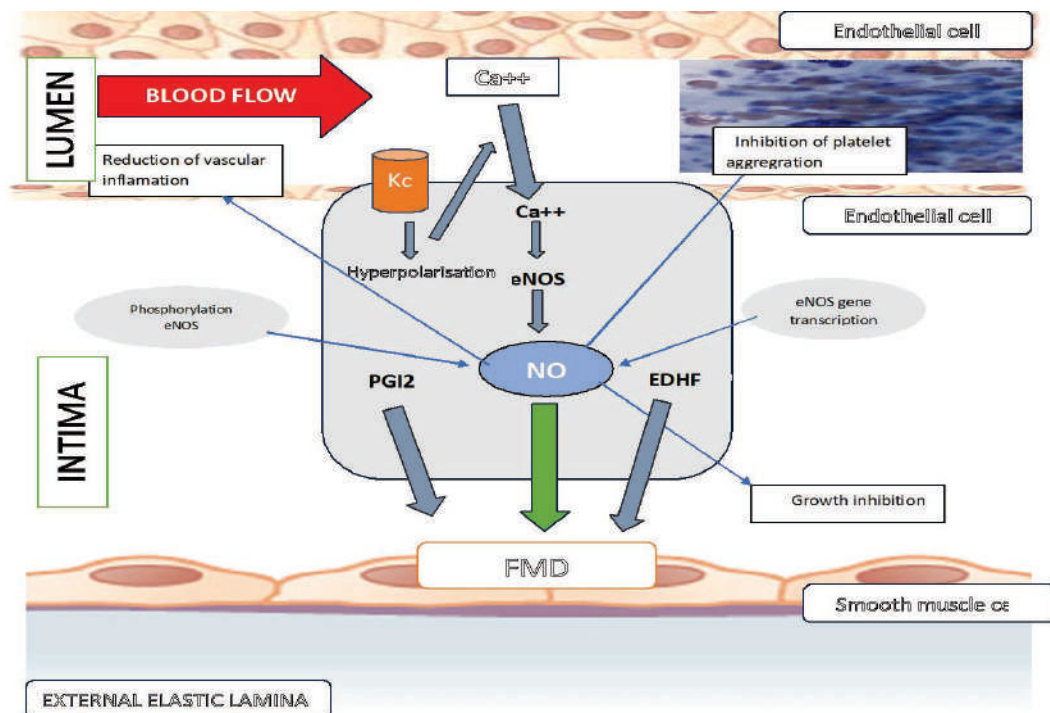


Figure 4: Endothelial Nitric Oxide Activation

The essential cardiovascular functions of omega-3 fatty acids EPA and DHA depend on their various mechanisms through which they protect heart health. The primary function of PUFAs results in decreased blood triglyceride levels because they inhibit the liver from producing very low-density lipoproteins which leads to an improved lipid profile through higher good cholesterol levels and lower bad cholesterol levels. PUFAs possess strong anti-inflammatory effects which serve as their main characteristic. The substances compete with arachidonic acid which is an omega-6 fatty acid that produces inflammatory substances to create less dangerous material. The process reduces inflammation which occurs because chronic inflammation acts as a major contributor to atherosclerosis development which involves plaque accumulation in arteries that results in heart attacks and strokes. The development of endothelial function provides another essential advantage. PUFAs improve blood vessel function because they enhance the endothelium's capacity to generate nitric oxide which helps blood vessels to relax and expand. The process leads to better blood circulation and reduced blood pressure which decreases the body's pressure on the heart.

3.4 REDUCE TRIGLYCERIDE LEVELS

The heart requires two essential fat types which include polyunsaturated fatty acids and omega-3 fatty acids

EPA and DHA to maintain its health through multiple vital functions. The primary function of PUFAs enables them to decrease triglyceride levels in the blood by reducing the liver's production of very low-density lipoproteins. The complete lipid profile improvement results in higher good cholesterol levels and lower bad cholesterol levels. The anti-inflammatory properties of PUFAs provide strong protection against inflammatory conditions. Their substance production leads to less toxic material because they compete with arachidonic acid. The reduction of inflammation becomes critical because chronic inflammatory processes drive the progression of atherosclerosis. This process provides endothelial function with another important benefit. PUFAs enhance blood vessels by improving their endothelial capacity to produce nitric oxide which causes blood vessels to relax and expand. The mechanism improves blood circulation while it decreases blood pressure which leads to reduced heart pressure.

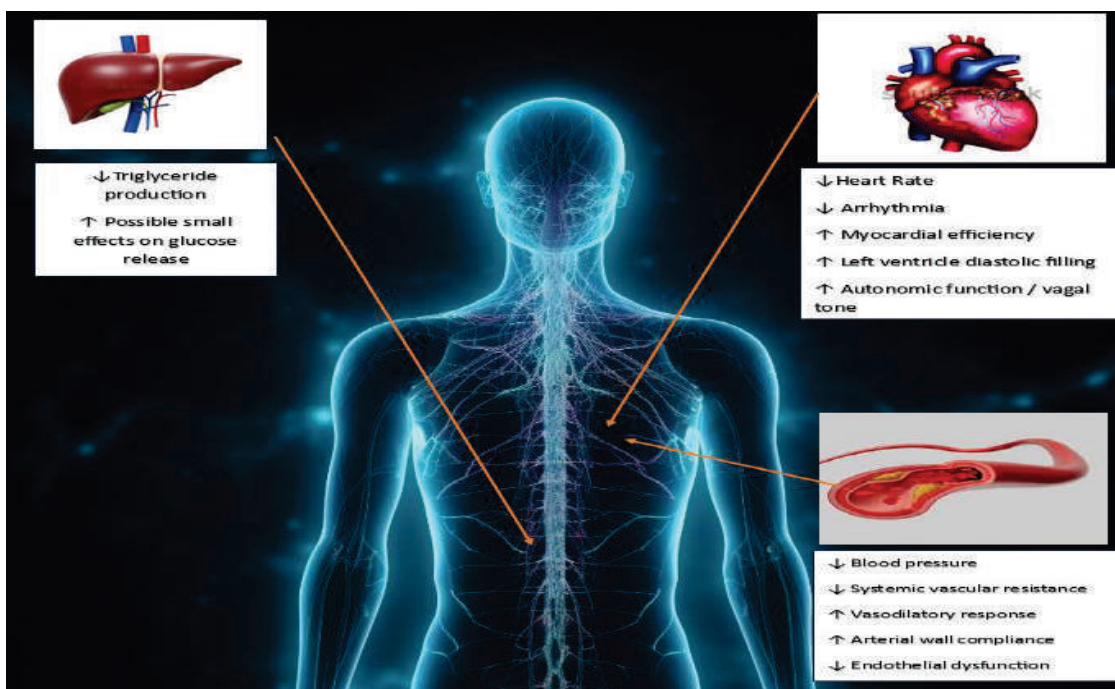


Figure 5: Reduce Triglyceride Levels

PUFAs decrease blood platelet aggregation, which leads to a reduced possibility of blood clots that result in arterial blockages. The substances assist in stabilizing heart cell membranes, which prevents dangerous heart rhythm disorders that can lead to deadly outcomes. PUFAs protect blood vessels through three mechanisms which include preventing vessel damage, decreasing vascular inflammation, and maintaining normal cholesterol levels. The compounds assist in controlling gene functions that govern fat burning and body response to injuries, which benefits cardiovascular health. Omega-3 PUFAs deliver multiple cardiovascular benefits through their ability to decrease dangerous blood lipids while they reduce body swelling, enhance blood vessel performance, stop blood clots from forming, and maintain regular heart rhythms. The heart-

healthy diet requires PUFAs from fish oil and flaxseed and walnuts because these foods lower the chances of developing heart disease and hypertension and stroke and other cardiovascular illnesses.

The body receives cardiovascular nutraceuticals which function to decrease cholesterol levels through their ability to stop both cholesterol creation and bile salt production. The liver produces cholesterol through a process which an enzyme called HMG-CoA reductase regulates. Red yeast rice and other nutraceuticals contain natural substances which block this enzyme to reduce the body's cholesterol production. The mechanism operates in a fashion which resembles cholesterol-lowering drugs but usually produces milder side effects. The specific nutraceuticals block bile salt formation which originates from cholesterol that the liver produces to assist in digestion of fats. The body uses more cholesterol to produce bile salts because diminished bile salt production causes this process to occur, which results in lower blood cholesterol levels. Soluble fibers from oats and psyllium together with plant sterols and saponins work to increase bile salt excretion through intestines, which forces the liver to use surplus cholesterol for bile salt production. The combination of reducing cholesterol production together with increased cholesterol usage for bile salt production leads to improved cholesterol levels which decrease heart disease risk while supporting better cardiovascular health.

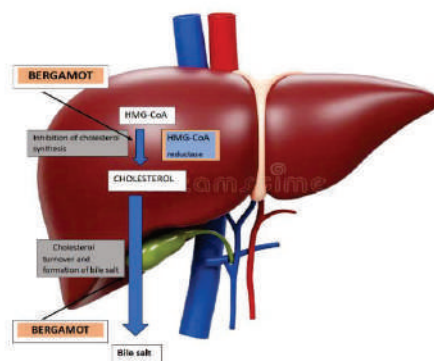


Figure 6: Inhibition of Cholesterol Synthesis and Bile Salt Formation

these nutraceuticals provide a natural, complementary method for regulating cholesterol levels, supporting heart health, and decreasing the risk of atherosclerosis and cardiovascular diseases without the side effects that some medications may cause.

3.6 SCAVENGING OF REACTIVE OXYGEN SPECIES (ANTIOXIDANT DEFENSE)

Essential cardiovascular nutraceuticals play a crucial function in maintaining heart health because their active compounds destroy reactive oxygen species (ROS) which create dangerous health effects through their capacity to oxidatively damage blood vessels and heart cells. The human body produces some reactive oxygen species (ROS) during its metabolic activities but excessive production leads to inflammation and cellular damage which causes heart diseases such as atherosclerosis and hypertension. The combination of vitamins C and E with Coenzyme Q10 and green tea and grape and berry polyphenols and flavonoids creates a powerful antioxidant system which operates as a nutraceutical. They use their electron donation process to protect critical cell components from damage which ROS cause through their destructive chemical reactions. The antioxidant defense system provides essential support for blood vessel health maintenance through its ability to reduce inflammation and slow down cardiovascular disease development. The body receives protection from oxidative damage through nutraceuticals which improve its natural defense system resulting in enhanced heart health and protection against heart attacks and strokes.

The body achieves enhanced antioxidant protection through nutraceuticals which activate the enzyme systems that include superoxide dismutase and glutathione peroxidase. The enzymes act as vital elements which help organisms to process and eliminate harmful reactive oxygen species. Coenzyme Q10 acts as an antioxidant which enhances mitochondrial function to reduce cellular ROS production. Polyphenols and flavonoids function as endothelial enhancers because they reduce oxidative damage which helps maintain blood flow while preventing plaque buildup in blood vessels. The anti-inflammatory properties of these nutraceuticals protect cells from damage which results in improved heart health. The body requires regular consumption of antioxidants through dietary sources and supplements because this practice supports cardiovascular health while reducing heart disease risk and extending lifespan.

3.7 ANTI- INFLAMMATORY MECHANISM AND ANTI- THROMBOTIC MECHANISM

Cardiovascular nutraceuticals function as essential protectors of the heart because they use their ability to reduce inflammation for protecting blood vessels and heart tissues from detrimental inflammatory reactions. Inflammation develops as a normal process which protects the body against injuries and infections; however, its persistent existence becomes a threat because it damages blood vessels and promotes atherosclerosis through plaque formation and increases the probability of heart attacks and strokes. The nutraceutical substances resveratrol, curcumin, and omega-3 fatty acids, and polyphenols work to block body inflammatory reactions through their action against specific molecules and pathways which include cytokines and COX-2 enzymes. The body uses these two processes to stop arterial narrowing and rigidity by improving blood flow while they protect heart cells from damage. The final outcome of this process results in decreased

cardiovascular disease risk while it supports complete heart health maintenance. The natural compounds present in these products achieve their purpose of inflammation reduction through regular dietary intake or supplement use which helps maintain a complete healthy cardiovascular system. The active components of cardiovascular nutraceuticals block both inflammatory molecules and the immune cell activation which triggers arterial inflammation. Omega-3 fatty acids enable the body to create anti-inflammatory substances called resolvins and protectins which function to reduce inflammation and support the healing process. Curcumin blocks the NF- κ B pathway which serves as an essential inflammation control pathway thereby stopping the production of dangerous substances which can harm blood vessels. The polyphenols found in green tea and berries protect against heart damage by neutralizing free radicals which trigger inflammatory responses. The nutraceuticals work to improve the balance between body signals that cause inflammation and those that prevent it which helps to stabilize arterial plaques and stop their breaking apart.

Cardiovascular nutraceuticals demonstrate the capability to control inflammatory signaling pathways through their impact on two specific pathways which include MAPK (Mitogen-Activated Protein Kinase) and JAK-STAT pathways. Resveratrol and quercetin inhibit these pathways which results in lower levels of C-reactive protein (CRP) and tumor necrosis factor-alpha (TNF- α) through their effects on both pathways. Certain nutraceuticals work to decrease the production of adhesion molecules which exist on blood vessel surfaces and this effect stops immune cells from sticking to blood vessels and causing damage to arteries. The process contributes to atherosclerosis progression by creating a delay in its development. The compounds achieve their effects through two mechanisms which include their direct impact on oxidative stress and their ability to reduce oxidative stress which ultimately benefits inflammation control because oxidation causes greater bodily inflammation. The combined effects create a better condition for blood vessels which leads to decreased chances of developing hypertension and plaque buildup and experiencing heart failure. The habitual intake of anti-inflammatory nutraceuticals serves as a vital element for maintaining cardiovascular wellness while protecting against heart disease.

3.8 CARDIOPROTECTIVE ACTION

Cardioprotective cardiovascular nutraceuticals are natural substances which protect the heart and blood vessels from damage while they support heart health maintenance. The nutraceuticals produce various effects which include decreasing inflammation and lowering bad cholesterol levels and enhancing blood circulation and blocking dangerous blood clotting. Omega-3 fatty acids from fish oil help reduce triglyceride levels while maintaining stable heart rhythms. Coenzyme Q10 functions as an antioxidant which protects heart cells from damage while it supports their energy production needs. Polyphenols from green tea and grapes provide two benefits which include enhancing blood vessel functionality and decreasing inflammation. Magnesium supports the body in managing heart rhythm and blood pressure levels. The combination of these nutraceuticals helps to enhance heart muscle function while decreasing heart attack and stroke probabilities and assisting with heart disease recovery. The consumption of these natural compounds through dietary

sources and supplements provides substantial advantages for cardiovascular well-being and heart disease prevention.

The study examined the cardioprotective effects of various nutraceuticals which included Omega-3 fatty acids and Coenzyme Q10 together with garlic that reduces blood pressure and cholesterol levels and vitamins C and E which shield heart cells from oxidative harm. L-arginine boosts nitric oxide production which results in enhanced blood vessel dilation together with improved blood circulation. Resveratrol which exists in red wine and grapes decreases inflammation while it stops plaque accumulation in arteries.

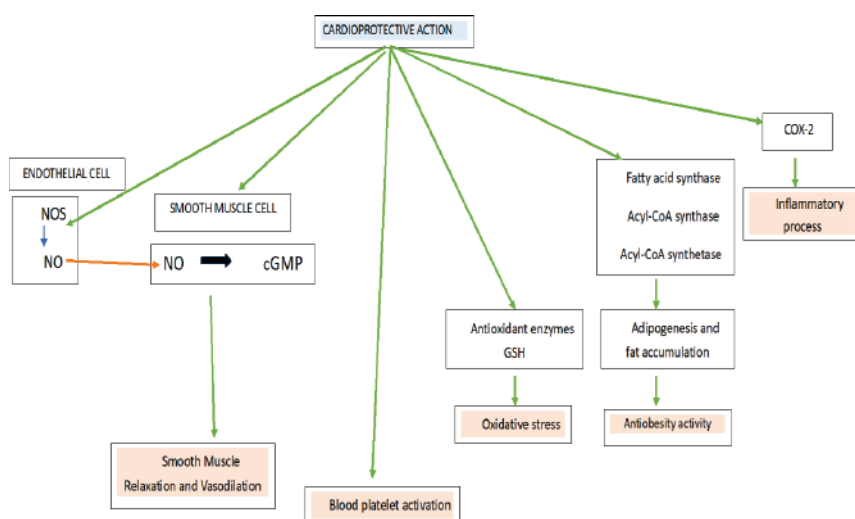


Figure 7: Cardioprotective Action

The nutraceuticals provide heart protection through their ability to enhance lipid profiles and decrease inflammation and block blood clot formation. The combination of both elements protects the heart from harm which results from high cholesterol and high blood pressure and oxidative stress. The continuous consumption of these natural substances leads to heart health maintenance while decreasing cardiovascular disease risks and enhancing life quality.

4. THE CLINICAL POTENTIAL OF BIOACTIVE COMPOUNDS

The pharmacological effects of bioactive compounds have led to their use in various Clinical Potential

4.1 Cardiovascular health: Bioactive compounds known as omega-3 fatty acids exist in fish oil which produces heart health benefits. The compounds decrease triglyceride levels which represent dangerous blood lipids that increase heart disease risk. The blood pressure reduction from omega-3s helps to lessen the cardiovascular system burden which affects heart function. The substances help protect blood vessel function which prevents plaque accumulation in arteries and stops abnormal heart rhythms. The anti-inflammatory and antioxidant abilities of flavonoids in fruits and vegetables create heart protective effects which lower the chance of cardiovascular diseases. Diets that include high amounts of omega-3s and flavonoids lead to improved heart health which decreases the likelihood of heart attacks and strokes. The naturally present

bioactive substances in this research help to maintain heart health while offering protection against cardiovascular diseases.

4.2 Antioxidant activity: Reactive oxygen species (ROS), which help protect cells from oxidative damage, and a range of bioactive substances have strong antioxidant qualities. The prevention of oxidative stress-related diseases, including cancer, neurological diseases, and cardiovascular diseases, depends heavily on antioxidants.

4.3 Cancer treatment: The treatment of cancer through several bioactive compounds depends on their ability to induce apoptosis which leads to the natural death of cancer cells. Researchers have extensively studied curcumin which is derived from turmeric as a potential cancer treatment. The substance can stop cancer cells from growing and spreading throughout the body. Curcumin decreases the inflammation which scientists connect to cancer development. The substance prevents cancer development by creating new blood vessels which tumors use for their growth. Curcumin blocks cancer development by affecting multiple protein and gene functions. Scientists are investigating methods to improve curcumin's body effects. The research uses advanced delivery systems which include nanoparticles as their method of investigation. Curcumin has shown effectiveness against multiple cancer types which include colon lung and breast cancer. Curcumin enhances cancer treatment outcomes when combined with other medical interventions.

4.4 Anti-inflammatory effects: Ginger contains gingerol which develops into bioactive compounds that help the body fight against inflammation. These compounds stop the body from producing the chemical substances that bring about pain and swelling. The effects of ginger can help people who suffer from inflammatory bowel disease and arthritis. The process reduces dangerous substances which include interleukins and TNF-alpha. The research results demonstrate that ginger can help reduce both joint pain and stiffness. Ginger provides a natural solution that competes with multiple anti-inflammatory medications while showing fewer adverse effects. The substance also protects cells from the harmful effects that result from inflammatory processes. Ginger strengthens the immune system through its ability to decrease body inflammation. The substance provides support for muscle recovery through its functions after physical exercise. Ginger functions as a strong natural substance that fights inflammation.

3.5 Neuroprotective effects: Resveratrol exists as a natural compound which people can find in both grapes and red wine, where it protects brain cells from experiencing damage. The substance decreases dangerous reactive oxygen species which represent harmful molecular entities. The substance protects Against harmful brain inflammation which results from the condition. The effects of this combination will improve both cognitive functions and memory performance. The compound resveratrol appears to decrease Alzheimer's disease development risk. The substance protects brain cells from dying while it supports their function. Scientists are studying how resveratrol benefits brain health. The mechanism activates protective systems which assist in cellular restoration. Resveratrol serves as a natural substance which shows potential to protect brain health.

3.6 Metabolic disorders: Bioactive compounds serve an essential function for diabetes treatment by controlling blood sugar levels in diabetic patients. They increase insulin secretion while improving the body's ability to utilize insulin. Some of these compounds slow the absorption of sugar from our diet. This helps to stabilize blood sugar levels. Bioactive compounds provide protection to the liver by preventing various forms of damage. They help to decrease both inflammatory responses and oxidative damage that occurs in liver cells. The use of plant materials that contain these compounds enables people to maintain control over their blood sugar levels while supporting their liver health.

4. CLINICAL TRIALS AND DRUG DEVELOPMENT

The number of clinical trials testing bioactive compounds and their derivatives has increased at a consistent rate. Natural products constitute a significant proportion of drug candidates progressing from early to late-phase clinical trials. The process faces three main challenges which include achieving optimal bioavailability and standardizing dosages and proving products to be safe for extended periods. The clinical benefits of delivery systems have advanced through the development of nanoparticles and colon-targeted carriers.

Table 2: Clinical Trials and Drug Development

Compound	Evidence Strength	Meta-Analysis Finding	Primary Effect
Coenzyme Q10 (CoQ10)	Randomized Controlled Trials (RCTs) and Meta-analyses: strong	42% decrease in mortality (Q-SYMBIO)	↓ Mortality rates, ↓ Events related to heart failure
Omega-3 Fatty Acids	Randomized Controlled Trials (RCTs) and Meta-analyses: strong	↓ lipids/BP, ↓ CV events	↓ TG, BP, risk of arrhythmia
Phytosterols	Randomized Controlled Trials (RCTs) and Meta-analyses: moderate	↓ LDL-C by 8-10%	Decrease in LDL-C levels (8-10%)
Phytosterols and Red Yeast Rice	Randomized Controlled Trials (RCTs) and Meta-analyses: strong	↓ LDL-C, safe in statin-intolerant	↓ LDL-C, TG, ↑ HDL-C
Polyphenols and Flavonoids (e.g., Resveratrol)	Randomized Controlled Trials (RCTs) and Meta-analyses: moderate	37% relative mortality reduction	Risk indicators/endothelial
Hawthorn Extract	Randomized Controlled Trials (RCTs) and Meta-analyses: moderate	Improved symptoms, safety proven	↑ Physical activity, ↓ SCD risk

These nutraceutical interventions particularly CoQ10, phytosterols, red yeast rice, polyphenols, omega-3 fatty acids, and hawthorn are underpinned by strong clinical evidence for specific cardiovascular uses, such as alleviating symptoms of heart failure, managing lipid levels, and preventing arrhythmias.

5. CURRENT CHALLENGES AND FUTURE PROSPECTIVES OF BIOACTIVE COMPOUNDS

Current Challenges

The main problem exists because the present clinical trials do not provide enough comprehensive and properly constructed studies which can prove the cardiovascular advantages of nutraceutical bioactive compounds including CoQ10 phytosterols red yeast rice polyphenols omega-3 fatty acids and hawthorn. The field of clinical application and consumer confidence faces major obstacles because of low bioavailability and varying formulation quality and the absence of stable regulatory standards.

Future Perspectives

The development of personalized nutrition through AI and genomics now enables tailored dietary plans which use individual genetic and metabolic and lifestyle information for cardiovascular treatment. The AI-based platforms use actual physiological measurements together with gut microbiome data to create nutrition plans which address specific cardiovascular risks. The advanced delivery systems that use

nanoencapsulation technology enable better stability and bioactive nutraceutical compound delivery which results in enhanced therapeutic effects and improved safety. Research now shows that targeted nutraceuticals can change the gut microbiome which leads to better cardiovascular health results. The development of stricter regulatory requirements now establishes higher standards for both evidence and product quality and consumer protection. The progress in research on nutraceuticals now enables their use as standard treatment methods for preventing and treating cardiovascular diseases. The use of personalized data-driven methods will improve patient treatment results together with their ability to follow medical advice which will result in better cardiovascular health outcomes.

CONCLUSION

Existing research on cardiac nutraceuticals shows a major deficiency because researchers have not conducted sufficient clinical studies to demonstrate how CoQ10 and phytosterols and red yeast rice and polyphenols and omega-3 fatty acids and hawthorn impact human heart health. The existing research studies show restricted study populations which conduct brief investigations using flawed research techniques. Nutraceutical studies face multiple challenges because food structure becomes complex and bioavailability problems occur and different product formulations exist which decrease their ability to achieve clinical results. Product quality and consumer trust suffer because regulatory agencies maintain different standards which create lack of product standardization. The initial results show potential but researchers require immediate execution of large-scale randomized controlled trials which must use uniform product formulations. The research needs improvements through better study designs and proper dose selection and increased collaboration with industry partners and regulatory organizations. The development of cardiac nutraceuticals into effective treatments for cardiovascular disease will proceed once researchers establish their efficacy through clinical studies.

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Authors' Contributions

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