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ROLE OF NUTRACEUTICALS AND FUNCTIONAL FOODS IN HUMAN DISEASES: REVIEW WITH SPECIAL REFERENCE TO CARDIOVASCULAR DISEASES, CANCER AND CHRONIC INFLAMMATORY DISEASES

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Abstract:

The connection between food and human health has become an important area of research because diet can influence several processes involved in the development of chronic diseases. Food provides essential nutrients, but some foods also contain biologically active compounds that may affect inflammation, oxidative stress, metabolism, cellular signalling, and the gut microbiome. This has increased interest in functional foods and nutraceuticals as supportive approaches for maintaining health and reducing disease risk. Nutraceuticals generally refer to food-derived substances or preparations consumed for their potential health benefits, while functional foods provide additional physiological benefits along with their normal nutritional value. Important bioactive substances include omega-3 fatty acids, polyphenols, flavonoids, carotenoids, curcumin, resveratrol, dietary fibre, probiotics and prebiotics. These compounds have been studied in relation to cardiovascular diseases, cancer and chronic inflammatory conditions. Omega-3 fatty acids may influence lipid metabolism and inflammatory mediator production, whereas plant-derived compounds can affect oxidative stress and cellular signalling. Dietary fibre and probiotic-containing foods may also influence health through interactions with intestinal microorganisms. Although many experimental studies have reported promising biological effects, clinical evidence is not equally strong for all nutraceuticals. Factors such as poor bioavailability, differences in dosage, formulation, metabolism, and individual response can influence their effectiveness.

Keywords: *Nutraceuticals, Functional Foods, Bioactive Compounds, Polyphenols, Omega-3 Fatty Acids, Cardiovascular Diseases, Cancer, Inflammation, Gut Microbiome.*

1. Introduction

Food is usually considered the main source of energy and nutrients required for growth, development, and normal body functions. However, research over the last few decades has shown that food can influence the body in ways that go beyond basic nutrition. Many foods contain naturally occurring compounds that can interact with metabolic, immune, and cellular pathways. This has led to increasing interest in functional foods and nutraceuticals. Nutraceuticals are generally described as food-derived substances or preparations that are used because of their proposed health-promoting or physiological effects (1). Functional foods, on the other hand, are foods that provide benefits beyond their basic nutritional role because of the presence of particular bioactive components (2). The growing interest in these areas is also related to the increasing occurrence of chronic diseases. Cardiovascular diseases, cancer and chronic inflammatory disorders do not usually result from one single cause. Instead, their development involves a combination of genetic, environmental, metabolic and lifestyle factors. Diet is one of the modifiable factors that can influence several of these processes. Plant foods are particularly important sources of bioactive compounds. Fruits, vegetables, cereals, legumes, tea, spices, nuts and seeds contain substances such as polyphenols, flavonoids and carotenoids. These compounds have been investigated for their effects on oxidative stress, inflammation and cellular signalling. Surh discussed the possible role of dietary phytochemicals in cancer chemoprevention and emphasized the importance of cellular signalling pathways in their biological effects (3). Omega-3 fatty acids are another important group of food-derived bioactive compounds. EPA and DHA, mainly obtained from marine sources, can become incorporated into cell membranes and influence the production of lipid mediators involved in inflammatory responses (4). Interest has also expanded towards the gut microbiome. Dietary fibre, probiotics, prebiotics and other food components can influence intestinal microorganisms, while microbial metabolism can generate compounds that affect the host. This provides another possible link between diet, inflammation and systemic health.

The present review discusses the potential role of nutraceuticals and functional foods in cardiovascular diseases, cancer and chronic inflammatory diseases. It also examines their mechanisms of action, the role of the gut microbiome and the major limitations that need to be considered while interpreting current evidence.

2. Nutraceuticals and functional foods

2.1 Concept of nutraceuticals

The word nutraceutical combines the concepts of nutrition and pharmaceutical activity. Although the term is widely used, there is no single internationally accepted definition that applies to all regulatory systems. In general, nutraceuticals are food-derived substances or preparations that are consumed or investigated for their possible physiological and health-related effects (1). They can be obtained from plants, animals, or microorganisms. Some nutraceutical products contain one concentrated compound, whereas others contain mixtures of several bioactive substances.

Common examples include curcumin, resveratrol, lycopene, flavonoids, polyphenols, dietary fibre, probiotics, prebiotics, selected vitamins and minerals, omega-3 fatty acids.

The concentration of a bioactive compound in a nutraceutical supplement can be considerably different from its concentration in the original food. Therefore, the effect of a purified compound cannot always be assumed to be identical to the effect of eating the whole food.

2.2 functional foods

Functional foods are foods that provide their normal nutritional value together with additional physiological benefits associated with their bioactive components (2).

Some commonly discussed examples are shown below:

Table 1: Functional Foods, their major bioactive components and potential health relevance

Food	Major bioactive component	Possible health relevance
Fatty fish	EPA and DHA	Cardiovascular and inflammatory pathways
Tomato	Lycopene	Oxidative and cellular pathways
Turmeric	Curcumin	Inflammatory signalling
Green tea	Catechins	Oxidative and cellular processes
Fruits and vegetables	Polyphenols, flavonoids, carotenoids	Metabolic and antioxidant effects
Whole grains	Dietary fibre and phytochemicals	Cardiometabolic health
Fermented foods	Probiotic microorganisms	Gut health
Nuts and seeds	Unsaturated fatty acids and phytochemicals	Cardiometabolic effects

An important feature of functional foods is that they contain several nutrients and bioactive compounds together. Therefore, the observed effect may result from the combined action of the food components rather than from one isolated molecule.

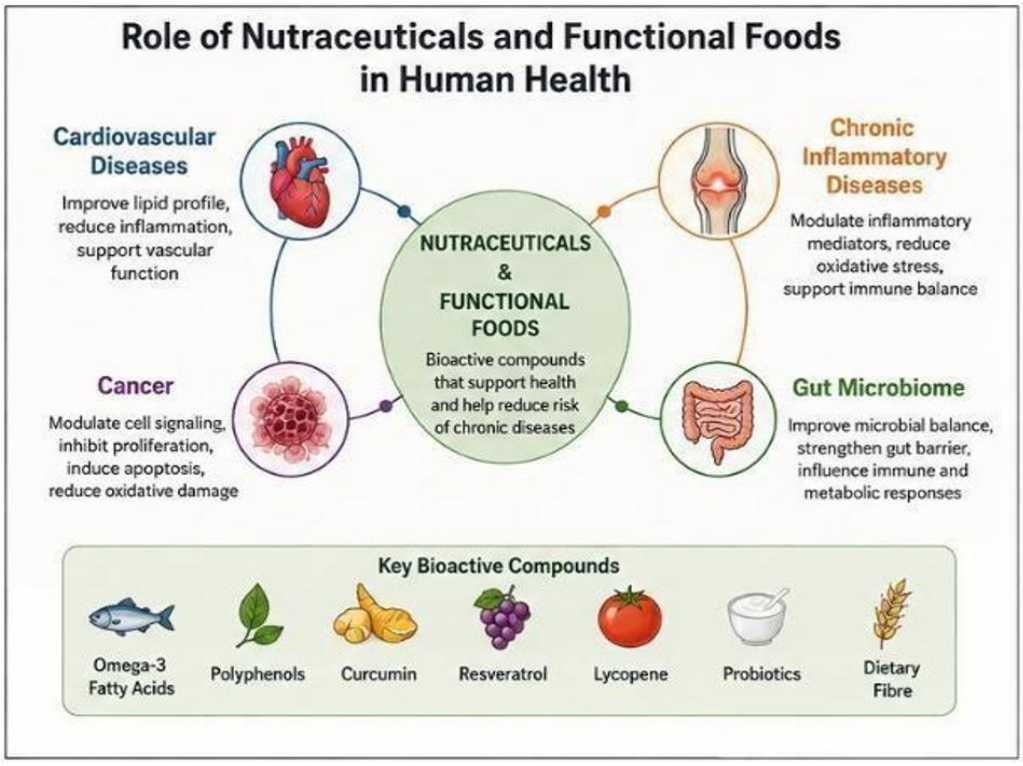

Figure 1: Role of Nutraceuticals and Functional Foods in Human Health

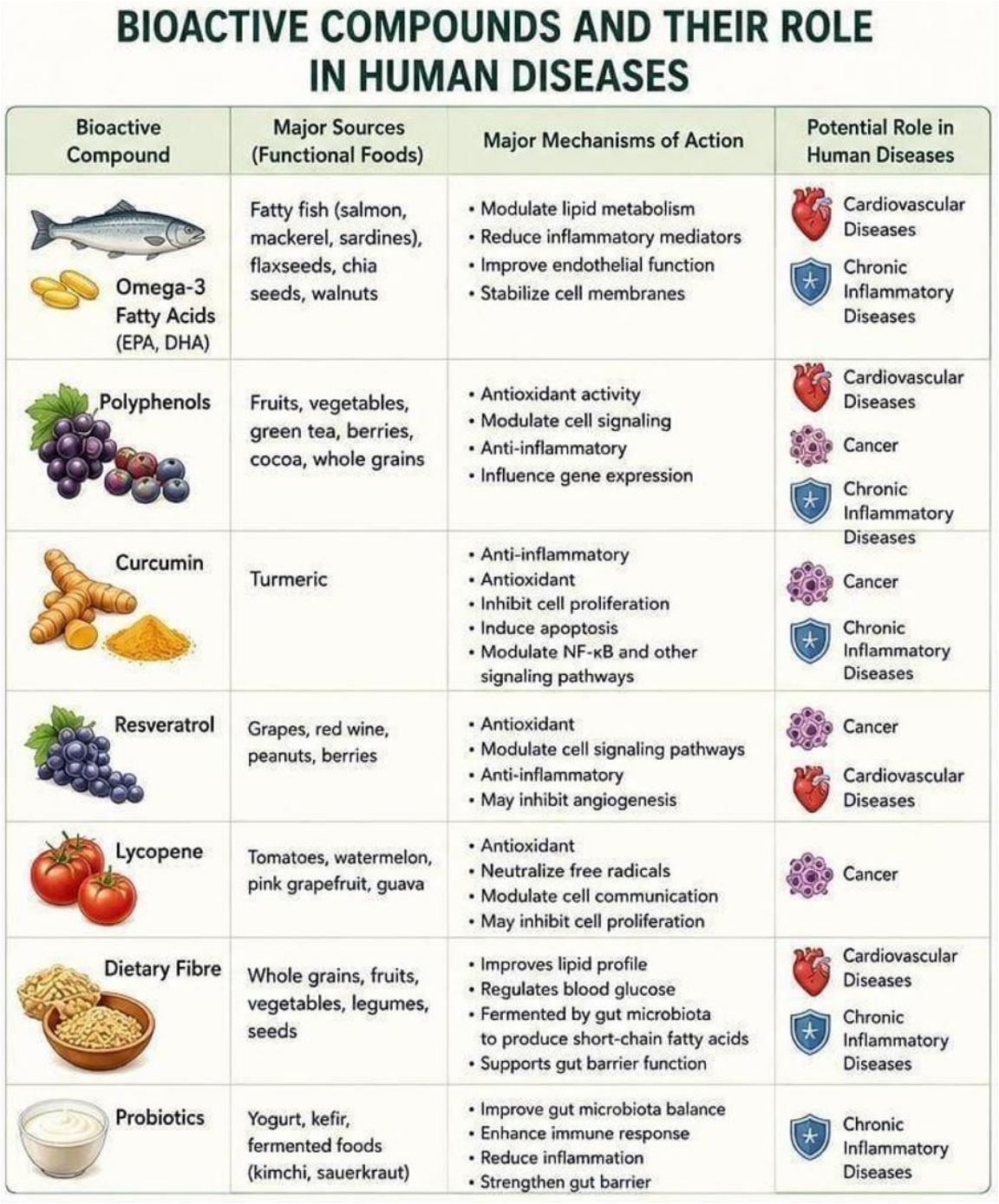

Figure 2: Bioactive Compounds and their role in human disease

3. Important bioactive components

3.1 Omega-3 polyunsaturated fatty acids

EPA and DHA are long-chain omega-3 polyunsaturated fatty acids commonly obtained from oily fish and other marine foods. They can become part of cell membranes and influence the types of lipid mediators produced by cells. This is particularly relevant to inflammation because changes in membrane fatty-acid composition can

modify inflammatory signalling and the production of inflammation-related mediators (4). Omega-3 fatty acids have therefore been investigated extensively in cardiovascular diseases.

3.2 Polyphenols

Polyphenols are a large group of plant-derived compounds found in fruits, vegetables, tea, cocoa, grapes, and many other foods. Their biological effects are not limited to antioxidant activity. Depending on the compound and biological system, polyphenols may affect inflammatory signalling, cellular communication, enzyme activity, and metabolic processes.

3.3 Flavonoids

Flavonoids form one of the major groups within polyphenols. They are widely distributed in plant foods and include compounds with different structures and biological properties. Research has examined their possible influence on oxidative stress, inflammatory pathways, and vascular function.

3.4 Carotenoids

Carotenoids are naturally occurring pigments responsible for many of the yellow, orange, and red colours found in fruits and vegetables.

Important examples include: Lycopene, β-carotene, Lutein, Zeaxanthin

Lycopene, particularly abundant in tomatoes, has been investigated for its antioxidant properties and possible relationship with chronic disease.

3.5 Curcumin

Curcumin is one of the major bioactive constituents of turmeric. It has attracted considerable research interest because experimental studies have associated it with effects on inflammation, oxidative stress, cell proliferation, and apoptosis. However, curcumin also has a major limitation: its conventional oral bioavailability is relatively low. This makes it difficult to directly compare results obtained from experimental models with the effects produced by normal dietary consumption.

3.6 Resveratrol

Resveratrol is a plant polyphenol associated mainly with grapes and some other plant foods. Experimental studies have examined its possible effects on oxidative stress, inflammation, cellular survival, and signalling pathways. Its potential health effects remain an area of research because absorption and metabolism can influence the amount of resveratrol that actually becomes available in the body.

3.7 Dietary fibre

Dietary fibre is important for normal intestinal function and also has metabolic effects. Some types of fibre are fermented by intestinal microorganisms, producing metabolites such as short-chain fatty acids. These metabolites can influence intestinal function, immune responses, and metabolism. Fibre has therefore been studied not only for digestive health but also in relation to cardiovascular and metabolic health.

3.8 Probiotics and prebiotics

Probiotics are living microorganisms that may provide health benefits when consumed in adequate quantities. Prebiotics are substances that can be selectively utilized by beneficial microorganisms. Both are important in functional-food research because of the increasing evidence connecting the gut microbiome with immunity, metabolism, and inflammation.

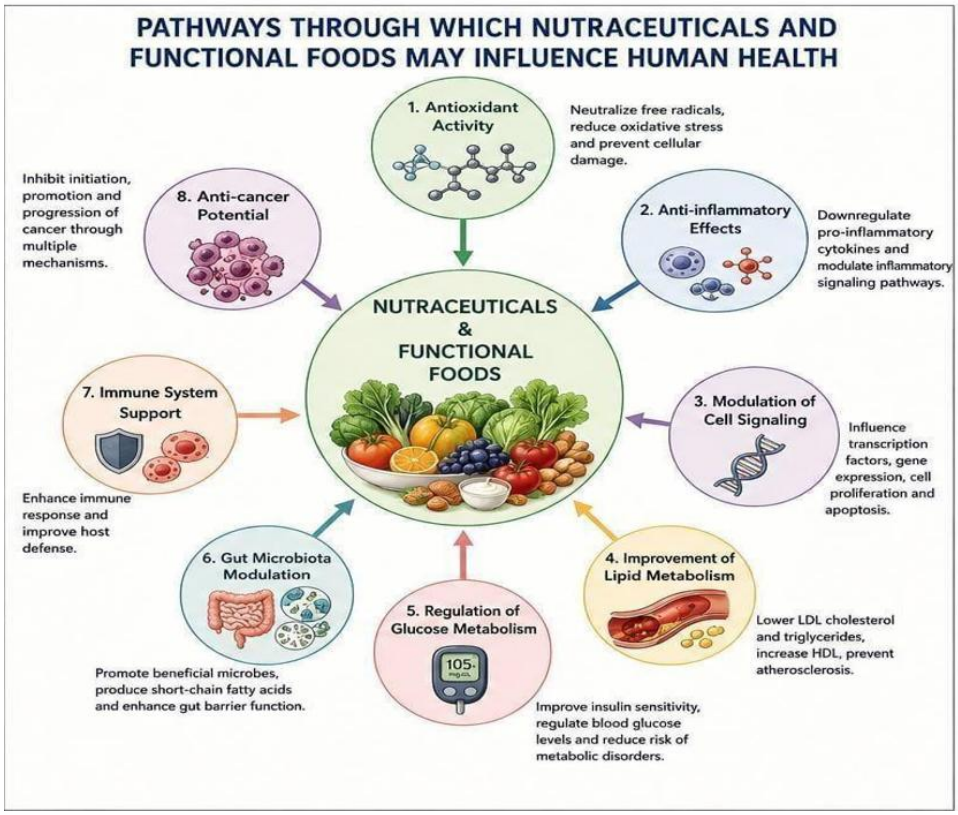

Figure 3: Pathways through which nutraceuticals and functional foods may influence human health

4. Biological mechanisms associated with nutraceuticals

Nutraceuticals generally do not work through a single biological pathway. Their effects can involve several interconnected processes.

4.1 Oxidative stress

Reactive oxygen species are produced naturally during normal metabolism. When their production becomes greater than the body's ability to control them, oxidative stress can occur. Long-term oxidative imbalance may damage cellular components and influence pathways involved in chronic diseases. Several plant compounds have therefore been studied for their effects on antioxidant defence systems and redox-sensitive signalling. However, it is important to distinguish between antioxidant activity observed in a laboratory experiment and a clinically meaningful health benefit in humans.

4.2 Inflammatory signalling

Inflammation is an essential protective response that helps the body deal with infection and tissue damage. Persistent inflammation, however, can contribute to the development of several chronic diseases. Omega-3 fatty acids can modify the availability of fatty-acid substrates used to produce lipid mediators. This can influence inflammatory signalling and pathways involved in inflammation resolution (4). Plant-derived compounds may also interact with inflammatory signalling networks.

4.3 Cellular signalling

Many phytochemicals have been investigated because they can influence intracellular signalling pathways. These pathways regulate:

- Cell proliferation
- Cell survival
- Apoptosis
- Inflammation
- Oxidative stress
- Angiogenesis

Surh highlighted intracellular signalling as an important area through which dietary phytochemicals may interfere with processes involved in carcinogenesis (3).

4.4 Regulation of inflammatory mediators

Nutraceuticals may influence different inflammatory mediators, including cytokines and lipid-derived signalling molecules. Research has shown that omega-3 fatty acids can modify inflammatory mediator production, while several plant-derived compounds have also been studied for their effects on inflammatory signalling. Siriwardhana *et al.* discussed the possible role of dietary bioactive compounds in modifying inflammation, particularly inflammation associated with adipose tissue and metabolic dysfunction (5).

4.5 Interaction with the gut microbiome

The gut microbiome provides another pathway through which food can influence human health. Dietary fibre, polyphenols, probiotics, and prebiotics can alter the intestinal microbial environment. In turn, microorganisms metabolize some dietary compounds and produce metabolites that can affect intestinal barrier function, immunity, and host metabolism (6, 7). This area is particularly interesting because differences in gut microbiome composition may contribute to differences in individual responses to the same food or dietary intervention.

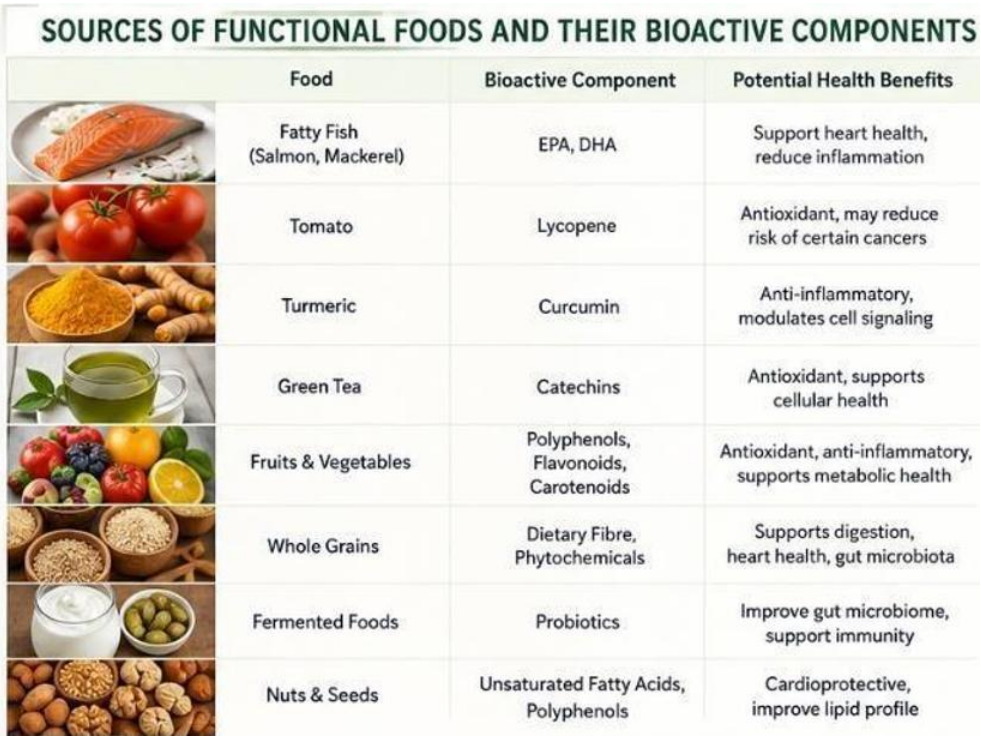

Figure 4: Sources of functional foods and their bioactive components

5. Nutraceuticals and cardiovascular diseases

Cardiovascular diseases involve several interacting processes, including abnormal lipid metabolism, endothelial dysfunction, inflammation, and oxidative stress. Because functional foods and nutraceuticals can influence more than one of these pathways, they have been investigated as possible supportive approaches to cardiovascular health.

5.1 Omega-3 fatty acids

Omega-3 fatty acids are among the most extensively studied food-derived compounds in cardiovascular research. EPA and DHA may influence:

- Lipid metabolism
- Inflammatory signalling
- Cell membrane composition
- Lipid mediator production
- Vascular responses
- Platelet-related processes

The biological effects of EPA and DHA on inflammatory pathways are well documented (4). Clinical evidence is more complicated, however. A large systematic review and meta-analysis found that the cardiovascular effects of omega-3 supplementation vary depending on the specific clinical outcome and study population (8). This illustrates an important point in nutraceutical research: a demonstrated biological mechanism does not necessarily mean that supplementation will produce the same magnitude of clinical benefit in every person.

5.2 Plant phytochemicals and cardiovascular health

Plant-based foods provide a mixture of polyphenols, flavonoids, carotenoids, fibre, and other nutrients. These compounds have been investigated for possible effects on oxidative stress, vascular function, inflammation, and metabolic health. Polyphenol-based nutraceuticals have also been studied in human clinical trials. Tomé-Carneiro and Visioli reviewed human evidence and concluded that polyphenol-based nutraceuticals and functional foods may have potential as supportive approaches in cardiovascular disease, although more long-term trials with clinically meaningful outcomes are required (10).

5.3 Functional foods and lipid metabolism

Whole grains, legumes, fruits, vegetables, nuts, and seeds provide combinations of fibre, minerals, unsaturated fatty acids, and phytochemicals. Dietary fibre can contribute to favourable changes in cholesterol metabolism, while nuts and seeds provide unsaturated fats and several bioactive compounds. Research on functional foods enriched with polyphenols has also examined cardiometabolic risk factors. A systematic review of randomized controlled trials reported promising effects in some areas but also highlighted the need for stronger and longer clinical studies (11). Therefore, functional foods are best considered as components of an overall dietary pattern rather than as isolated treatments.

5.4 Cardiovascular inflammation

Inflammation plays an important role in the development and progression of atherosclerosis and other cardiovascular conditions. Nutraceuticals that influence inflammatory pathways have therefore received considerable attention. Omega-3 fatty acids, polyphenols, and fibre-rich foods may affect different components of

this process. However, the presence of anti-inflammatory activity does not automatically mean that a nutraceutical can prevent cardiovascular events. Clinical outcomes remain the most important measure of effectiveness.

6. Nutraceuticals and cancer

Cancer develops through a complex sequence of genetic and cellular changes. Abnormal proliferation, altered cell survival, tissue interactions, and changes in signalling pathways all contribute to disease progression. Because many plant foods contain biologically active compounds, dietary phytochemicals have been widely studied in cancer research.

6.1 Cancer chemoprevention

Cancer chemoprevention refers to the use of natural or synthetic compounds to delay, prevent, or interfere with the development of cancer. A simplified sequence is: Carcinogenic exposure → Cellular damage → Initiation → Promotion → Progression → Malignant disease. Dietary phytochemicals may potentially influence more than one of these stages. Surh described several mechanisms through which dietary phytochemicals can interact with pathways involved in carcinogenesis (3).

6.2 Curcumin

Curcumin has received extensive attention in experimental cancer research. Studies have associated it with effects on inflammatory signalling, oxidative stress, cell proliferation, and apoptosis. However, experimental activity should not be interpreted as proof of clinical effectiveness. A recent critical analysis of clinical trials found that the available evidence does not convincingly establish curcumin as an effective treatment for malignant diseases. The review also emphasized the major problem of low bioavailability (12). Therefore, curcumin remains scientifically interesting, but its clinical role requires stronger evidence.

6.3 Resveratrol

Resveratrol has been investigated in experimental models because of its possible effects on cellular survival, proliferation, inflammation, and oxidative pathways. Its potential role in cancer prevention is still being studied. Differences in dose, metabolism, and bioavailability make it difficult to directly compare laboratory findings with effects in humans.

6.4 Lycopene

Lycopene is a carotenoid commonly obtained from tomatoes and tomato-based foods. Its antioxidant properties and possible effects on cellular processes have led to research into its relationship with cancer risk. However, associations observed in nutritional studies do not necessarily establish a direct cause-and-effect relationship.

6.5 Tea polyphenols

Tea, particularly green tea, contains several polyphenolic compounds called catechins. These compounds have been investigated for possible antioxidant, anti-inflammatory, and cellular effects. Experimental findings have been encouraging in some areas, although the strength of human evidence varies according to the specific cancer and study design.

6.6 Importance of clinical evidence

A major challenge in phytochemical cancer research is the difference between laboratory findings and clinical outcomes. Kotecha *et al.* reviewed clinical evidence for several dietary phytochemicals, including curcumin, resveratrol, lycopene, and tea polyphenols. Their analysis showed that although preclinical findings are often promising, clinical evidence remains inconsistent for many compounds (9).

More recent research continues to emphasize the gap between laboratory findings and clinical application. Functional-food compounds may affect apoptosis, inflammation, oxidative stress, and cellular signalling, but their effectiveness in patients depends on factors such as dose, bioavailability, and the clinical setting (13).

Some important limitations include:

- Poor absorption
- Low bioavailability
- Rapid metabolism
- Differences in dosage
- Differences in formulation
- Individual variation
- Long periods required to observe cancer-related outcomes

Thus, nutraceuticals should not be described as established cures for cancer.

7. Nutraceuticals and chronic inflammatory diseases

Inflammation is normally a protective process involved in defence and tissue repair. The problem arises when inflammatory activity persists for long periods or becomes poorly regulated. Chronic low-grade inflammation is associated with several metabolic and chronic diseases. This has led to increased interest in dietary compounds that may influence inflammatory pathways.

7.1 Omega-3 fatty acids and inflammation

EPA and DHA can become incorporated into cell membranes and alter the fatty-acid substrates available for lipid mediator production. This can influence inflammatory signalling and may also support pathways involved in the resolution of inflammation (4). The process can be represented as: Dietary omega-3 intake → EPA/DHA availability → Changes in membrane composition → Altered lipid mediator production → Changes in inflammatory signalling → Potential support for inflammation resolution.

7.2 Plant-derived anti-inflammatory compounds

Curcumin, polyphenols, and other plant-derived compounds have been investigated for their possible anti-inflammatory effects. Potential targets include:

- Inflammatory transcription factors
- Cytokine production
- Oxidative signalling
- Cellular stress pathways
- Enzyme activity

Siriwardhana *et al.* discussed the influence of dietary bioactive compounds on inflammatory and metabolic processes (5). Recent research has also highlighted the combined importance of polyphenols, omega-3 fatty acids, probiotics, and prebiotics in the regulation of inflammation and metabolic pathways associated with chronic disease (13).

7.3 Functional foods and chronic inflammation

A diet containing fruits, vegetables, whole grains, legumes, nuts, seeds, and sources of unsaturated fats provides several compounds that may influence inflammatory and metabolic pathways. The advantage of this approach is

that multiple nutrients and bioactive compounds are consumed together. It therefore differs from taking a single purified compound. Overall dietary quality may be more important than relying on one nutraceutical.

8. Functional foods, gut microbiome and inflammation

The gut microbiome has become an important area of research because intestinal microorganisms can interact with dietary components and influence host physiology. Food components such as fibre, polyphenols, probiotics, and prebiotics can modify the intestinal environment. Microorganisms can then metabolize some of these compounds and produce metabolites that influence the intestinal barrier, immune system, and metabolism (6, 7). A simplified relationship can be represented as:

Functional food
↓
Changes in intestinal microbial environment
↓
Changes in microbial metabolites
↓
Effects on gut barrier and immune pathways
↓
Possible changes in systemic inflammation

Dietary fibre is particularly important because gut microorganisms can ferment it to produce short-chain fatty acids. Probiotic-containing functional foods are another area of interest. Recent research on probiotic-fermented edible herbs suggests that fermentation can alter bioactive components and may influence antioxidant, anti-inflammatory, and gut-microbiome-related properties (14). However, the response of the gut microbiome is not identical in everyone. Age, diet, genetics, medication, lifestyle, and the existing microbial community can all influence the outcome.

9. Integrated role in human diseases

One of the most interesting aspects of nutraceutical research is that a single compound can be relevant to more than one disease. For example:

Omega-3 fatty acids

- Membrane modification
- Altered lipid mediator production
- Changes in inflammation
- Possible cardiovascular and inflammatory benefits.

Polyphenols

- Modulation of oxidative signalling
- Effects on inflammatory pathways
- Changes in cellular signalling
- Possible relevance to cardiovascular disease and cancer. Another example is:

Dietary fibre

- Intestinal fermentation
- Microbial metabolite production
- Changes in gut and metabolic function

- Possible effects on inflammation and cardiovascular health

These connections exist because many chronic diseases share common biological processes, as summarized in Table 2.

Table 2: Common biological processes involved in cardiovascular disease, cancer, and chronic inflammatory disease

Biological process	Cardiovascular disease	Cancer	Chronic inflammation
Oxidative stress	✓	✓	✓
Inflammatory signalling	✓	✓	✓
Cellular signalling	✓	✓	✓
Metabolic imbalance	✓	✓	✓
Gut microbiome	Possible role	Possible role	✓

This overlap provides a biological basis for studying functional foods as part of strategies aimed at supporting overall health rather than focusing on only one disease.

10. Recent advances in nutraceuticals and functional foods

Recent studies have shown that nutraceuticals and functional foods are becoming increasingly important in the prevention and management of different human diseases. Their benefits are not only related to their nutritional value but also to the presence of bioactive compounds that can influence different processes in the body. These compounds may help regulate inflammation, oxidative stress, and other processes involved in chronic diseases (15).

Food processing can also influence the health benefits of functional foods. Probiotic fermentation of edible herbs may modify their composition and improve the availability of certain bioactive compounds. This suggests that fermentation can be used as a food biotechnology approach for developing functional foods with improved health-promoting properties (14).

Phytochemicals are another important group of compounds found in functional foods. Compounds such as curcumin, resveratrol, quercetin, and gingerol have been studied for their possible effects on inflammation and chronic diseases. They may influence different inflammatory pathways and may therefore have potential benefits in conditions such as cardiovascular diseases, cancer, and metabolic disorders (16).

Plant-based foods are also rich sources of fibre, vitamins, minerals, phenolic compounds, and antioxidants. Regular consumption of fruits, vegetables, legumes, and other plant foods may support normal immune function and contribute to cardiovascular and metabolic health (17). Therefore, consuming a variety of functional foods may be more beneficial than depending on a single nutraceutical or supplement.

Nutraceuticals and functional foods have also been investigated in relation to cancer prevention. Some dietary compounds may influence processes associated with cancer development, including cellular metabolism and gene regulation. However, the evidence is not equally strong for all nutraceuticals, and further human studies are required to confirm their effectiveness (18).

Overall, recent research indicates that nutraceuticals and functional foods have promising applications in human health. Their development involves several fields, including nutrition, food biotechnology, microbiology, and

molecular biology. Future research should focus on improving bioavailability, understanding interactions with the gut microbiome, and conducting well-designed clinical studies (14–18).

11. Challenges and limitations

Although nutraceuticals and functional foods are promising areas of research, several challenges need to be considered.

11.1 Bioavailability

A compound may show strong activity in a laboratory experiment but reach only a small concentration in human tissues after oral consumption. Curcumin is a clear example in which poor bioavailability has complicated the translation of experimental findings into clinical applications (12).

11.2 Dose differences

The concentration of a compound used in cell or animal experiments may be much higher than the amount obtained from normal food consumption. Therefore, experimental results should not automatically be interpreted as evidence that the same effect will occur after eating a particular food.

11.3 Individual variation

People can respond differently to the same dietary intervention. Age, genetics, metabolic health, gut microbiome composition, lifestyle, and medication use can all influence the response.

11.4 Clinical evidence

A large amount of nutraceutical research is based on cell culture, animal experiments, or observational studies. These studies are useful for identifying possible mechanisms, but well-designed human clinical trials are needed to determine whether those mechanisms produce meaningful health outcomes.

11.5 Whole food versus isolated compound

The effect of a compound consumed as part of a whole food may differ from the effect of a concentrated supplement. A food contains several nutrients and bioactive substances that may interact with each other. This is one reason why a healthy dietary pattern should not be reduced to one "active ingredient."

11.6 Safety and interactions

Natural origin does not automatically mean that a nutraceutical is completely safe. Concentrated supplements may have side effects or interact with medicines. Therefore, dosage, product quality, individual health status, and possible drug interactions should be considered.

12. Future perspectives

Research in this field is moving towards a more individualized understanding of nutrition. Important future areas include:

- Personalized nutrition
- Gut microbiome-based approaches
- Improved delivery systems
- Increased bioavailability
- Combination formulations
- Long-term clinical trials
- Food-matrix research
- Nutrigenomics

- Individual response prediction

Recent research on functional foods has also emphasized the importance of developing better formulations and delivery systems to improve the stability and bioavailability of bioactive compounds. The gut microbiome may become especially important because it provides one possible explanation for why the same dietary intervention can produce different effects in different individuals. Future research should therefore focus not only on laboratory biomarkers but also on clinically meaningful outcomes. Stronger randomized controlled trials and long-term studies will be necessary to determine which nutraceuticals provide genuine health benefits.

13. Conclusion

Nutraceuticals and functional foods have become an important area of research because food-derived compounds can interact with several biological processes involved in chronic diseases. Omega-3 fatty acids, polyphenols, flavonoids, carotenoids, curcumin, resveratrol, dietary fibre, probiotics, and prebiotics have all been investigated for their possible physiological effects.

In cardiovascular health, omega-3 fatty acids, fibre-rich foods, and plant-derived compounds may influence lipid metabolism, inflammation, and vascular processes. In cancer research, compounds such as curcumin, resveratrol, lycopene, and tea polyphenols have shown interesting biological effects, particularly in experimental studies. In chronic inflammatory conditions, omega-3 fatty acids and selected plant compounds may influence inflammatory signalling. Functional foods may also affect health indirectly through their interaction with the gut microbiome.

At the same time, promising laboratory results should not be considered equivalent to proven clinical benefits. Bioavailability, dosage, formulation, individual variation, and differences in study design remain important limitations.

Therefore, nutraceuticals and functional foods are best viewed as supportive components of a balanced diet and healthy lifestyle. They may contribute to maintaining health and reducing disease risk, but they should not be considered universal substitutes for established medical treatments.

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