Review

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Effects of Bioactive Compounds in Foods on Metabolic Diseases

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Posted Date: 22 May 2023

doi: 10.20944/preprints202305.1474.v1

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Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 May 2023 doi:10.20944/preprints202305.1474.v1

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Abstract: Bioactive compounds are the food constituents, providing beneficial health effects to functional foods and nutraceuticals. These compounds have antioxidants activity including anti-inflammatory, antifungal, and have additional preventative actions. Since these compounds are important constituents enhancing function of the foods, therefore, these constituents are necessary to be incorporated under the umbrella of functional foods. Functional foods provides health benefits though bioactive compounds, as these compounds target mechanisms that manage, prevent, and/or treat chronic or acute diseases. The bioactive compounds are quite essential for functional foods that are crucial for optimal health, thereby leading to the inclusion of these compounds in the most recent definition of functional foods. Some experts have defined that bioactive compounds are the chemical components that contributes and regulates in biological mechanisms. These bioactive compounds are more accurately defined by Dr. Martirosyan and Pisarski as the "primary and secondary metabolites of nutritive and non-nutritive natural components generating health benefits by preventing or managing chronic disease or its symptoms". These compounds have potential antioxidant and anti-inflammatory activity, which provide benefits to health. Although they are a small proportion of a food source, these compounds can also trigger the mechanisms that will alter and can improve human health. Certain bioactive compounds present in foods are extremely beneficial, but if consumed in excess, they can cause toxicity. Therefore, each bioactive compound must be fully evaluated in order to establish a beneficial and a toxic threshold amount.

Keywords. functional foods; healthy diet; diseases; micronutrient

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Introduction

Bioactive compounds are important constituents of a healthy diet. The diets that contain the appropriate and standard amount of bioactive compounds can be instrumental in functional foods providing the best function. There is a controversy in the definition of functional foods. Functional foods are generally defined as those foods, that improve health as well as treat diseases. In 2017, the Functional Food Centre has updated their definition of biologically active compounds found in processed or in natural foods that, when consumed in a defined form or in a effective form, and also in non-toxic amounts, are clinically proven and documented to relieve symptoms of chronic diseases, therefore, utilizing specific biomarker for the prevention, management, or treatment of chronic disease or its symptoms. This communication aims to highlight the role of bioactive compounds in health and diseases and discuss the exact meaning of functional foods in relation to health and diseases.

Bioactive Compounds and Functional Foods

 doi:10.20944/preprints202305.1474.v1

There is evidence that bioactive compounds are the constituents of foods, particularly the functional foods, that gives the beneficial health properties [1,2]. These benefits include the antioxidants property, anti-inflammatory property, antifungal property, and various additional preventative properties [1–4]. The usefulness of these compounds illustrates how the bioactive compounds are the real-life example of Hippocrates' notion "let thy food be thy medicine" [2]. There are many definitions of functional foods neglected to acknowledge the bioactive compounds importance [3]. These compounds are the constituents enhancing the functional foods and are therefore necessary to be incorporated under the umbrella of functional foods. Functional foods provides the health benefits though bioactive compounds, as these compounds target mechanisms that manage, prevent, and/or treat disease [3]. The Functional Food Center asserts that functional foods contain bioactive compounds, which are essential for optimal health, contributing to the definition of functional foods' bioactive compounds as essential components.

There is an unmet need to appreciate the significance of biologically active compounds within the role of functional foods, hence bioactive compounds should be clearly defined. Chemical substances known as bioactive compounds play a role in controlling biological processes [1]. It seems that, bioactive compounds are more accurately explained by Dr. Martirosyan and Pisarski as the following: "food bioactive compounds are primary and secondary metabolites of nutritive and non-nutritive natural components generating health benefits by preventing or managing chronic disease or its symptoms" [1,2]. Since these compounds are antioxidants, anti-inflammatory, etc., bioactive compounds provide benefits to health [2]. Although they are a small proportion of a food source, These compounds have the potential to activate mechanisms that will alter and improve human health. However, while bioactive compounds are extremely beneficial they can be consumed in plenty, but may cause adverse effects [1]. Therefore, each compound that is bioactive must be assessed in order to determine a beneficial and toxic threshold [1,2]. The best effect of functional foods can be achieved by diets with the right proportion of bioactive compounds.

Controversy in Definition of Functional Foods.

Functional food definitions are not regulated. As a result, numerous institutions have different definitions. There is no universally accepted definition of functional foods. Functional foods are generally defined as those that improve health and can help treat disease. The Functional Food Centre previously defined functional foods as natural or processed foods containing chemically active compounds in defined, effective, and non-toxic amounts that are beneficial for the prevention, management, or treatment of chronic diseases [2]. However, in 2017, the Functional Food Center updated their definition to bioactive substances found in natural or processed foods that provide clinically proven and documented health benefits using specific biomarkers for prevention, diagnosis, management, or treatment of chronic disease.[2]. The new change removes the notion of the unknown compounds, which acknowledges that there are bioactive compounds. Furthermore, there is understanding that bioactive compounds can be useful in treating symptoms as well as chronic disease management. Countless studies on functional foods show "the intake of selected foods and their associated constituents can have profound physiologic effects." These effects are driven by the bioactive compounds in the functional foods [3].

It seems that bioactive compounds have specific health benefits that contribute to the function of functional foods and should therefore be included in the definition of functional foods. Some institutions have their own definition of functional foods, as there is no regulated standard definition [3–5]. These foods are described as "foods and components of food which offer health benefits beyond basic nutrition" by the Institute of Food Technologists. These compounds frequently provide essential nutrients in excess of what is required for normal repair, development, and growth, as well as additional compounds with biological activity that have a positive impact on health [6]. While this definition does mention biologically active components, there is a failure to discuss the important aspects of bioactive compounds that further ensure health. More specifically, there is no discussion of toxicity of an excess of bioactive compounds or a minimum level in the diet to obtain the benefits.

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Without the proper inclusion of bioactive compounds, the definition does not identify the important aspect of functional foods that interact with the biomarkers and improve health. The Functional Food Center's improved definition which explains the biological process of functional foods by recognising that bioactive compounds that interact with biomarkers, which signify effectiveness [2]. A functional food, previously defined, is a food containing biologically active compounds that can be used to treat a disease and/or its symptoms. With the rise of chronic disease, effective treatment is in high demand [3]. The Japanese pioneered the concept, believing that certain foods could perform functions other than nutritional effects [7]. Functional foods target specific mechanisms that are linked to chronic diseases such as cancer and Alzheimer's disease [4]. Through targeting these mechanisms, functional foods accomplish what medication often fails to do: treat chronic disease. If consumed in a toxic dose, functional foods effectively manage chronic diseases and their associated symptoms without the excessive side effects associated with medication. However, medication frequently brings adverse side effects while functional foods, using bioactive compounds, can treat disease. [3].

Type 2 Diabetes is a chronic disease that falls within the conflict of which is the best treatment: medication or diet. Medication often works to help the person lose weight and regain insulin sensitivity, which is similar to what a diet in functional foods that target these mechanisms can do [7]. Functional foods medicine", which suggests that functional food could also be medicine [2]. Type 2 Diabetes is not the only chronic disease that has been treated with functional foods. Various studies have explored the use of functional foods to treat cardiovascular diseases. For example, seaweeds, a functional food candidate, are used as a preventative measure when treating those at risk for heart disease [8]. The metabolites in seaweed, such as lipids and fiber, act as bioactive compounds that interact with biological aspects. These interactions in turn provide protective properties against cardiovascular disease [8]. There has even been investigation into the employment of functional foods in treating, preventing, and managing cancer. Many herbal remedies such as leaves and bark are considered functional foods. Cancer patients have been using these herbal remedies to manage cancers, including breast, colon, and prostate cancer. The functional food remedies have been clinically shown to help these patients in management, solidifying the importance of functional foods in managing chronic disease [9]. The bioactive compounds are the primary source of functional foods being able to treat, manage, and prevent chronic disease. Consequently, bioactive compounds must be acknowledged to fully understand the concept of functional foods clinical research. Bioactive compounds are the driving force that establishes the functional aspect of functional foods. A standard acknowledgement of these compounds will bring a general understanding as to how functional foods improve health. Thus, the Functional Food Center's updated definition is a stride in the right direction. Bioactive compounds have an essential role in functional foods as the component that improves health and helps to treat disease [2,3,9]. Some experts have proposed functional farming to grow functional foods rich in bioactive agents.[9].

Polyphenols and Anthocyanins on Inflammation

A few studies worth mentioning discuss the relationship between bioactive compounds found in certain foods and inflammation [9,10]. Many experts believe that some of the preventable chronic conditions are inflammatory in nature. Anthocyanins are natural bioactive compounds found to have several health benefits. In 2018, Shah et al. conducted a meta-analysis and systematic review of randomised controlled trials. The mean difference of hs-CRP was found to be 0.164 after reducing inflammatory markers. This study concluded that anthocyanin improves inflammation and lipid profile [10]. Two studies in 2020 will also be discussed for the effect of anthocyanins on inflammation. Poulsen et al. conducted a meta-analysis and systematic review of 16 studies. Results for all articles showed significant reductions in C-reactive protein (CRP). Significant effects of anthocyanins and plant oils on CRP in diabetics and [2]. Bioactive compounds interact with biomarkers. In doing this, these compounds can further enhance people's quality of life, which is exhibited in overweight/obese patients were observed. In conclusion, the results suggested that a diet high in fruits/vegetables and plant-oils is beneficial for attenuating elevated CRP. [11] Also, in 2020, Fallah et al. performed a meta-analysis and systematic review of 32 randomised controlled trials for researching the effects of anthocyanins in the human body. Researchers found that anthocyanins administered in higher doses (>300 mg/day) significantly decreased levels of CRP, Interleukin 6 (IL-6), tumor necrosis factor alpha (TNF-α), and vascular cell adhesion molecule (VCAM-1). Anthocyanins in food reduce widespread and blood vessels inflammation levels in humans, according to study results [12].

Polyphenols are also natural bioactive compounds found in certain foods that have several health benefits. Moua et al. published a meta-analysis and systematic review of 11 studies in 2020. involving over 60,000 participants. In three studies with the largest sample sizes, researchers noticed a significant association among the consumption of coffee and CRP levels. The associations among Europeans and Americans (US) women, as well as Japanese men, were inverse (1.3%-5.5% decrease in CRP per 100 mL of coffee consumed). [13] In 2021, Sarkhosh-Khorsani, et al, performed a meta-analysis and systematic review 17 randomized controlled trials involving over 600 participants. CRP levels were significantly affected by higher grape polyphenol doses (>500 mg/d) and longer periods of intervention (*12 weeks) based on the subgroup analysis, additionally, grape polyphenols effectively lowered CRP levels in patients with a clinical condition. The results show that grape seed extract, as well as grape juice and raisins, have a significant effect on CRP levels. Results from the meta-regression reveal that CRP levels are affected by the duration and amount of grape polyphenol supplementation. CRP levels varied significantly depending on the number of polyphenols in grape products. [1].

Table 1. Effect of bioactive compounds Polyphenols and anthocyanins on inflammation.

Authors	Shah, et al,2018	Khorsani, et al,2021
Condition	Lipid profile and inflammatory status, 17 studies.	Chronic inflammation, 17 studies.
Study	Systematic review and meta-analysis	Systematic review and meta-analysis
Study Design	Randomized controlled studies (n=1535)	Randomized controlled trials(n=668)
Measure	Triglycerides, low density lipoprotein, apolipoprotein B, high density lipoprotein,Tumor necrosis factor, C-reactive protein, interleukin- 6	C-reactive protein
Results	Anthocyanin supplementation significantly improves lipid profile and inflammatory status	Grape products containing polyphenols decreased CRP significantly

Effect of the Polyphenol on blood Pressure

According to the World Health Organization over 1 billion people have hypertension around the world. In 2015, a meta-analysis of 10 randomised controlled trials by Shao-Hua et al. In comparison to control subjects (12 comparisons), grape polyphenols significantly reduced systolic blood pressure by 1.48 mmHg per day. A subgroup analysis indicated a larger reduction was found for patients with metabolic syndrome (median consumption of grape polyphenols * 733 mg/day) or the intake of low-dose grape polyphenols (* 733 mg/day). [15] In 2017, Marx, et al, carried out a meta-analysis and systematic review of 12 studies. A number of polyphenol-rich interventions were used, including soybeans, cocoa, pomegranates, grapes, and turmeric. There was significant improvement in diastolic blood pressure with polyphenol-rich interventions (Mean difference -5.62 mmHg) [16] In 2020, Weaver, et al, performed a meta-analysis and systematic review of 37 studies. Researchers observed significant reductions in systolic blood pressure in human studies that used pure resveratrol (-3.7 mm Hg) Following the results, researchers concluded that red wine polyphenols were effective in reducing blood pressure. Human populations at risk for cardiovascular disease may benefit from these therapies, particularly by lowering systolic blood pressure. [17].

Table 2. Effect of polyphenol on blood pressure.

	Shao-hua, et al, 2015	Weaver, et al,2020
Condition	High Blood pressure	High Blood pressure
Study design	Meta-analysis, 10 studies.	Systematic review and meta-analysis, 37 studes
Criteria	Randomized controlled trials (n=543)	Randomized, Placebo-controlled trials. (n=2093)
Measure	Systolic blood pressure	Systolic blood pressure

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Results	Regular consumption of grape polyphenols may significantly lower systolic blood pressure	Studies indicated significant improvements in systolic blood pressure overall for red wine polyphenols and pure resveratrol

Effect of Polyphenols and Anthocyanins on Blood Lipids

According to the World Health Organization, stroke and heart disease are associated with high cholesterol levels. In 2019, George, et al, published a meta-analysis and systematic review of 26 studies. In this study, high polyphenol olive oil, as compared to low polyphenol olive oil, significantly improved measures of oxidized LDL (Standard Mean Difference: -0.44) total cholesterol (MD 4.5 mg/dL) and HDL cholesterol (Mean difference of 2.37 mg/dL) [18]

In 2016, Liu, et al, conducted a meta-analysis and systematic review of 6 studies including over 500 participants. The findings suggested the significant effects of anthocyanin supplementation on total cholesterol [MD = -24.06,] triglycerides [MD = -26.14], LDL-C [MD = -22.10] and HDL-C (MD = 5.58, 95%). The study concluded that in dyslipidemia patients, anthocyanin therapy reduces serum total cholesterol, triglycerides, and LDL cholesterol levels, and increases HDL cholesterol. [19] In 2018, Shah, et al, carried out a meta-analysis and systematic review of randomized controlled trials. According to this analysis, Triglyceride levels were significantly reduced by a mean difference of -9.16, low density lipoprotein levels were decreased by a mean difference -8.86, and levels of apolipoprotein B were decreased by -7.13, and the levels of high-density lipoprotein increased by 1.67. [10] In 2021, A systematic review and meta-analysis of 44 randomised controlled trials and 15 prospective studies were conducted by Lin et al. The results revealed that supplementation of purified anthocyanin significantly reduced blood LDL cholesterol and triglyceride concentrations (WMD: -5.43 mg/dL and -6.2 mg/dL, respectively), and significantly increased HDL cholesterol (WMD: 11.49 mg/dL). Another study demonstrated that anthocyanin-rich berry administration led to a significant decrease in blood cholesterol (WMD: -4.48 mg/dL), as well as improved blood lipid profiles and a reduction in circulating pro-inflammatory cytokines, which may reduce the risk for cardiovascular disease. [20]. finally, in 2022, Wilken, et al, published a meta-analysis and systematic review of 21 articles. Low-density lipoprotein was generally reduced in the studies (p=0.04). After a 4-6-week intervention, HDL levels increased with the consumption of cranberries and freeze-dried berries. Fruit products like freeze-dried strawberries, which contain concentrated berry compounds, showed notable effects. [21].

Table 3. Effect of polyphenols and anthocyanins on blood lipids.

Authors	George, et al,2019	Liu, et al,2016
Condition	Cardiovascular disease, 26 studies	Dyslipidemia, 6 studies
Study design	Systematic review and meta-analysis	Systematic review and meta-analysis
Criteria	Randomized controlled trials (n=925)	Randomized controlled trials (n=586)
Measure	Oxidized LDL, total cholesterol, HDL cholesterol,	Total cholesterol, triglycerides, LDL-C, HDL-C
Results	Measures of oxidised LDL, total cholesterol, and HDL cholesterol were all significantly improved when high polyphenol olive oil was compared to low polyphenol olive oil.	Anthocyanin supplementation significantly reduces TC, TG and LDL-C levels in patients with dyslipidemia.

Effect of Polyphenols and Anthocyanins on Glucose Parameters

According to the World Health Organization Diabetic complications accounted for an estimated 1.5 million deaths directly related to diabetes in 2019. In 2017, Palma-Duran, et al, conducted a systematic review and meta-analysis of 36 randomized controlled trials. For 0.7 to 12 months, polyphenol (extracts, supplements, and foods) supplementation (28 mg to 1.5 g) were tested. Polyphenol supplementation significantly reduced HbA1c% by -0.53 units when combined across all subjects (n = 1954, mean-baseline HbA1c = 7.03%, 53 mmol/mol). Study participants with type-2 diabetes mellitus experienced significant reductions in HbA1c and lowered HbA1c% by 0.21. The study concluded polyphenols are effective in reducing HbA1c in type 2 diabetes mellitus without any intervention at the glycemic level and can reduce diabetes complications. [22]. In 2020,

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Raimundo, et al, carried out a meta-analysis of twenty randomized controlled trials. A comparison of the intervention and control means showed overall that polyphenol consumption contributed to reduced fasting glucose levels (- 3.32 mg/dL). Despite this, hemoglobin A1C decreased only modestly (- 0.24%). Comparative analyses showed that consumption of (poly)phenols was more associated with lower levels of blood glucose in diabetes individuals (- 5.86 mg/dL) and that these compounds could act in combination with anti-diabetic medications (- 10.17 mg/dL). Results suggest that consumption of (poly)phenols may contribute to lower levels of blood glucose in individuals with type-2 diabetes or at risk of diabetes. [23]

With respect to the effect of anthocyanins on glucose parameters 2 studies will be mentioned. In 2017, Yang, et al, performed a meta-analysis and systematic review of 32 randomized and controlled trials involving over1400 subjects. In addition to reducing fasting glucose (SMD: -0.31), 2-hour postprandial sugar (SMD: -0.82), glycated hemoglobin (SMD: -0.65), and total cholesterol (SMD: -0.33), anthocyanins also improved whole blood lipid profile (SMD: -0.35).

The health advantages of anthocyanins in the management and prevention of cardiometabolic disease are supported by these findings [24]. Finally, in 2020, Fallah, et al, published a systematic-review and meta-analysis of randomized controlled trials. Compared to control subjects, fasting blood sugar (FBS; -2.70 mg/dl), 2-hour postprandial glucose (PPG; -11.1 mg/dl) and glycated hemoglobin (HbA1c; -11.1 mg/dl) levels were significantly reduced. For at least eight weeks and at doses of more than 300 mg/day, anthocyanin consumption dramatically reduced FBS, 2-h PPG, HbA1c, and homeostasis model assessment of insulin resistance (HOMA-IR) levels. A study reported decreased levels of FBS, HbA1c, 2-h PPG, and HOMA-IR in type 2 diabetics and overweight/obese individuals after anthocyanins administration. The biomarkers of glycemic control and glucose metabolism in diabetics have generally been shown to be improved by dietary anthocyanins. [25].

Table 4. Effect of polyphenols and anthocyanins on glucose parameters.

Authors	Palma-Duran et al 2017	Yang, et al,2020
Condition	Type 2 diabetes mellitus, 36 studies	Cardio-metabolic diseases, 32 studies.
Study	Systematic review and meta-analysis	Systematic review and meta-analysis.
Inclusion criteria	Randomized, controlled trials.(n=1954)	Randomized controlled trials (n=1491)
Measure	Hb A1c %	Fasting glucose, 2-hour glucose, Hb 1c,, total cholesterol, LDL cholesterol.
Results	Polyphenol supplementation significantly lowered HbA1c % in type-2 diabetes mellitus without any intervention at glycemia, and could contribute to the prevention of diabetes	Anthocyanins significantly reduced fasting glucose, 2 hour postprandial glucose, glycated hemoglobin, total cholesterol and LDL. Anthocyanins are beneficial in the management and prevention of cardiometabolic disease, as evidenced by the notable improvements in lipids and glycemic control.

Oxidative stress and metabolic diseases

When the body's capacity to neutralize and eliminate reactive oxygen species (ROS) and its rate of production were out of balance, a physiological condition known as oxidative stress results. ROS are generated as a byproduct of normal metabolic processes, but they can also be produced in response to environmental stressors such as UV radiation, air pollution, and toxins. When ROS levels become excessive, they can damage cellular components such as DNA, lipids, and proteins, resulting in disease and cellular dysfunction [28,29]. Numerous diseases, including cancer, cardiovascular disease, neurodegenerative disorders, and diabetes, have been associated with oxidative stress [29]. Oxidative stress not only contributes to disease, but also to ageing and the ageing process [30].

Metabolic syndrome is a metabolic abnormality that increases the risk of developing cardiovascular disease and type-2 diabetes. It is defined as the presence of at least three of the following criteria: abdominal obesity, elevated blood pressure, elevated fasting glucose, elevated triglycerides, and reduced high density lipoprotein (HDL) cholesterol levels [31,32]. Abdominal obesity is a key component of metabolic syndrome, as it is associated with insulin resistance and the release of pro-inflammatory cytokines from adipose tissue. High blood pressure is also a

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characteristic of metabolic syndrome and is thought to result from an increased sympathetic tone and impaired endothelial function [32]. Resistance to insulin and hyper-insulinemia are often present in individuals with metabolic syndrome and are linked to dyslipidemia, as well as the development of non-alcoholic fatty liver disease [32,33]. Metabolic syndrome is a growing public health concern, as it is estimated to affect approximately one-quarter of adults worldwide [32]. It is associated with high risk of cardiovascular disease and type-2 diabetes, as well as other conditions such as non-alcoholic fatty liver disease and polycystic ovary syndrome [31,32].

Chronic inflammation and oxidative stress are closely linked and can both contribute to the occurrence of metabolic diseases. Oxidative stress is the imbalance between the ROS production and the body's ability to detoxify these harmful molecules, leading to cellular damage. Chronic inflammation is a persistent immune response that leads to tissue damage and dysfunction [9]. Oxidative stress can trigger chronic inflammation by activating pro-inflammatory signaling pathways, which in turn exacerbates oxidative stress and creates a cycle of inflammation and damage [33,34]. Chronic inflammation can also lead to oxidative stress by increasing the production of ROS from immune cells and damaged tissues [35]. The combined effects of chronic inflammation and oxidative stress can contribute to the metabolic diseases development by impairing normal metabolic processes. For example, oxidative stress and inflammation can cause insulin resistance, a key feature of metabolic disorders such as type-2 diabetes [36]. Insulin resistance occurs when cells become less responsive to insulin, leading to impaired glucose uptake and elevated blood sugar levels. Inflammation and oxidative stress can also contribute to the metabolic diseases development, such as obesity and non-alcoholic fatty liver disease (NAFLD) [33,37,38].

Therefore, reducing chronic inflammation and oxidative stress through lifestyle modifications and medical interventions may be an effective strategy for preventing and treating metabolic diseases.

Studies show that at molecular level excessive (ROS) generated can attack cellular proteins, lipids, and nucleic acids, which results in cellular dysfunction and a range of pathologies. Highly reactive molecules constitute ROS that can damage cellular components, including proteins, lipids, and nucleic acids, through a process called oxidative stress. Oxidative stress induced by ROS can cause damage to proteins by modifying their amino acid residues, leading to altered protein function or degradation [39,40]. Lipids are also susceptible to oxidative stress, and lipid peroxidation can occur in the presence of ROS, leading to the formation of harmful reactive lipid species that can damage cellular membranes and alter cellular signaling pathways [41]. In addition, oxidative stress can cause DNA damage by modifying nucleic acids, leading to genetic mutations and chromosomal abnormalities [42]. DNA damage can lead to altered cellular transport mechanisms and decreased biological activity, as well as increased immune activation and inflammation [40,43].

Wide-ranging and potentially contributing to a variety of pathologies, such as cancer, metabolic disorders, cardiovascular diseases, and neurodegenerative diseases, are the effects of oxidative stress-induced cellular dysfunction [43]. The loss of energy metabolism, altered cell signaling and cell cycle control, genetic mutations, altered cellular transport mechanisms, and decreased biological activity are all potential outcomes of oxidative stress-induced cellular dysfunction [40]. This oxidative stress-induced cellular damage can contribute to a range of pathologies, highlighting the importance of maintaining redox balance in the body. Studies suggest that the nutritional stress caused by a high-fat, high-carbohydrate diet can also promote oxidative stress, as evidenced by increased lipid peroxidation products, protein carbonylation, and decreased antioxidant system and reduced glutathione (GSH) levels. These changes can lead to the initiation of a pathogenic milieu and the development of several chronic diseases.

A high-fat, high-carbohydrate diet can lead to the accumulation of (ROS) in the body, which can cause oxidative stress and damage to cellular components [44]. Increased levels of ROS can lead to lipid peroxidation, resulting in the formation of harmful reactive lipid species that can damage cellular membranes and alter cellular signaling pathways. Furthermore, oxidative stress can cause damage to proteins by modifying their amino acid residues, leading to altered protein function or degradation, as evidenced by increased protein carbonylation in response to a high-fat, high-

 doi:10.20944/preprints202305.1474.v1

carbohydrate diet [45]. This can lead to alterations in cellular signaling and metabolic pathways and contribute to the chronic diseases development. The antioxidant system, which helps to regulate oxidative stress, can also be affected by a high-fat, high-carbohydrate diet. This can lead to decreased levels of antioxidants such as reduced (GSH), which can exacerbate oxidative stress and contribute to the chronic diseases development [46]. Therefore the changes occurs by a high-fat, high-carbohydrate diet, including increased lipid peroxidation products, protein carbonylation, and decreased antioxidant system and GSH levels, can lead to the initiation of a pathogenic milieu and the development of several chronic diseases, including obesity, type 2 diabetes, and cardiovascular diseases and can lead to the initiation of a pathogenic milieu and contribute to the development of several chronic diseases [44–48].

Overall several studies suggest that chronic inflammation and oxidative stress are closely linked, and both are involved in the pathogenesis of chronic diseases. Oxidative stress results from an imbalance between the ROS production and the body's antioxidant defense mechanisms, while chronic inflammation is a response to tissue damage or infection and involves the release of pro-inflammatory cytokines and chemokines [49]. Studies have suggested that chronic inflammation and oxidative stress can lead to the chronic diseases development through various cellular and molecular mechanisms. For example, oxidative stress can cause DNA damage and impair DNA repair mechanisms, leading to genetic mutations and the development of cancer [50]. Similarly, chronic inflammation can lead to the development of insulin resistance and type 2 diabetes through the activation of pro-inflammatory signaling pathways, which impair insulin signaling and glucose uptake in peripheral tissues [51]. In addition, both chronic inflammation and oxidative stress can promote the development of atherosclerosis and cardiovascular disease through their effects on endothelial function, lipid metabolism, and plaque stability [52]. Furthermore, chronic inflammation and oxidative stress can also impair cell cycle regulation, leading to abnormal cell growth and the development of cancer [49].

In conclusion, clinical research has shown a positive impact of these compounds on individuals' quality of life. Chronic inflammation and oxidative stress are significant underlying factors that contribute to the development of pathologies such as carcinogenesis, obesity, diabetes, and cardiovascular diseases through altered cellular and nuclear mechanisms, including impaired DNA damage repair and cell cycle regulation. Functional foods' ability to perform is based on their bioactive ingredients. An understanding of how functional foods improve health will become more widespread with an acknowledgement of these compounds. As such, the Functional Food Center's updated definition represents an important step forward. As a component of functional foods, bioactive compounds play a crucial role in improving health and treating disease. The results discussed previously indicate that polyphenols and anthocyanins possess bioactive properties that have the ability to reduce inflammation, blood pressure, lipid levels, and glucose levels. Additional research is necessary to confirm these results.

Authors contribution. All authors participated in writing the article equally.
Funding: This publication was supported by grant AKARDIO COVID-19, ITMS: 313011AUB1, Operational Program Integrated Infrastructure, co-founded by European Regional Development Fund.
Acknowledgements: The International College of Nutrition and International College of Cardiology are thanked for supporting this article.
Competing Interests: Conflict of interest has not been declared by the authors.

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