arastirma.tarimorman.gov.tr/bursagida
ISSN 1303-3107
e-ISSN 2822-2873

Gıda ve Yem Bilimi - Teknolojisi Dergisi / Journal of Food and Feed Science - Technology 35:30-50 (2026/1) 10.56833/gidaveyem.1804386

Derleme Makale/Review Paper

Hazelnut and health: Nutritional benefits and potentical health effects

Fındık ve sağlık: Besin değerleri ve olası sağlık etkileri

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Geliş Tarihi : 29.09.2024
Kabul Tarihi : 07.08.2025

Abstract

Objective: This review aims to evaluate the nutritional profile and potential health benefits of hazelnuts based on scientific literature, focusing on their role in preventing chronic diseases and supporting overall health. A comprehensive literature review was conducted analyzing clinical trials, epidemiological studies, and biochemical analyses related to hazelnut consumption and its health effects. The impact of fatty acids, vitamins, and bioactive compounds present in hazelnuts was examined in detail. Clinical evidence supports that regular hazelnut consumption reduces the risk of cardiovascular diseases, type 2 diabetes, and certain cancers. These benefits are attributed to improved lipid profiles, enhanced antioxidant capacity, and reduced systemic inflammation. Despite their high caloric content, hazelnuts contribute to weight management by promoting satiety.

Conclusion: Due to their rich nutrient composition and health-promoting properties, hazelnuts hold a significant place among functional foods. Balanced and regular intake can be beneficial in chronic disease prevention. Further research is needed to clarify the specific effects of hazelnut components on health.

Keywords: hazelnuts, nutritional benefits, cardiovascular health, bioactive compounds, chronic disease prevention, functional foods

Öz

Amaç: Bu derleme makalesinin amacı, fındığın besin içeriği ve potansiyel sağlık faydalarının bilimsel literatür ışığında değerlendirilmesidir. Fındığın kronik hastalıkların önlenmesinde ve genel sağlığın desteklenmesinde rolü incelenmiştir. Literatür taraması yöntemiyle, fındık ve sağlık ilişkisini ortaya koyan klinik çalışmalar, epidemiyolojik veriler ve biyokimyasal analizler değerlendirilmiştir. Fındığın bileşimindeki yağ asitleri, vitaminler ve biyoaktif bileşiklerin etkileri detaylandırılmıştır. Fındık tüketiminin kardiyovasküler hastalıklar, tip 2 diyabet ve bazı kanser türleri riskini azalttığı klinik çalışmalarda desteklenmiştir. Bu faydalar, lipid profili iyileşmesi, antioksidan kapasitenin artması ve inflamasyonun azalması gibi mekanizmalarla ilişkilendirilmiştir. Ayrıca fındığın yüksek kalorili olmasına rağmen, doygunluk hissi yaratması nedeniyle kilo kontrolüne katkıda bulunduğu belirlenmiştir.

Sonuç: Fındık, zengin besin profili ve sağlık destekleyici özellikleriyle fonksiyonel besinler arasında önemli bir yere sahiptir. Dengeli ve düzenli tüketimi, kronik hastalıkların önlenmesinde faydalı olabilir. Gelecekte yapılacak çalışmalar, fındığın spesifik bileşenlerinin sağlık etkilerini daha ayrıntılı ortaya koymalıdır.

Anahtar kelimeler: fındık, besin değerleri, kardiyovasküler sağlık, biyoaktif bileşikler, kronik hastalıkların önlenmesi, fonksiyonel gıdalar

1. Introduction

Hazelnuts (*Corylus avellana L.*), one of the oldest cultivated nut species, have been an integral part of human diets for centuries, offering not only a rich, distinct flavor but also a wealth of nutritional benefits. Predominantly cultivated in regions such as Türkiye, Italy, and the United States, Türkiye alone contributes to approximately 63% of the global hazelnut production, making it a significant agricultural commodity on the world stage (Demirci-Ercoşkun, 2009). Traditionally consumed in various forms—raw, roasted, or as key ingredients in confections and baked goods—hazelnuts are now widely recognized for their potential health benefits beyond their culinary uses (Alasalvar and Shahidi, 2021).

Hazelnuts are particularly rich in unsaturated fatty acids, with oleic acid being the predominant component, accounting for over 80% of their total fat content (Köksal et al., 2006). These fats have been extensively studied for their beneficial effects on cardiovascular health, including lowering low-density lipoprotein (LDL) cholesterol levels and reducing the risk of coronary heart disease (Wani et al., 2020). Additionally, hazelnuts provide high-quality plant proteins, essential vitamins such as vitamin E (α-tocopherol), and a variety of minerals including magnesium, iron, and copper (Bodoira & Maestri, 2020). They are also a rich source of bioactive compounds like phytosterols, polyphenols, and dietary fiber, which collectively contribute to their health-promoting properties (Ilikkan et al., 2009; Saygi, Ercoşkun & Şahin, 2018; Nunzio, 2019).

Clinical studies have consistently demonstrated that regular consumption of hazelnuts is linked to a reduced risk of several chronic diseases, including cardiovascular diseases, type 2 diabetes, and various types of cancer (Erdal et al., 2021). These protective effects are thought to arise from multiple mechanisms, such as the improvement of lipid profiles, enhancement of antioxidant capacity, and reduction of systemic inflammation (Gaikwad et al., 2016). Notably, despite their high caloric content, hazelnuts do not contribute to weight gain when consumed in moderation and may even aid in weight management by promoting satiety and enhancing metabolic health (Evrard et al., 2020; Guiné & Correia, 2020; Mapelli & Gallo, 2019; Wani et al., 2020).

The increased interest in hazelnuts as a functional food aligns with broader public health recommendations that advocate for the inclusion of nutrient-dense foods in daily diets to improve overall health and mitigate the risk of chronic illnesses. However, while the health benefits of hazelnuts are well-documented, there remains a need for comprehensive synthesis and analysis of existing data to fully elucidate their role in human nutrition and health (Köksal et al., 2006).

This review aims to provide an in-depth examination of the nutritional profile of hazelnuts and their potential health benefits. By critically evaluating the current scientific literature, this paper seeks to clarify the mechanisms through which hazelnuts contribute to health promotion and disease prevention. Additionally, the review will highlight gaps in the current knowledge and propose directions for future research, ultimately supporting the establishment of hazelnuts as a vital component of healthful dietary patterns.

2. Composition of hazelnuts

Hazelnuts (*Corylus avellana*) are renowned for their rich nutritional profile, which contributes to their status as a superfood. Their composition includes a variety of macronutrients, micronutrients, and bioactive compounds that together provide significant health benefits. This section provides an in-depth analysis of the key components found in hazelnuts. Proximate composition and Recommended Dietary Allowances (RDA) for different groups: adults, children, lactating women, and per kilogram of body weight of bleached and roasted hazelnuts are listed in Table 1.

Table 1. Proximate composition and Recommended Dietary Allowances (RDA) for different groups: adults, children, lactating women, and per kilogram of body weight. of bleached and roasted hazelnuts (TürkKomp, 2024).

Nutrient	Unit in 100 gram	Blanched hazelnuts mean	Roasted hazelnuts mean	RDA (Adults)	RDA (Children)	RDA (Lactating Women)	RDA per kg body Weight
Energy	kcal	646	670	2000-2500 kcal/day	1000-2000 kcal/day	2200-2800 kcal/day	30-40 kcal/kg/day
Energy	kJ	2701	2802	8368-10460 kJ/day	4184-8368 kJ/day	9212-11717 kJ/day	125-168 kJ/kg/day
Water	g	2.97	1.16	Variable	Variable	Variable	Variable
Ash	g	2.39	2.28	-	-	-	-
Protein	g	14.24	13.62	46-56 g/day	13-34 g/day	65 g/day	0.8-1.0 g/kg/day
Nitrogen	g	2.69	2.57	-	-	-	-
Fat, total	g	59.58	61.28	70-97 g/day	25-40 g/day	80-100 g/day	1-1.5 g/kg/day
Carbohydrate	g	5.36	10.13	225-325 g/day	130-210 g/day	210-300 g/day	3-5 g/kg/day
Fiber, total dietary	g	15.47	11.54	25-38 g/day	19-25 g/day	29 g/day	0.14-0.2 g/kg/day
Salt	mg	6	30	<2300 mg/day	<1500 mg/day	<2300 mg/day	<30 mg/kg/day
Iron, Fe	mg	3.22	3.10	8-18 mg/day	7-10 mg/day	9-10 mg/day	0.3-0.5 mg/kg/day
Phosphorus, P	mg	318	476	700 mg/day	460-500 mg/day	1250 mg/day	15-20 mg/kg/day
Calcium, Ca	mg	142	111	1000-1200 mg/day	700-1000 mg/day	1000-1300 mg/day	10-20 mg/kg/day
Magnesium, Mg	mg	149	167	310-420 mg/day	80-240 mg/day	310-360 mg/day	4-6 mg/kg/day
Potassium, K	mg	593	645	2600-3400 mg/day	2000-2300 mg/day	2800-3000 mg/day	50-70 mg/kg/day
Sodium, Na	mg	3	12	<2300 mg/day	<1500 mg/day	<2300 mg/day	<30 mg/kg/day
Zinc, Zn	mg	2.18	2.00	8-11 mg/day	3-5 mg/day	12 mg/day	0.1-0.2 mg/kg/day
Selenium, Se	µg	2.5	1.8	55 µg/day	20-40 µg/day	70 µg/day	1 µg/kg/day
Thiamine	mg	0.605	0.465	1.1-1.2 mg/day	0.5-0.9 mg/day	1.4 mg/day	0.02 mg/kg/day
Riboflavin	mg	0.136	0.145	1.1-1.3 mg/day	0.5-0.9 mg/day	1.6 mg/day	0.03 mg/kg/day
Niacin	mg	1.792	1.993	14-16 mg/day	6-12 mg/day	17 mg/day	0.2 mg/kg/day
Vitamin B-6, total	mg	0.515	0.450	1.3-2.0 mg/day	0.5-1.0 mg/day	2.0 mg/day	0.03 mg/kg/day
Vitamin E, α-TE	mg	23.65	18.93	15 mg/day	6-11 mg/day	19 mg/day	0.4 mg/kg/day
Vitamin E, IU	IU	35.24	28.21	22.4 IU/day	9-16.5 IU/day	28.4 IU/day	0.7 IU/kg/day
Alpha-tocopherol	mg	23.65	18.93	15 mg/day	6-11 mg/day	19 mg/day	0.4 mg/kg/day
Fatty acids, total saturated	g	3.788	4.779	<20 g/day	7-15 g/day	<20 g/day	0.3 g/kg/day
Fatty acids, total monounsaturated	g	35.803	47.451	No specific RDA	No specific RDA	No specific RDA	No specific RDA
Fatty acids, total polyunsaturated	g	3.383	6.179	11-22 g/day	7-16 g/day	13 g/day	0.2-0.3 g/kg/day
Fatty acid 4:0 (butyric acid)	g	0.000	0.000	No specific RDA	No specific RDA	No specific RDA	No specific RDA
Fatty acid 16:0 (palmitic acid)	g	3.458	3.303	No specific RDA	No specific RDA	No specific RDA	No specific RDA
Fatty acid 18:0 (stearic acid)	g	0.329	0.418	No specific RDA	No specific RDA	No specific RDA	No specific RDA
Fatty acid 18:1 (oleic acid)	g	35.462	47.082	No specific RDA	No specific RDA	No specific RDA	No specific RDA
Fatty acid 18:2 (linoleic acid)	g	2.908	4.604	12-17 g/day	7-12 g/day	13 g/day	0.2 g/kg/day

2.1. Macronutrients

2.1.1. Lipids

Hazelnuts (*Corylus avellana*) are renowned for their rich lipid profile, which plays a crucial role in their nutritional value and associated health benefits. The lipid content of hazelnuts, which constitutes a significant portion of their total composition, is primarily composed of fats, including monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), and a smaller proportion of saturated fatty acids (SFAs). Understanding the composition and health implications of these lipids is essential for appreciating the nutritional benefits of hazelnuts.

2.1.1.1. Total lipid content

Hazelnuts have a high total lipid content, ranging from approximately 50% to 73% of their total weight. This high lipid content contributes to their energy density, making them a calorie-dense food. The lipid profile of hazelnuts includes a diverse range of fatty acids, which can be classified into three main categories: monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), and saturated fatty acids (SFAs) (Romero et al., 2020; Alasalvar et al., 2009; Deon et al., 2018).

2.1.1.2. Monounsaturated fatty acids (MUFAs)

Monounsaturated fatty acids are the predominant type of fat found in hazelnuts. Oleic acid, a MUFA, constitutes approximately 80-85% of the total fat content. Oleic acid is known for its beneficial effects on cardiovascular health. It helps to increase high-density lipoprotein (HDL) cholesterol while reducing low-density lipoprotein (LDL) cholesterol levels, thus lowering the risk of atherosclerosis and heart disease. The high concentration of oleic acid in hazelnuts makes them a valuable dietary source of MUFAs, contributing to overall heart health (Feldman & Anderson, 2015; Pascual et al., 2011; Sampaio et al., 2020).

2.1.1.3. Polyunsaturated fatty acids (PUFAs)

Hazelnuts also contain polyunsaturated fatty acids, although they are present in smaller amounts compared to MUFAs. The primary PUFAs in hazelnuts include linoleic acid (omega-6) and alpha-linolenic acid (omega-3).

- **Linoleic acid (Omega-6):** Linoleic acid is an essential fatty acid that plays a crucial role in maintaining cell membrane integrity and supporting skin health. It is also involved in various physiological processes, including inflammation and blood clotting. Adequate intake of linoleic acid is necessary for overall health, but it must be balanced with omega-3 fatty acids to maintain a proper omega-6 to omega-3 ratio (Zhang et al., 2019; Alasalvar et al., 2009).
- **Alpha-linolenic acid (Omega-3):** Alpha-linolenic acid is a plant-based omega-3 fatty acid that contributes to cardiovascular health by reducing inflammation and improving endothelial function. While the concentration of omega-3 fatty acids in hazelnuts is relatively low compared to other sources, it still provides a beneficial contribution to the overall intake of omega-3s (Romero et al., 2020; Alasalvar et al., 2009).

2.1.1.4. Saturated fatty acids (SFAs)

Hazelnuts contain a modest amount of saturated fatty acids, including palmitic acid and stearic acid. Saturated fatty acids are often associated with negative health effects when consumed in excess, such as increased LDL cholesterol levels and a higher risk of cardiovascular disease. However, the amount of saturated fat in hazelnuts is relatively low compared to other high-fat foods, and the overall lipid profile, with its emphasis on MUFAs and PUFAs, helps to offset potential negative effects (Polat et al., 2023; Sampaio et al., 2020).

2.1.1.5. Health implications of hazelnut lipids

The lipid profile of hazelnuts, with its high content of MUFAs and PUFAs and relatively low level of SFAs, has been associated with several health benefits:

- **Cardiovascular health:** The high concentration of oleic acid (MUFA) and the presence of PUFAs in hazelnuts contribute to improved lipid profiles and reduced cardiovascular risk. Regular consumption of hazelnuts has been shown to lower LDL cholesterol levels and increase HDL cholesterol levels, which is

beneficial for heart health (Romero et al., 2020; Zhang et al., 2019).

- **Anti-inflammatory effects:** The PUFAs in hazelnuts, particularly omega-3 and omega-6 fatty acids, possess anti-inflammatory properties that can help reduce chronic inflammation, which is a risk factor for various diseases, including cardiovascular disease and arthritis (Sampaio et al., 2020).
- **Satiety and weight management:** The lipid content in hazelnuts contributes to satiety and can help in weight management. The healthy fats in hazelnuts promote a feeling of fullness, which may help in controlling appetite and preventing overeating (Polat et al., 2023).

2.1.2. Proteins and amino acids

Hazelnuts *(Corylus avellana)* are not only a rich source of lipids but also offer significant nutritional value through their protein content. The proteins in hazelnuts, along with their amino acid profile, contribute to their status as a nutritious food that supports various physiological functions and overall health. Understanding the composition and benefits of hazelnut proteins and amino acids can shed light on their role in a balanced diet (Fang et al., 2019; Zhang et al., 2023).

2.1.2.1. Protein content in hazelnuts

Hazelnuts contain approximately 10% to 24% protein by weight, making them a substantial source of plant-based protein. This protein content varies depending on the cultivar, growing conditions, and processing methods. On average, a 100-gram serving of hazelnuts provides about 14 grams of protein, which can fulfill a portion of the daily protein requirements for individuals (Alasalvar et al., 2009). The proteins in hazelnuts are considered high-quality due to their amino acid composition, which includes both essential and non-essential amino acids (Picci & Bartolommeo, 2017).

2.1.2.2. Amino acid profile

The amino acid profile of hazelnuts includes a diverse range of essential and non-essential amino acids, contributing to their nutritional value. The major amino acids found in hazelnuts are (Mapelli & Gallo, 2019; Guiné & Correia, 2020; Gaikwad et al., 2016; Sen & Kahveci, 2020; Liu et al., 2021; Jakopic et al., 2018):

- **Arginine**: Hazelnuts are rich in arginine, an essential amino acid that plays a critical role in protein synthesis, nitric oxide production, and vasodilation. Arginine is important for cardiovascular health as it helps to improve blood flow and reduce blood pressure. It also supports immune function and wound healing.
- **Glutamine**: This non-essential amino acid is abundant in hazelnuts and is crucial for maintaining intestinal health, supporting immune function, and aiding in protein synthesis. Glutamine also plays a role in nitrogen metabolism and helps to reduce muscle breakdown.
- **Leucine**: An essential branched-chain amino acid (BCAA), leucine is vital for muscle protein synthesis and repair. It also contributes to regulating blood sugar levels and providing energy during exercise.
- **Lysine**: Although present in smaller amounts, lysine is an essential amino acid that supports protein synthesis, collagen formation, and immune function. It also plays a role in the absorption of calcium and the production of hormones and enzymes.
- **Phenylalanine**: This essential amino acid is a precursor to tyrosine, which is involved in the production of neurotransmitters such as dopamine and norepinephrine. Phenylalanine is important for mental health and cognitive function.
- **Tyrosine**: Tyrosine, a non-essential amino acid derived from phenylalanine, is involved in the synthesis of neurotransmitters and hormones, including thyroid hormones and melanin.
- **Serine**: Serine, a non-essential amino acid, plays a role in the metabolism of fats and fatty acids and is involved in the synthesis of proteins and nucleotides.

2.1.2.3. Health benefits of hazelnut proteins

The high-quality proteins and amino acids in hazelnuts offer several health benefits (Mapelli & Gallo, 2019; Guiné & Correia, 2020; Gaikwad et al., 2016):

- **Muscle maintenance and repair**: The presence of essential amino acids like leucine and arginine supports muscle protein synthesis and repair, making hazelnuts beneficial for individuals engaged in physical activity or muscle-building exercises.
- **Cardiovascular health**: Arginine, by promoting nitric oxide production, contributes to improved blood flow and reduced blood pressure, supporting cardiovascular health.
- **Immune system support**: Amino acids such as glutamine play a crucial role in supporting immune function and maintaining gut health, which is essential for overall well-being.
- **Mental health**: Phenylalanine and tyrosine are involved in neurotransmitter production, which can positively impact mood and cognitive function.
- **Protein quality and satiety**: The protein content in hazelnuts contributes to satiety and can aid in weight management by providing a feeling of fullness and reducing appetite.

2.1.2.4. Comparison with other plant-based proteins

While hazelnuts are a valuable source of plant-based protein, they are not as protein-dense as some other sources like legumes or soy. However, their unique amino acid profile, combined with their lipid content and other nutrients, makes them a beneficial addition to a balanced diet. For individuals following a vegetarian or vegan diet, combining hazelnuts with other protein sources can help achieve a complete amino acid profile (Guiné & Correia, 2020; Sen & Kahveci, 2020; Jakopic et al., 2018).

2.1.3. Carbohydrates and dietary fiber

Hazelnuts (*Corylus avellana*) are not only known for their rich lipid and protein content but also for their significant contributions to carbohydrate and dietary fiber intake. These components play a crucial role in maintaining various aspects of health, including energy regulation, digestive health, and metabolic functions. Understanding the carbohydrate composition and fiber content of hazelnuts can provide insight into their benefits and roles in a balanced diet (Hannan et al., 2020).

2.1.3.1. Carbohydrate content

Hazelnuts contain a moderate amount of carbohydrates, constituting approximately 10% to 22% of their total weight. The carbohydrate content in a 100-gram serving of hazelnuts typically ranges between 15 to 17 grams. This carbohydrate content primarily includes (Lanza et al., 2014):

- **Simple Sugars**: Hazelnuts contain small amounts of simple sugars, such as glucose and fructose, which contribute to their slightly sweet flavor. These sugars are present in limited quantities compared to other food sources.
- **Complex Carbohydrates**: The majority of carbohydrates in hazelnuts are complex carbohydrates, including starches and oligosaccharides. Complex carbohydrates are gradually digested and absorbed, providing a steady release of energy. The glycemic index (GI) of hazelnuts is relatively low, meaning they have a minimal impact on blood sugar levels. This makes them a suitable option for individuals managing blood glucose levels or those with diabetes (Hannan et al., 2020).

2.1.3.2. Dietary fiber content

Hazelnuts are an excellent source of dietary fiber, with a content of approximately 10.4% by weight. This high fiber content contributes to several health benefits, which are outlined as follows:

2.1.3.3. Types of dietary fiber

The dietary fiber in hazelnuts includes both soluble and insoluble fibers. Soluble fiber can dissolve in water and forms a gel-like substance in the digestive tract, while insoluble fiber does not dissolve and adds bulk to the stool (Lanza et al., 2014).

- **Soluble fiber**: This type of fiber helps to regulate blood sugar levels by slowing the absorption of glucose, which can be beneficial for managing diabetes and reducing the risk of cardiovascular diseases. It also aids in lowering blood cholesterol levels by binding to bile acids

and promoting their excretion (D'Anci et al., 2006).

- **Insoluble fiber**: Insoluble fiber enhances digestive health by promoting regular bowel movements and preventing constipation. It adds bulk to the stool, facilitating its passage through the intestines. Insoluble fiber also contributes to overall gut health by supporting the growth of beneficial gut microbiota (Guiné & Correia, 2020).

2.1.3.4. Digestive health

The high fiber content in hazelnuts supports gastrointestinal health by improving digestion and preventing common digestive issues such as constipation. A diet rich in fiber is associated with a lower risk of developing gastrointestinal disorders and can promote a healthy digestive tract (Alasalvar & Shahidi, 2021).

2.1.3.5. Satiety and weight management

Dietary fiber increases feelings of fullness and satiety, which can help with weight management by reducing overall calorie intake. The slow digestion of fiber-rich foods like hazelnuts helps to control appetite and prevent overeating (Jakopic et al., 2018).

2.1.3.6. Chronic disease prevention

Regular consumption of fiber-rich foods, including hazelnuts, has been linked to a reduced risk of chronic diseases such as heart disease, stroke, and certain types of cancer. The fiber in hazelnuts helps to improve blood lipid profiles and reduce inflammation, contributing to overall cardiovascular health (Mapelli & Gallo, 2019; Jakopic et al., 2018).

2.1.3.7. Comparison with other nuts and seeds

While hazelnuts are a good source of dietary fiber, their fiber content is comparable to other nuts and seeds. For instance, almonds and walnuts also offer substantial amounts of dietary fiber and complex carbohydrates. However, hazelnuts have a unique nutrient profile, with specific benefits related to their fiber content and carbohydrate composition (D'Anci et al., 2006; Mapelli & Gallo, 2019; Guiné & Correia, 2020).

2.2. Micronutrients

2.2.1. Vitamins

Hazelnuts (*Corylus avellana*) are renowned not only for their lipid and protein profiles but also for their rich vitamin content. These vitamins play essential roles in various physiological functions, contributing to overall health and well-being. This section provides a comprehensive overview of the vitamins found in hazelnuts and their potential health benefits (Cui et al., 2022).

2.2.1.1. Vitamin E (α-Tocopherol)

2.2.1.1.1. Content and forms

Hazelnuts are an excellent source of Vitamin E, predominantly in the form of α-tocopherol. The α-tocopherol content in hazelnuts ranges from 382 to 472 mg/kg. Vitamin E acts as a potent antioxidant, protecting cells from oxidative damage caused by free radicals (Alasalvar et al., 2009).

2.2.1.1.2. Health benefits:

2.2.1.1.3. Antioxidant Protection

α-Tocopherol neutralizes free radicals, thus protecting cellular membranes from oxidative stress. This action helps prevent cellular damage and supports overall cellular health (Ceballos et al., 2021).

- **Cardiovascular health**: By reducing oxidative stress, Vitamin E contributes to cardiovascular health. It helps prevent the oxidation of low-density lipoprotein (LDL) cholesterol, which is a key factor in the development of atherosclerosis (Sánchez-Gómez et al., 2019).
- **Immune function**: Vitamin E plays a role in enhancing immune function by supporting the activity of immune cells, which can improve the body's defense against infections (Pascual et al., 2011).
- **Skin health**: The antioxidant properties of Vitamin E contribute to skin health by reducing the appearance of signs of aging and protecting against UV-induced skin damage (Picci & Bartolommeo, 2017).

2.2.1.2. Vitamin B1 (Thiamine)

2.2.1.2.1. Content and forms

Hazelnuts contain a moderate amount of Vitamin B1 (thiamine), with approximately 0.6 mg per 100 grams of nuts. Thiamine is crucial for carbohydrate metabolism and energy production (Evrard et al., 2020).

2.2.1.2.2. Health benefits:

- **Energy metabolism**: Thiamine is essential for the conversion of carbohydrates into energy. It plays a key role in the decarboxylation of pyruvate, facilitating energy production in the form of ATP.
- **Neurological function**: Thiamine is vital for maintaining proper neurological function. It supports nerve cell health and neurotransmitter synthesis, which is important for cognitive and nerve function.
- **Cardiovascular health**: Adequate thiamine levels are important for cardiovascular health, as thiamine deficiency can lead to conditions such as beriberi, which affects the heart and blood vessels.

Comparison with other nuts and seeds

Hazelnuts provide a unique combination of vitamins compared to other nuts and seeds. While almonds and walnuts also offer essential vitamins, the specific profile of hazelnuts, particularly their Vitamin E content, highlights their distinct nutritional benefits. Incorporating a variety of nuts and seeds into the diet can help ensure a comprehensive intake of essential vitamins and minerals (Cui et al., 2022; Alasalvar et al., 2009).

3. Bioactive compounds

3.1. Phytosterols

Phytosterols are plant-derived compounds that resemble cholesterol in structure and are known for their potential health benefits, particularly concerning cardiovascular health. Hazelnuts (*Corylus avellana*) are a significant source of phytosterols, which contributes to their nutritional value and overall health benefits. This section provides a detailed overview of the phytosterol content in hazelnuts, their biological functions, and their associated health benefits.

3.1.1. Phytosterol content in hazelnuts

3.1.1.1. Composition and types

Hazelnuts are rich in phytosterols, with β-sitosterol being the most prevalent. The total concentration of phytosterols in hazelnuts is estimated to be around 0.45 to 0.60 mg per gram of nuts. Key phytosterols found in hazelnuts include (Bodoira & Maestri, 2020; Di Nunzio, 2019):

- **β-Sitosterol**: The dominant phytosterol in hazelnuts, constituting up to 90% of the total sterol content.
- **Campesterol**: Present in smaller quantities, approximately 4% of the total phytosterol content.
- **Stigmasterol**: Contributing about 2% of the total phytosterol content.
- **4-Methylsterols**: Including citrostadienol, obtusifoliol, and gramisterol, which are found in trace amounts.

3.1.2. Biological functions of phytosterols

3.1.2.1. Cholesterol absorption inhibition

Phytosterols are known for their ability to inhibit the absorption of dietary cholesterol in the intestines. They compete with cholesterol for absorption sites in the intestinal lining, thus reducing the amount of cholesterol that enters the bloodstream. This mechanism can lead to decreased levels of low-density lipoprotein (LDL) cholesterol, commonly referred to as "bad" cholesterol, and is associated with a lower risk of cardiovascular diseases (Erdal, Arslan, & Yıldız, 2021).

3.1.2.2. Anti-inflammatory effects

Phytosterols exhibit anti-inflammatory properties that can be beneficial in managing chronic inflammation related to various health conditions. They may help reduce inflammatory markers in the blood and improve overall inflammatory responses (Evrard, Tardy, & Lemoine, 2020).

3.1.2.3. Antioxidant properties

Phytosterols have antioxidant properties that aid in neutralizing free radicals and protecting cells from oxidative stress. This antioxidant activity can contribute to a reduced risk of chronic diseases and support overall cellular health (Gorji, Moeini, & Memariani, 2018).

3.1.2.4. Immune system support

Phytosterols may influence immune system function by modulating the production and activity of immune cells and cytokines. This can support the body's defense mechanisms and improve immune responses (Nawaz & Khalifa, 2022).

3.1.3. Health benefits of phytosterols from hazelnuts

3.1.3.1. Cardiovascular health

The primary health benefit of phytosterols is their impact on cardiovascular health. Regular consumption of phytosterol-rich foods like hazelnuts has been linked to lower levels of LDL cholesterol and improved lipid profiles. Studies have shown that incorporating phytosterols into the diet can lead to a significant reduction in total cholesterol and LDL cholesterol levels, thus reducing the risk of atherosclerosis and heart disease (Picci & Bartolommeo, 2017).

3.1.3.2. Weight management

Despite their fat content, nuts, including hazelnuts, have been associated with benefits for weight management. Phytosterols may help regulate fat metabolism and promote feelings of fullness, which can assist in weight control and prevent obesity (Wani et al., 2020).

3.1.3.3. Digestive health

The fiber content in hazelnuts, coupled with their phytosterol content, supports digestive health by enhancing bowel regularity and promoting a healthy gut microbiome. Phytosterols may help maintain a healthy digestive tract and prevent constipation (Di Nunzio, 2019).

3.1.3.4. Cancer prevention

Preliminary research suggests that phytosterols may have potential anticancer properties. They have been observed to inhibit the growth of cancer cells and induce apoptosis in certain cancer types. However, further research is necessary to fully understand their role in cancer prevention and treatment (Glei et al., 2018; Sang, Guo, & Lee, 2017).

3.2. Polyphenols and antioxidants

Hazelnuts (*Corylus avellana*) are celebrated for their rich nutritional content and significant levels of polyphenols and antioxidants. These compounds play a crucial role in safeguarding health by protecting against oxidative stress and various chronic diseases. This section explores the types, concentrations, and health benefits of polyphenols and antioxidants found in hazelnuts, referencing recent studies and reviews (Kamiloglu & Sari, 2020; Maioli, Piccinelli, & Nicoletti, 2018; Pelvan, Alasalvar, & Uzman, 2012; Puscas & Berton, 2021).

3.2.1. Polyphenol content in hazelnuts

3.2.2. Types of polyphenols

Polyphenols are a diverse group of plant compounds with strong antioxidant properties. In hazelnuts, the primary polyphenolic compounds include (Schmitzer et al., 2011; Toker, Akin, & Kucukcetin, 2008; Bener et al., 2022; Bodoira & Maestri, 2020; Kamiloglu & Sari, 2020):

3.2.2.1. Flavonoids

Key flavonoids in hazelnuts include quercetin, kaempferol, and isorhamnetin. These compounds are known for their robust antioxidant and anti-inflammatory effects.

3.2.2.2. Phenolic acids

Hazelnuts contain various phenolic acids, such as caffeic acid, ferulic acid, and p-coumaric acid, which enhance the nuts' overall antioxidant activity.

3.2.2.3. Tannins

These polyphenolic compounds can bind proteins and other macromolecules, contributing to the astringency and antioxidant capacity of hazelnuts.

3.2.2.4. Concentration

The total polyphenol content in hazelnuts typically ranges from 100 to 150 mg per 100 grams. This concentration can vary based on factors such as cultivar, processing methods, and growing conditions. Raw hazelnuts generally retain higher polyphenol levels compared to processed ones due to potential losses during roasting (Schmitzer et al., 2011; Toker, Akin, & Kucukcetin, 2008; Bener et al., 2022; Bodoira & Maestri, 2020; Kamiloglu & Sari, 2020).

3.2.3. Antioxidant activity of hazelnuts

3.2.3.1. Mechanism of action

The polyphenols in hazelnuts exhibit antioxidant activity through several mechanisms (Kamiloglu & Sari, 2020; Liu et al., 2021; Maioli, Piccinelli, & Nicoletti, 2018; Mehmet, Çetin, & Dündar, 2020):

3.2.3.2. Free radical scavenging

Polyphenols neutralize free radicals by donating electrons, which helps prevent cellular damage and reduces oxidative stress.

3.2.3.3. Metal chelation

Some polyphenols chelate metal ions like iron and copper, which are involved in oxidative reactions. By binding these metals, polyphenols prevent them from participating in harmful oxidative processes.

3.2.3.4. Enzyme inhibition

Polyphenols can inhibit pro-oxidant enzymes, such as lipoxygenase and cyclooxygenase, reducing the production of reactive oxygen species.

3.2.3.5. Antioxidant capacity

Various assays, including DPPH (2,2-diphenyl-1-picrylhydrazyl), FRAP (ferric reducing antioxidant power), and ORAC (oxygen radical absorbance capacity), measure the antioxidant capacity of hazelnuts. Research shows that hazelnuts exhibit significant antioxidant activity, largely due to their polyphenol content (Mishra & Tripathi, 2016; Nair, Sankar, & Krishna, 2014; Puscas & Berton, 2021).

3.2.4. Health benefits of polyphenols and antioxidants in hazelnuts

- **Cardiovascular health:** The antioxidant properties of hazelnuts support cardiovascular health by reducing oxidative stress and inflammation, key factors in cardiovascular diseases. Polyphenols may help lower blood pressure, reduce LDL cholesterol oxidation, and improve endothelial function (Schmitzer et al., 2011; Toker, Akin, & Kucukcetin, 2008; Bener et al., 2022; Bodoira & Maestri, 2020; Kamiloglu & Sari, 2020).
- **Anti-cancer effects:** Polyphenols in hazelnuts may offer protective effects against cancer by reducing oxidative DNA damage and inhibiting cancer cell proliferation. Studies suggest that polyphenol-rich foods, including hazelnuts, are associated with a lower risk of cancers such as breast and colorectal cancer.
- **Anti-inflammatory effects:** The polyphenols in hazelnuts have been shown to modulate inflammatory pathways, which is beneficial for conditions like arthritis and other inflammatory disorders.
- **Neuroprotective effects:** Antioxidants in hazelnuts may support brain health by protecting neurons from oxidative damage and potentially reducing the risk of neurodegenerative diseases. Compounds like quercetin and kaempferol have been linked to improved cognitive function and a reduced risk of Alzheimer's disease.
- **Digestive health:** Hazelnuts' fiber content, combined with their polyphenolic compounds, supports digestive health by promoting a healthy gut microbiota and improving bowel regularity. Additionally, the antioxidant properties of polyphenols help protect the gastrointestinal tract from oxidative damage.

3.3. Tocopherols and carotenoids

Hazelnuts (*Corylus avellana*) are known for their nutritional benefits, including their content of tocopherols and carotenoids, which are essential for maintaining health and preventing chronic diseases. This section explores the types, concentrations, and health benefits of tocopherols and carotenoids found in hazelnuts (Cui et al., 2022).

3.3.1. Tocopherols in hazelnuts

3.3.1.1. Types of tocopherols

Tocopherols are compounds that constitute vitamin E, an essential fat-soluble antioxidant. In hazelnuts, the primary tocopherols are:

- **α-Tocopherol:** The most prevalent form of vitamin E in hazelnuts, α-tocopherol is renowned for its strong antioxidant activity. It protects cells from oxidative damage by scavenging free radicals and mitigating oxidative stress.
- **γ-Tocopherol:** Present in smaller amounts compared to α-tocopherol, γ-tocopherol contributes to the overall antioxidant capacity of hazelnuts and has distinct properties.
- **Concentration:** The tocopherol content in hazelnuts varies with cultivar and processing methods. On average, hazelnuts contain approximately 382 to 472 mg/kg of α-tocopherol, with γ-tocopherol present in smaller quantities. The levels of tocopherols are generally higher in raw hazelnuts compared to processed ones due to potential degradation during roasting (Cui et al., 2022).

3.3.2. Carotenoids in hazelnuts

3.3.2.1. Types of carotenoids

Carotenoids are pigments in plants with antioxidant properties and vitamin A precursors. In hazelnuts, the main carotenoids are:

- **β-Carotene:** A prominent carotenoid and precursor to vitamin A, β-carotene provides antioxidant protection and supports vision, immune function, and skin health.
- **Lutein and zeaxanthin:** These carotenoids are important for eye health. They accumulate in the retina, protecting against age-related macular degeneration and cataracts.
- **Concentration:** Hazelnuts contain carotenoids in relatively lower concentrations compared to other fruits and vegetables. However, they still add to the nutritional value of hazelnuts. Specific quantitative data on carotenoid levels in hazelnuts varies, but they are present in appreciable amounts (Alasalvar & Shahidi, 2021).

3.3.3. Health benefits of tocopherols and carotenoids in hazelnuts

3.3.3.1. Antioxidant activity

Tocopherols and carotenoids both contribute to the antioxidant activity of hazelnuts. α-Tocopherol protects cell membranes from oxidative damage, reducing the risk of chronic diseases such as cardiovascular diseases and cancer. Carotenoids, especially β-carotene, help neutralize free radicals and reduce oxidative stress (Alasalvar & Shahidi, 2021).

3.3.3.2. Cardiovascular health

The antioxidant properties of tocopherols and carotenoids help maintain cardiovascular health by reducing oxidative stress and inflammation. α-Tocopherol can lower LDL cholesterol oxidation and improve endothelial function, while carotenoids like β-carotene are linked to a reduced risk of cardiovascular diseases (Sánchez-Gómez, Moreno, & Martínez, 2019; Yılmaz, Dönmez, & Taşkın, 2013; Brown, Ware, & Tey, 2022).

3.3.3.3. Eye health

Carotenoids such as lutein and zeaxanthin are crucial for eye health, protecting the retina from oxidative damage and reducing the risk of age-related macular degeneration and cataracts. While the concentration in hazelnuts is modest, they contribute to overall eye health when included in a balanced diet (Cui et al., 2022).

3.3.3.4. Skin health

Tocopherols and carotenoids support skin health by protecting against oxidative damage from UV exposure and environmental pollutants. Vitamin E (α-tocopherol) helps maintain skin integrity and may reduce signs of aging, while carotenoids like β-carotene enhance skin pigmentation and protect against sun-induced damage (Alasalvar, Shahidi, Liyanapathirana, & Ohshima, 2003).

3.3.3.5. Immune function

Vitamin E enhances immune function by supporting immune cell activity and reducing oxidative stress. Carotenoids also play a role in

immune health by modulating immune responses and protecting against infections (Alasalvar & Shahidi, 2021).

4. Hazelnut consumption and health

Hazelnuts (*Corylus avellana*) are not only a delicious addition to the diet but also provide numerous health benefits due to their rich content of unsaturated fatty acids, proteins, dietary fiber, vitamins, minerals, and bioactive compounds. This section explores the impact of hazelnut consumption on various aspects of health, including cardiovascular health, metabolic benefits, and weight management (Alasalvar & Shahidi, 2021).

4.1. Cardiovascular health

4.1.1. Cholesterol reduction

Regular hazelnut consumption has been linked to improved cholesterol profiles. Hazelnuts are rich in monounsaturated fatty acids (MUFA), especially oleic acid, which helps lower LDL cholesterol and increase HDL cholesterol. Studies have shown that incorporating raw hazelnuts into the diet improves lipid profiles, particularly in individuals with type 2 diabetes (Damavandi et al., 2012; Damavandi et al., 2013).

4.1.2. Blood pressure management

Hazelnuts may aid in blood pressure regulation due to their potassium content, which helps counteract sodium effects and support healthy blood pressure. The antioxidant properties of hazelnuts also contribute to reducing oxidative stress and inflammation, factors that can lead to hypertension (D'Anci, Venter, & Sherman, 2006; Erdal, Arslan, & Yıldız, 2021; Sánchez-Gómez, Moreno, & Martínez, 2019).

4.1.3. Endothelial function

Hazelnut consumption has been shown to positively influence endothelial function by reducing oxidative stress and inflammation. This benefit promotes better blood vessel health and lowers the risk of atherosclerosis (Fang et al., 2019).

4.2. Metabolic benefits

4.2.1. Blood sugar regulation

Hazelnuts have a low glycemic index, making them suitable for individuals with diabetes or those managing blood sugar levels. The fiber and healthy fats in hazelnuts help stabilize blood glucose levels by slowing carbohydrate absorption and preventing rapid sugar spikes. Research suggests that incorporating hazelnuts into a balanced diet may improve glycemic control and insulin sensitivity (Damavandi et al., 2013).

4.2.2. Anti-inflammatory effects

Chronic inflammation is a common factor in metabolic disorders such as obesity, diabetes, and cardiovascular diseases. Hazelnuts contain bioactive compounds, including polyphenols and vitamin E, with anti-inflammatory properties. Regular hazelnut consumption can help modulate inflammatory responses and reduce the risk of inflammation-related diseases (Renzo et al., 2019; Romero, Bafundo, & Figueroa, 2020; Sang, Guo, & Lee, 2017).

4.3. Weight management

4.3.1. Satiety and portion control

Despite concerns about nuts contributing to weight gain, hazelnuts can actually aid in weight management. The high fiber and protein content of hazelnuts enhance satiety, helping individuals feel full longer and potentially reducing overall calorie intake. Studies indicate that including nuts like hazelnuts in the diet does not lead to weight gain and can be associated with a lower risk of obesity (D'Anci, Venter, & Sherman, 2006; Renzo et al., 2019).

4.3.2. Energy density

Hazelnuts are energy-dense due to their fat content; however, they predominantly contain healthy unsaturated fats. When consumed in moderation, they provide substantial nutritional benefits without excessive calorie intake (D'Anci, Venter, & Sherman, 2006; Renzo et al., 2019).

4.4. Chronic disease prevention

4.4.1. Cancer prevention

Hazelnuts, rich in antioxidants such as vitamin E and polyphenols, may aid in cancer prevention by combating oxidative stress and neutralizing free radicals, which can otherwise cause cellular damage. Additionally, β-sitosterol, a plant sterol

found in hazelnuts, has been associated with a reduced risk of certain cancers, including breast, prostate, and colon cancer. Although more research is necessary to establish definitive links, incorporating hazelnuts into a balanced diet may offer protective benefits against cancer through their antioxidant and anti-inflammatory properties (Gallego et al., 2017; Sang, Guo, & Lee, 2017; Glei et al., 2018).

4.4.2. Bone health

Hazelnuts contribute to bone health due to their mineral content, particularly magnesium and copper. Magnesium supports bone formation and maintenance, while copper is essential for collagen synthesis, which is crucial for bone integrity. These nutrients help in maintaining bone mineral density and strength, potentially reducing the risk of bone-related conditions (Jakopic, Stibilj, & Gligora, 2018; Alasalvar et al., 2009).

5. The physiological effects of hazelnut consumption

Hazelnuts are a valuable food with a rich nutrient profile that provides multifaceted positive effects on human physiology. Thanks to components such as monounsaturated fatty acids, vitamin E, magnesium, calcium, and polyphenols, hazelnuts promote cardiovascular, digestive, bone, and brain health. Their antioxidant content prevents cellular damage, while their high fiber content supports the digestive system and balances the gut microbiota. Additionally, the energy-dense nature of hazelnuts promotes satiety, which can aid in weight management. However, caution is needed in their consumption, especially for individuals with nut allergies, as they pose serious health risks (Ceylan et al., 2023; Daştan et al., 2023; Franco Estrada et al., 2022; Zao et al., 2023).

5.1. Cardiovascular health effects

Hazelnuts are a valuable food for cardiovascular health due to their high content of monounsaturated fatty acids (MUFA), which help lower LDL cholesterol and increase HDL cholesterol levels. These fats play a key role in preventing atherosclerosis and improving overall heart health. Clinical studies have shown that regular consumption of hazelnuts can positively impact blood lipid profiles by reducing LDL cholesterol, which is a primary risk factor for cardiovascular diseases (CVD), while boosting HDL cholesterol that helps clear the arteries. Additionally, the oleic acid found in hazelnut oil contributes significantly to these cardiovascular benefits (Brown et al., 2022; Zibaeenezhad and Elyaspour 2022).

Hazelnuts also support blood pressure regulation due to their potassium and magnesium content, which help dilate blood vessels and lower hypertension risk. Meta-analyses have confirmed that hazelnuts can lead to a modest yet significant reduction in both systolic and diastolic blood pressure. Furthermore, their antioxidant properties, thanks to vitamin E, phenolic compounds, and phytochemicals, reduce oxidative stress and inflammation in the cardiovascular system, preventing arterial stiffness. Hazelnuts also contain phytosterols, such as β-sitosterol, which help lower cholesterol absorption in the intestines, further supporting healthy blood lipid levels and preventing atherosclerosis. Additionally, the amino acids in hazelnuts, particularly arginine, aid in blood flow regulation by promoting vasodilation and enhancing nitric oxide production, which helps maintain blood pressure and overall vascular health. Epidemiological studies, such as the PREDIMED study, have highlighted that adding hazelnuts to the diet can significantly reduce the risk of heart attacks and strokes, emphasizing their protective role in cardiovascular health (Yi et al., 2022; Akcan et al., 2023; Şeker, 2023).

5.1.1. Regulation of metabolism

Hazelnuts, with their rich nutritional profile and bioactive compounds, play a significant role in regulating metabolism and supporting overall health. The healthy fats, proteins, fiber, vitamins, and minerals in hazelnuts help balance metabolic processes, making them beneficial for both the prevention and management of chronic diseases. Hazelnuts are particularly effective in regulating blood sugar levels, as the monounsaturated and polyunsaturated fats slow carbohydrate digestion and glucose release. The high fiber content also delays glucose absorption, helping to control post-meal blood sugar spikes. Regular consumption of hazelnuts has been linked to improved insulin sensitivity and a reduced risk of type 2 diabetes, thanks to their ability to reduce insulin resistance (Eslami et al., 2022; Luvián-Morales et al., 2022).

In addition to regulating blood sugar, hazelnuts assist with energy balance and weight management. Their high fiber and protein content

promote satiety, helping to control appetite and reduce overeating. Despite their energy density, some of the fats in hazelnuts are excreted without being absorbed, which can help prevent weight gain. Hazelnuts also support metabolic rate by enhancing mitochondrial function and energy production, aiding in weight management. Furthermore, hazelnuts positively impact lipid metabolism, improving cholesterol levels and supporting cardiovascular health. Their antioxidant-rich composition, including vitamin E, phenolic compounds, and flavonoids, helps reduce inflammation and oxidative stress, further promoting healthy metabolic processes. Additionally, the healthy fats in hazelnuts contribute to hormonal balance, influencing appetite-regulating hormones and thyroid hormone metabolism, which are key to maintaining optimal metabolic health (Balakrishna et al., 2022; Franco Estrada et al., 2022).

5.1.2. Effects on the digestive system

Hazelnuts are an important food that supports digestive health due to their high fiber content. Fiber consists of complex carbohydrates that are indigestible by the human body, and it has multiple beneficial effects on the digestive system. The impact of hazelnut consumption on the digestive system can be examined across a wide range of areas, from regulating bowel movements to supporting healthy gut flora and preventing digestive diseases (Ceylan et al., 2023; Mandaları et al., 2023).

5.1.2.1. Regulation of bowel movements

Hazelnuts are particularly rich in insoluble fiber, which helps regulate bowel movements. Insoluble fiber retains water in the digestive tract, increasing stool volume and making it easier to pass through the intestines. This process plays an effective role in preventing common digestive issues, such as constipation. Regular bowel movements help eliminate toxins and waste products from the body, improving overall digestive health (Karaosmanoğlu, 2022).

5.1.2.2. Support for gut microbiota

The dietary fiber in hazelnuts serves as an energy source for beneficial bacteria in the gut, exhibiting probiotic effects. These beneficial bacteria ferment the fiber, producing short-chain fatty acids (SCFAs), which nourish the intestinal wall, reduce inflammation, and strengthen the immune system, thereby supporting gut health. A healthy gut microbiota has positive effects not only on digestive health but also on overall immune function (Daştan et al., 2023).

5.1.2.3. Prevention of gut diseases

The high fiber content of hazelnuts creates a healthy environment in the gut, which can reduce the risk of inflammatory bowel diseases (IBD). Regular consumption of hazelnuts may also lower the incidence of common digestive disorders such as diverticulitis and irritable bowel syndrome (IBS). The anti-inflammatory properties of fiber play an important role in preventing such conditions by protecting the intestinal mucosa (Daştan et al., 2023).

5.1.2.4. Cholesterol elimination

The soluble fiber found in hazelnuts helps promote the elimination of cholesterol from the body by binding bile acids in the intestines. Bile acids are involved in the breakdown of fats during digestion, and their reabsorption can increase cholesterol production. Consuming hazelnuts ensures that bile acids are bound to fiber in the intestines and excreted with stool, which contributes to lower cholesterol levels and indirectly supports heart health (Eslami et al., 2022).

5.1.2.5. Antioxidant effects

In addition to fiber, hazelnuts are rich in antioxidants. Compounds such as vitamin E, polyphenols, and tocopherols found in hazelnuts protect cells in the digestive system from the harmful effects of free radicals. This helps support the health of the intestinal wall, reduces inflammation, and may lower the long-term risk of digestive system cancers (Brown et al., 2022; Şahin et al., 2022; Selli et al., 2022).

5.1.2.6. Glycemic control and digestive effects

The low glycemic index and high fiber content of hazelnuts help slow down the absorption of carbohydrates in the digestive system, contributing to balanced blood sugar levels. This feature can help reduce the risk of insulin resistance and type 2 diabetes. Furthermore, this slow absorption process optimizes digestion and provides a prolonged sense

of fullness (Brown et al., 2022; Fernández-Rodríguez et al., 2022).

5.1.2.7. Contributions to bone health

Hazelnuts are a nutrient-dense food, offering essential minerals and compounds that play a crucial role in maintaining bone health. Rich in magnesium, calcium, phosphorus, copper, and zinc, hazelnuts support the skeletal system by promoting bone strength and preventing age-related bone loss. Magnesium and calcium, key components of bone matrix, work together to increase bone density and prevent fractures. Additionally, phosphorus contributes to bone hardness, copper aids in collagen synthesis for bone tissue renewal, and zinc supports bone metabolism and repair. Together, these minerals form a potent combination that supports bone health, especially in older individuals and postmenopausal women, who are at higher risk of osteoporosis (Şeker, 2023;Yang et al., 2023).

In addition to their mineral content, hazelnuts possess antioxidant properties that further enhance bone health. Tocopherols (vitamin E), polyphenols, and phytochemicals in hazelnuts neutralize free radicals, reducing oxidative stress that can damage bone cells and accelerate aging. The omega-9 fatty acids and anti-inflammatory compounds found in hazelnuts also help reduce inflammation in bone tissue, which, if left unchecked, can increase the activity of osteoclasts and contribute to bone degradation. Furthermore, the mineral content of hazelnuts supports bone development in children, promoting healthy skeletal growth. By incorporating hazelnuts into a balanced diet, individuals can benefit from improved bone health, reduced risk of osteoporosis, and enhanced physical performance through increased bone density and better mineral absorption during physical activity (Polat et al., 2023).

5.1.3. Effects on the immune system

Hazelnuts are an excellent source of several essential nutrients that contribute to the optimal functioning of the immune system. Rich in vitamin E, particularly tocopherols, hazelnuts act as powerful antioxidants, protecting immune cells from oxidative stress and maintaining their functionality. Vitamin E plays a vital role in enhancing the immune response, particularly in older adults where immunity tends to decline. In addition to vitamin E, hazelnuts contain trace minerals like zinc, selenium, and copper, all of which are crucial for immune cell development and function. Zinc, for example, supports T cells and natural killer cells, while selenium strengthens antioxidant defenses, and copper aids in inflammation control and immune cell production (Salem et al 2022; Zhao et al., 2023).

Beyond these nutrients, hazelnuts are packed with phenolic compounds that offer both antioxidant and anti-inflammatory benefits, further supporting immune function. These compounds regulate inflammatory processes and help maintain immune balance by preventing chronic inflammation. Hazelnuts also provide omega-9 fatty acids, specifically oleic acid, which contributes to reduced inflammation and supports immune cell health by maintaining cell membrane integrity. Additionally, the fiber in hazelnuts promotes gut health, which is a critical aspect of immune regulation. By nourishing beneficial gut bacteria, hazelnuts help maintain gut barrier integrity, ultimately strengthening the immune system. The protective effects of hazelnuts are also evident in their potential to mitigate the immune suppression caused by chronic diseases such as diabetes and obesity, offering a valuable dietary component for immune support (Salem et al 2022; Zhao et al., 2023).

5.1.4. Effects on brain health

Hazelnuts, with their rich nutrient composition, offer numerous benefits for both general and brain health. They are an excellent source of omega-3 fatty acids, vitamin E, phytosterols, magnesium, zinc, and polyphenols, all of which play crucial roles in supporting brain function and preserving mental performance as we age. Omega-3 fatty acids, especially docosahexaenoic acid (DHA), are essential for the structure of cell membranes, which facilitate nerve cell communication. Regular consumption of omega-3s found in hazelnuts helps reduce inflammation in the brain, providing potential support in managing psychiatric conditions such as depression and anxiety. Additionally, DHA aids in maintaining cognitive function and may lower the risk of neurodegenerative diseases like Alzheimer's (Nishi et al., 2023; Wu et al., 2023).

The vitamin E content in hazelnuts provides powerful antioxidant protection, shielding brain

cells from oxidative stress, which is associated with age-related cognitive decline and conditions like Alzheimer's. Moreover, the polyphenols found in hazelnuts possess neuroprotective effects, reducing inflammation and oxidative stress in the brain, potentially lowering the risk of neurological diseases such as Parkinson's and Alzheimer's. These compounds, along with magnesium, optimize neural transmission and enhance memory and cognitive function. Hazelnuts' ability to protect against neurodegenerative diseases is also noteworthy, as their nutrients prevent the formation of harmful beta-amyloid plaques and reduce damage to brain cells. Additionally, omega-3s and magnesium contribute to the production of neurotransmitters like serotonin and dopamine, offering a positive impact on mental health and mood regulation. Regular consumption of hazelnuts thus supports both cognitive and emotional well-being (Polat et al., 2023; Nijssen et al., 2023).

5.1.5. Hazelnut allergy

Hazelnuts are a popular, nutrient-rich food, but they can cause severe allergic reactions in some individuals. Hazelnut allergy occurs when the immune system overreacts to certain proteins in hazelnuts. The severity of reactions can range from mild symptoms to life-threatening conditions like anaphylaxis. It is essential for individuals with this allergy to avoid hazelnuts and seek proper treatment. Raising awareness about hazelnut allergies is also crucial for effective management. While hazelnuts offer health benefits, they should be completely avoided by those with this allergy . Hazelnut allergy arises when the immune system reacts to specific proteins, such as "prunin" and "2S albumin," in hazelnuts. This response leads to the release of histamine and other inflammatory substances. Genetic predisposition and environmental factors, such as early exposure to allergens, contribute to the development of hazelnut allergies. Individuals with a family history of allergies or other nut allergies are at higher risk.Symptoms of hazelnut allergy can range from mild to severe and usually occur shortly after consumption (Borres et al., 2022; Chen et al., 2023; Giannetti et al., 2023). Common symptoms include:

- **Skin reactions**: Itching, redness, rashes, and swelling.
- **Digestive symptoms**: Nausea, vomiting, abdominal pain, and diarrhea.
- **Respiratory difficulties**: Shortness of breath, wheezing, and coughing.
- **Angioedema**: Swelling in the lips, tongue, or throat.
- **Anaphylaxis**: A severe, life-threatening reaction that can cause loss of consciousness, rapid heart rate, and respiratory failure. Immediate medical attention is essential.

6. Conclusion

Hazelnuts are recognized for their remarkable nutritional profile and associated health benefits. Our study has explored the potential advantages of hazelnuts for heart health, weight management, diabetes control, and overall metabolic support. Rich in antioxidants, healthy fats, vitamins, and minerals, hazelnuts offer a wide range of health benefits.

Evidence suggests that regular hazelnut consumption may help reduce the risk of cardiovascular diseases, support metabolic functions, and lower inflammation and oxidative stress. The presence of vitamin E, magnesium, and other essential nutrients in hazelnuts contributes to overall health and immune function.

To maximize the benefits of hazelnuts, adhere to the following guidelines:

i. **Daily consumption amount:** For optimal health benefits, aim to consume approximately 30 grams of hazelnuts daily. This portion size helps achieve the nutritional advantages while managing calorie intake.

ii. **Inclusion in diet:** Incorporate hazelnuts into a balanced diet, complementing them with other nutrient-rich foods. Combining hazelnuts with proteins, fiber, and healthy fats can enhance their health benefits.

iii. **Types and processing of hazelnuts:** Choose natural, unprocessed hazelnuts and avoid those that are salted or sweetened. Further research on specific dietary applications and conditions that benefit from hazelnut consumption is advisable.

iv. **Education and awareness:** Promote awareness of the health benefits of hazelnuts through educational initiatives to encourage more people to include them in their diets appropriately.

In summary, hazelnuts are a valuable addition to a balanced diet, offering substantial health benefits when consumed thoughtfully. Adhering to these recommendations can help individuals fully realize the advantages of incorporating hazelnuts into their daily nutrition.

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