Review Article
DOI: https://doi.org/10.70749/ijbr.v3i12.2711

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://ijbr.com.pk
ISSN: 2960-2793/ 2960-2807

Nutraceutical Potential of Strawberries, It's Phytochemicals and Health Benefits: A Comprehensive Review

Rameen Irshad[1], Rai Muhammad Amir[1], Muhammad Tauseef Azam[1], Fatmah Azhar Abbasi[1], Eisha Fatima[1], Muhammad Zunair[2], Rabia Kausar[1], Salma Razzaq[1], Zainab Chaudhary[1], Saman Afzal[1]

[1]Institute of Food and Nutritional Sciences, PMAS-Arid Agriculture University, Rawalpindi, Punjab, Pakistan.
[2]Department of Horticulture, PMAS-Arid Agriculture University, Rawalpindi, Punjab, Pakistan.

ARTICLE INFO

Keywords: Strawberry, Phytochemicals, Functional Food, Nutraceutical Components, Health Benefits, Cellular Mechanism, Anti-cancer and Anti-inflammatory.

Correspondence to: Rameen Irshad, Institute of Food and Nutritional Sciences, PMAS-Arid Agriculture University, Rawalpindi, Punjab, Pakistan.
Email: rameenirshad524@gmail.com

Declaration
Authors' Contribution
All authors equally contributed to the study and approved the final manuscript.

Conflict of Interest: No conflict of interest.

Funding: No funding received by the authors.

Article History
Received: 21-09-2025 Revised: 03-12-2025
Accepted: 17-12-2025 Published: 30-12-2025

ABSTRACT

Strawberry (*Fragaria × ananassa*) world widely recognized as a nutrient-dense fruit containing a wide range of bioactive compounds like anthocyanins, flavonoids, ellagitannins and other phenolic compounds that exhibit strong anti-inflammatory and antioxidant properties. Over the past two decades, advances in techniques like chromatography and mass spectrometry have significantly expanded the understanding of the characterization of these compounds among different cultivar types, post-harvest handling, and plant tissues. Experimental evidence from various in vitro and human studies indicates that strawberry phytochemicals are capable of modulating oxidative stress, providing neuroprotection, enhancing endogenous detoxification systems and modulating cognitive and metabolic functions. However, despite all these promising biological effects of strawberry phytochemicals, there remain some uncertainties regarding their metabolic fate, bioavailability and their long-term effects on human health. By synthesizing findings from recent literature, this review highlights the chemical composition, biological effects, and potential health benefits of strawberry consumption either raw or in supplement form or as freeze-dried strawberry powder. This review also emphasizes that, strawberries should be consumed as a whole rather than in supplemental constituents because there are many phytochemicals that provide multiple health benefits despite focusing on a single benefit. While focusing on the need for an analytical approach and more clinical studies in the future.

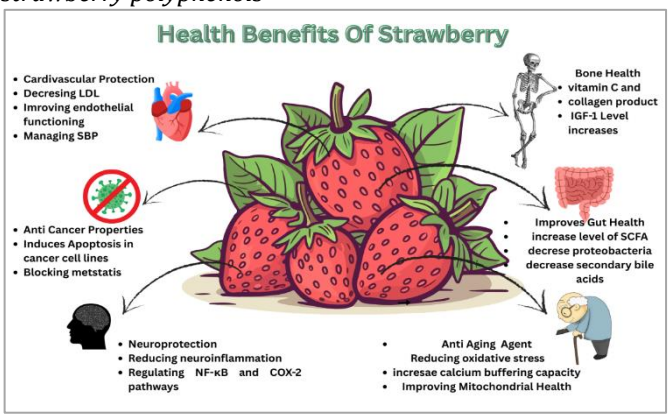
INTRODUCTION

Chronic diseases are spreading increasingly worldwide, which has boosted the concern to use a healthy dietary pattern to avoid the incidence of these diseases rather than later depending upon pharmaceuticals for a cure. By taking approximately 1 to 2 cups of fruits per day. Evidence from multiple studies suggests that greater fruit intake is associated with lower rates of morbidity and mortality (Ubago-Guisado et al., 2021). Plant-based foods contain a diversity of phytonutrients, essential micronutrients that provide oxidant defense, and flavan-3-ols (flavanols), which support cardio metabolic health with a dietary recommendation of 400–600mg/day (Crowe-White et al., 2022). Cocoa, tea and berries, such as strawberries, are the foods that can meet this dietary recommendation (Zuelch et al., 2023). People of Europe, North and South America have been consuming strawberries for ages. Fragaria vesca is a wild strawberry species that is the genetic ancestor to the modern cultivated strawberry (*Fragaria x ananassa*), which belongs to North America, obtained from the hybridization of a wild strawberry species, *Fragaria virginiana* and *Fragaria chiloensis.* The name (*Fragaria x ananassa)* was derived when farmers use "straw" for its mulching practice. Europeans discovered strawberries for the very first time in the year 1588. (Seki et al., 2023). Strawberries are fruits belonging to the family "Rosaceae" and genus "Fragaria", mostly grown in the Mediterranean region (Warner et al., 2021). Strawberry contains 90.1% water, 7.7% carbohydrate, 0.7% protein, and 0.3% of lipid. The main sugars found are fructose, sucrose, and glucose and are known as the predominant sugar. Ascorbic acid is present in the highest content which is around 58.8 g per 100 g. A moderate quantity of lutein which is (26 µg per 100 g), folate (24 µg per 100 g), and choline (5.7 µg per 100 g) are also present. While vitamin K, pantothenic acid, thiamin, riboflavin, niacin, and vitamin B6 are present in very trace levels. Minerals are also present in strawberries, like K 153 mg per 100 g, followed by P (24 mg per 100 g), Ca (16 mg per 100 g), and Mg (13 mg per 100 g (Šic Žlabur

et al., 2020). Among all fruits, strawberries are preferred because of their high nutritional profile, including a wide range of polyphenolic compounds like flavonoids, tannins, phenolic acids, and lignans. Not only this, but strawberries also contain many minerals, vitamins, fatty acids, and fiber. Due to these characteristics, the worldwide demand for strawberries is increasing and so is the production, which reached 9175.4, 886.5, and 1113.6 ktons in 2021 (FAO, 2023). For instance, the Global Fresh Strawberry market is supposed to reach USD 22,450 million by 2026, which was USD 18,370 million in 2020, with a compound annual growth rate (CAGR) of 3.4%, according to the production in 2021. China is the leading producer, then the United States, Turkey, and Mexico (FAO, 2023). From the previous few years, strawberries consumption have been extensively studied for its beneficial effects on health, which includes the prevention of obesity, type II diabetes, cardiovascular diseases, neurodegenerative disorders which are related to aging, enhancing metabolism and some types of cancers (Tang et al., 2019) Studies have shown that women who consume a single weekly serving of strawberries have a reduced risk of cancer, cardiovascular disease and have experienced low levels of inflammatory marker in their blood. Strawberries also exhibit a large amount of cancer-fighting phytochemicals (Ivey et al., 2017).

Figure 1

Major cellular and regulatory health benefits related to strawberry polyphenols



Strawberry flavonoids are anthocyanins, flavanols, and flavonols. Phenolics, ellagic acid (EA), ellagitannin (ET), fiber, micro nutrients, and vitamins are the additional health-promoting phytonutrients in the strawberry, which are plants' secondary metabolites derived through the shikimate and PPP pathway (Holt et al., 2022). The combination of all these phytonutrients can have overpowering impacts on health. There is another class of phenolic compounds present in strawberries known as hydrolyzable tannins, i.e., ellagitannins, which are not commonly present in other kinds of berries and dried nuts. Strawberries are also very rich in condensed tannins, i.e., proanthocyanidin. Glycosides of quercetin and kaempferol are the flavonols of strawberry (Nowicka et al., 2019). Strawberry intake can improve metabolism and systemic physiology, as well as the gastrointestinal microbiome. This aspect is very significant as dietary shifts can reshape the gut microbiome, which results in improving overall health by improving metabolic activity and functioning of both the cardiovascular and nervous systems. The nutritional composition of strawberries helps in balancing the free radical production in the body and scavenging to stop the occurrence of several health disorders (Rahman et al., 2019). This review focuses on the nutrient and phytochemical contents of the strawberry and its impact on human health. An overview of the bioavailability and metabolism of strawberry phytochemicals after consumption, and the health benefits related to strawberries, mainly the recent evidence in the field of cardiovascular health and cancer prevention.

Table 1

Nutritional Composition of fresh Strawberries per standard serving (166g)

Nutrient	Quantity per serving	DRV	%DV
Macronutrients			
Protein	1.1g	50 g	2.2
Total fat	0.5g	78g	0.6
Carbohydrate	12.7g	275g	4.6
Total sugars	8.1g	-	-
Dietary fibre	3.3g	28g	11.9
Sodium	1.7mg	2300mg	0.1
Micronutrients			
Calcium	26.6mg	1300mg	2.1
Iron	0.7mg	18mg	3.8
Magnesium	21.6mg	420mg	5.1
Phosphorus	39.8mg	1250mg	3.2
Potassium	254mg	4700mg	5.4
Zinc	0.2mg	11mg	2.1
Copper	0.1mg	0.9mg	8.9
Manganese	0.6mg	2.3mg	27.9
Vitamin C	97.6mg	90mg	108.4
Folate	39.8µg	400µg	10
Vitamin A	1.7µg	900µg	0.2

Note: DRV = Daily Reference Value; %DV = Percent Daily Value. Data sourced from Bhagwat and Haytowitz (2022), Rothwell et al. (2013), and USDA (2016).

Nutraceutical Facts

Nutraceutical Components of Strawberries

Nutraceutical constituents of strawberries are evaluated by various advanced tools and techniques. The most commonly used tools include Liquid Chromatography or Mass Spectrometry paired with Ultraviolet detection (Aaby et al., 2007). The aromatic volatile compounds present in strawberries are mostly evaluated by using the GC-MS method. For the evaluation of the structure of secondary metabolites of strawberry, NMR spectroscopy, paired with LC-MS, is employed. Modern techniques like (FTICR-MS) Fourier Transform Ion Cyclotron Resonance Mass Spectrometry and Colloidal (GALDI) Geomatrix-Assisted Laser Desorption/Ionization (Zhang et al., 2007) are also sometimes used for strawberry nutraceutical constituents evaluation.

A wild strawberry species, *Fragaria vesca* L., contains several bioactive components (D'Urso et al., 2016). These wild strawberries are not just tasty and aromatic, instead they are also very rich in easily and quickly absorbable monosaccharides, vitamins (C, B1, B2, and K), and organic acids such as malic, citric, and salicylic acid (Milivojevic et al., 2011). The level of total polyphenols present in wild strawberry is much higher than compared of strawberry, *Fragaria* x *ananassa,* which is commonly available, and also wild strawberries are higher in antioxidant activity

than that of the common strawberry (Milivojevic et al., 2011).

The following table summarizes the key differences between wild and cultivated species:

Table 2

Phytochemical and Nutritional Comparison between Wild and Cultivated Strawberries

Feature	Wild Strawberry (*Fragaria vesca*)	Cultivated Strawberry (*Fragaria x ananassa*)	Key Characteristics	Reference
Genetic Origin	Ancestral species	Hybrid of *F. virginiana* and *F. chiloensis*	Wild species are the genetic ancestors of modern cultivars.	Seki et al., 2023
Antioxidant Activity	Higher	Lower relative to wild species	Wild strawberries exhibit denser stress-response metabolites.	Milivojevic et al., 2011
Polyphenol Content	High	Variable	Total polyphenols are significantly higher in wild species.	Milivojevic et al., 2011
Nutrient Profile	Rich in monosaccharides, Vitamins (C, B1, B2, K), and organic acids (malic, citric, salicylic).	High Vitamin C (58.8g/100g), Folate (24µg), and Choline.	Wild species are noted for easily absorbable monosaccharides and specific organic acids.	D'Urso et al., 2016; Milivojevic et al., 2011; Šic Žlabur et al., 2020

Adopting cereal breeding strategies like MAS, QTL mapping, and GWAS, which have proven to identify stress-tolerance loci in wheat can accelerate strawberry improvement to capture these superior traits. Integrating these with CRISPR-Cas9 and pan-omics offers a promising pathway for designing climate-resilient cultivars with optimized phytochemical profiles (Bibi et al., 2025).

While the nutritional composition of 100g of whole strawberries according to Aaby 2007 is almost 32 kilocalories, with 59 mg of vitamin C content, 2.0g of fiber content, potassium 153 mg of potassium, vitamin A present in almost 12 IU, 24 µg of folate, low molecular weight sugars approximately 4.8g, and carotenoids are also present in the form of β-carotene and lutein, phytosterols, and polyphenolic compounds like (anthocyanins, flavonoids, hydroxycinnamic acid derivatives, and ellagitannins) are also present (Aaby et al., 2007). The polyphenolic compounds found in strawberries are non-nutritive but very important due to their health-promoting benefits. According to Aaby et al. (2005), strawberry achenes exhibit 11% of the total phenolics and 14% of the antioxidant activity of the strawberry. Ellagic acid and its derivatives are also available in strawberries in the form of EA-4-arabinoside, EA-4-acetylarabinoside, and EA-4-acetylxyloside.

The total phenolic content in strawberries at different ripening stages was studied by Wang and Lin (2000). According to him, phenolic content is highest in small green strawberries. The study also showed that anthocyanin content, total phenolics, and antioxidant capacity varied significantly in different cultivars of strawberry.

Flavonoids

Strawberries are very rich in a diverse range of flavonoid compounds. Flavonoid is further divided into subclasses like flavones, flavanones, isoflavones, anthocyanidins, flavonoids, and flavanols (Krga and Milenkovic 2019), many of which contain hydroxyl substitutions at the 3′ and 4′ positions of the backbone of the B ring. Among the most prominent flavonoid metabolites in strawberry are derivatives of quercetin, kaempferol, and related flavonoids. The fruit also contains some amounts of anthocyanidins, particularly cyanidin and pelargonidin, as well as flavan-3-ols such as (epi)catechin and (epi)epiafzelechin, all of which combine to make the overall flavonoid composition (Aaby et al., 2005). Flavonoid consumption results in enhanced vascular function (Crowe-White et al., 2022) and improved metabolic health(Raman et al., 2019).

Anthocyanins

Anthocyanins are an important subdivision of flavonoids they are glycosylated derivatives of anthocyanidin or flavylium ions. The diversity in its structure arises from differences in the order and number of hydroxyl and methoxyl groups on the anthocyanidin backbone, the structural diversity is also due to the nature, position, and degree of acylation of the connected glycoside residues (Wu et al., 2002). Strawberry anthocyanins are mainly present in three forms, pelargonidin-3-glucoside is the dominant anthocyanin (83 %), then pelargonidin-3-rutinoside which is (8%) and cyanidin-3-glucoside which is (7%) (Wu et al., 2002). The key flavonoids typically found in strawberries include quercetin and kaempferol, which exist in several conjugated forms such as glucuronides and rutinosides, for example, quercetin-rutinoside, quercetin-glucoside, quercetin-glucuronide and kaempferol-glucuronide (Seeram et al., 2006). As the fruit matures, the anthocyanin content significantly increases (Wang and Lin, 2000). Anthocyanin consumption has anti-obesity, anti-cancer, anti-inflammatory and neuroprotective effects on the body (Li et al., 2017; Krga and Milenkovic, 2019) as well as improves memory and learning (Afzal et al., 2019)

Catechins

Catechin, one of the typical flavanols present in strawberries, occurs in several forms, including isomers of (p-coumaroyl-glucoside) and (p-coumaroyl ester). (Määttä-Riihinen et al., 2004; Seeram et al., 2006). In strawberries, catechins are predominantly present in free form rather than in glycosylated form (Törrönen and Määttä, 2002). Many catechin molecules can link together to produce dimers, oligomers, and larger polymers collectively known as proanthocyanidins. If kept under acidic and high-temperature conditions, these condensed structures can be broken down through hydrolysis to form

anthocyanidins, which are greatly beneficial to health (Törrönen and Määttä, 2002).

Hydrolyzable Tannins

In strawberries, hydrolyzable tannins are mainly present in higher molecular weight as ellagitannins or gallotannins, while gallotannins and complex tannins are predominantly present in strawberries (Karlińska et al., 2021). The glucose contains a center polyol which is esterified with either gallic acid or hexahydroxydiphenic (HHDP) groups and, it readily solubilizes in any aqueous environment (Seeram et al., 2006). When exposed to acidic conditions, ellagitannins undergo hydrolysis, and HHPD is released, which results in ellagic acid formation by oxidative coupling of two gallic acid units (Määttä-Riihinen et al., 2004). Ellagic acid content in the diet can be obtained by consuming strawberries, as berries like strawberries, blackberries, and raspberries are very rich in these acids (Wu et al., 2002). The antioxidant activity of strawberry achenes is due to the presence of ellagic acid and ellagitannins, and the level of polymerization of ellagitannins depends upon the number of HHDP groups available (Banc et al., 2023). Qualitative analysis has shown that strawberries are rich in ellagitannin structures such as lambertianin C, sanguiin H-6, and galloyl-bis-HHDP-glucose (Seeram et al., 2006; Aaby et al., 2007). Among all natural bioactive compounds, resveratrol is one of the most studied products; it is rarely reported in strawberry fruit and achenes.

Hydroxycinnamic Acid Derivatives

The esters of hydroxycinnamic acid, present in strawberries, are glucose and quinic acid, and p-coumaric acid, as its derivative is also present (Määttä-Riihinen et al., 2004).

Table 3

Major Flavonoids and Phenolic Compounds in Strawberries

Phytochemical	Major Compounds	Chemical Form	Key Functions	References
Flavonols	Quercetin, Kaempferol	Glucosides, Rutinosides, Glucuronides	Antioxidant, anti-inflammatory, enzyme cofactor	Seeram et al., 2006
Anthocyanins	Pelargonidin-3-glucoside, Pelargonidin-3-rutinoside, Cyanidin-3-glucoside	Glycosylated	Antioxidant, cardioprotective, anti-inflammatory	Wu et al., 2002
Flavan-3-ols (Catechins)	(Epi)catechin, (Epi)epiafzelechin	Free, p-coumaroyl ester / p-coumaroyl-glucoside	Antioxidant, proanthocyanidin precursor	Määttä-Riihinen et al., 2004; Törrönen & Määttä, 2002
Hydrolyzable Tannins	Ellagitannins (Lambertianin C, Sanguiin H-6, Galloyl-bis-HHDP-glucose)	Conjugated / Hydrolyzable	Antioxidant, chemoprotective	Seeram et al., 2006; Aaby et al., 2007
Hydroxycinnamic acids	p-Coumaric acid	Glucose / Quinic acid esters	Antioxidant, enzyme modulation	Määttä-Riihinen et al., 2004

Vitamin C and Folate

Water-soluble antioxidants play an important role for protecting the body against the damage caused due to free radicals activity. They also act as a cofactors for many enzymatic reactions and helps in the regeneration of vitamin E (Jacob et al., 2003). Daily consumption of vitamin C has been proven to lower the risk of stroke and some kind of cancers. Post harvest research has shown that high storage temperatures are responsible for reducing ascorbic acid content in fruits like strawberries. Strawberries are an amazing source of ascorbic acid, and even a small portion of this fruit can provide the recommended daily intake of vitamin C. Furthermore, strawberries are also a good source of folate; taking 200–250 grams of the fruit can provide 62% of the daily folic acid requirement for adults in Europe (200–300 µg/day) (Bailey and Gregory, 1999).

Phytoestrogen

Lignin, a class of phytoestrogen, is found in small fruits. It is associated with protection against osteoporosis, cardiovascular diseases, and hormone-dependent cancers. Strawberries rank as the richest source of lignans among all small fruits (Mazur et al., 2000). Strawberry has the ability to manage oxidative stress, which is because of inflammatory changes that occur due to the consumption of a high-fat and carbohydrate diet. Strawberry also reduces the postprandial inflammation response that also occurs due to the consumption of high-carbohydrate and excess fat meals in obese people, while enhancing insulin response and also increasing plasma levels of anthocyanins (Edirisinghe et al., 2011). Ellagic acid is the most important phenolic compound present in strawberries. It is very important because of its antibacterial, cardio-protective and anti-inflammatory effects on human health (Vattem et al., 2005). The anthocyanins from strawberries are rapidly absorbed in the stomach and further absorption occurs in the small intestine as methylated, sulphated compounds and glucuronidated derivatives. Strawberries are very rich in anthocyanins and therefore serve as an excellent fruit to research the bioavailability of Pelargonidin glucoside (Pel-glc). The daily intake of strawberries has been shown to increase Pel-glc bioavailability (Hollands et al., 2008).

Table 4

Major Vitamins and Phytoestrogens in Strawberries

Nutrient / Compound	Content in 100 g Fruit	Main Health Benefits	References
Vitamin C (Ascorbic acid)	59 mg per 100 g	Antioxidant, stroke prevention, anti-cancer and immune support	Carr & Frei, 1999
Folate	24–25 µg per 100 g	DNA synthesis, cell growth, cardiovascular support	Bailey & Gregory, 1999

Lignans (Phytoestrogens)	—	Bone health, anti-cancer, cardiovascular protection	Mazur et al., 2000; Bingham et al., 1998
Ellagic Acid	—	Anti-inflammatory, chemoprotective, antibacterial	Vattem et al., 2005

Health Benefits Related to Strawberries

Nutritional Health Benefits of the Strawberry

Many previous cohort studies have scrutinized the consumption of foods rich in flavonoids, such as strawberries, on disease risk. Data from the Nurses' Health Study II, of 93,000 women aged between 29 and 42 years, showed that women consuming strawberries at least once a week experienced reduced long-term mortality. Specifically, the risk of death from any cause was 20% lower, and the risk of cancer-related mortality was approximately 17% lower as compared to women who did not consume strawberries at all (Ivey et al., 2017). Another prospective study from the Japan Public Health Center, in which a group of approximately 87,000 adults aged between 44 and 76 years was monitored for 13 years. During this time period, researchers reported over 4,000 stroke cases and about 2,000 cases of coronary heart disease (CHD). The upper categories of strawberry intake are defined at around 18 g per day for men and 27 g per day for women (Gao et al., 2021). After analyzing the adjustments that were done for factors such as age, lifestyle habits and existing cardiometabolic disease, the individuals with the highest level of strawberry intake showed 28% lower risk of stroke in men and 32% reduction in women, respectively. (Yang et al. 2020).

Strawberry and Cardiovascular Disease

Anthocyanins present in strawberry provide extensive health benefits such as lowering the risk of cardiovascular diseases CVD's (Bell and Gochenaur, 2006), as well as lowering the risk of several cancers, and improving neuron functioning. Besides this, it also contributes to the protection of brain tissue under hypoxic ischemic conditions. Freeze-dried powder of strawberry reduces SBP (systolic blood pressure) in young people with hypocholesterolemia (Huang et al., 2021). Research further indicates that anthocyanins may enhance several cognitive and sensory functions, including visual performance, memory, and also play a role in suppressing excess weight gain (Tsuda, 2008). Among the diverse effects of berry phenolics, the ability to induce apoptosis is one of the most significant effects. These phenolics, especially anthocyanins, show antimicrobial activities that can help regulate pathogens and slow the development of antibiotic resistance. Their well-developed antioxidant properties are a major contributor to human health, providing protection against degenerative diseases and slowing their progression. Research has highlighted berries as naturally rich and valuable sources of many vitamins (Wang and Lin, 2000).

Strawberry and Cholesterol

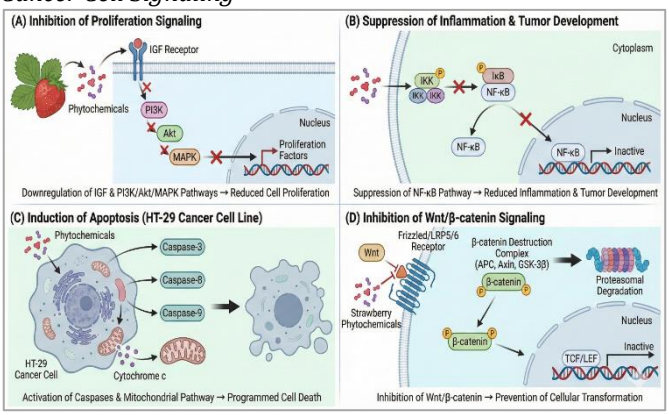
Strawberries support a reduction in serum lipid levels when daily consumed and also enhance the savoriness of cholesterol-lowering foods. Nickel et al. (2009) reported that the body's level of cholesterol can be dropped by consuming supplements of freeze-dried strawberry powder. The compounds such as fiber, phytochemicals, and phytosterols present in freeze-dried strawberry powder are responsible for lowering cholesterol. Extensive research revealed that phytosterols are responsible for reducing cholesterol absorption and low cholesterol levels (Rudkowska et al., 2008). Cholesterol-lowering nutraceutical potential of strawberries could also be due to the dietary fiber present in strawberries (Nickel et al., 2009).

Strawberry Phytochemicals and their Anti-Cancerous Effect

The phenolic compounds of strawberry, through the anti-oxidation process, protect DNA from oxidative damage and have anti-cancerous effects as well (Seeram et al., 2006). Colorectal cancer (CRC) is among the most common cancers, and after lung cancer, it is the second deadliest cancer (Sammarco et al., 2020). In all human cancers, diet contributes almost 20 to 42% and 50 to 80% specifically in colon cancers. Intake of foods rich in bioactive compounds, such as strawberries, has a potential cancer preventive factor (Wang et al., 2012). Research has shown that bioactive compounds can retard the growth of colon cancer cells by regulating multiple cellular and regulatory pathways, such as IGF, PI3K/Akt/MAPK, NF-κB, as well as Wnt/β-catenin signaling pathways(Vanamala et al 2013). The berry extracts have shown an apoptotic effect on human cancer cells. Recent studies have shown that 13 to 24g of strawberry powder intake has improved cognitive performance (Miller et al., 2021; Krikorian et al.,2023). Strawberry phytochemicals are responsible for changing gene expression and retarding its transcription, which results in suppressing the cancer cell proliferation, their transformation, and tumor development. Strawberries contain antioxidants that restrict the potential oxidative damage. Strawberry extract has chemopreventive and antiangiogenic properties, which is because of its ability to restrict mutagenesis caused by certain carcinogens. Research also found that this extract has the ability to induce apoptosis in HT-29, in colon cancer cell lines of humans (Seeram et al., 2006)

Figure 2

Mechanism of Action of Strawberry Phytochemicals on Cancer Cell Signaling



Strawberry as an Antioxidant

Strawberry polyphenols are responsible for their antioxidant properties. Strawberries are a source of

natural antioxidants (Wang and Lin, 2000; Khanizadeh et al., 2008). Human skin and liver are mostly used to study oxidative stress on cells because these organs are most exposed to chemical and environmental agents. Research shows that strawberry bioactive molecules have shown protective effects on in vitro human dermal fibroblasts when treated with chemicals AAPH and H_2O_2 and UV radiation. These molecules sustain cellular viability, reducing the accumulation of reactive oxygen species (ROS), decreasing oxidative DNA damage, and supporting healthier mitochondrial activity (Giampieri et al., 2014a; Oyewole et al., 2014). The same results were obtained with HepG2, which is the standard model used for studying human liver (Lee et al.,2014).

The World Health Organization highlights the important role of small and bright fruits of different colors, such as different kinds of berries consumption specifically for the phenolic constituents present in them, which have antioxidant activity, that safe human beings from several problems related to health like diabetes, all kinds of cardiovascular diseases, several cancers, and obesity (Stapleton et al., 2008). Berries contain higher levels of ellagitanins, approximately three levels more than walnuts and pecans, and nearly fifteen levels more than the levels present in other fruits and nuts. These phenolic components in berries perform significant roles in many biological mechanisms these including removal of ROS, suppressing their production, cell cycle regulation, repression of several tumors, enzymes detoxification, modulation of intracellular signal pathways, apoptosis, and metabolic regulation (Han et al., 2007).

Strawberry as an Oral Disease Preventive

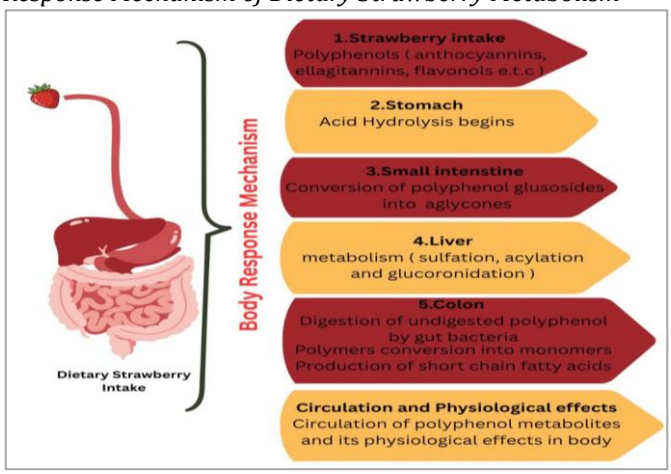
Oral health is very important for the overall well-being of humans and quality of life. Oral health, if not maintained properly, could lead to many major health problems, like as oral cancer was diagnosed in 2010, and the cases exceeded 35000 (Centers for Disease Control and Prevention, 2009). The phytochemicals present in strawberries are capable of improving oral maladies (Palacios et al., 2009). Research conducted on several preclinical animal models shows that phenolics present in small fruits have a significant protective role on the oral mucosa and are more beneficial than expensive medications that may have side effects as well (Seeram, 2008; Stoner, 2009). Infections, genetics, chronic inflammation, and potentially nutrition may be the reasons for chronic diseases and oral health. In the same context, Seeram et al. (2006) reported that strawberry extract, if given in a controlled dose has an anti-proliferative role in oral cell lines. Another study reported that crude extract of strawberry and 32 nutraceutical compounds isolated from strawberry have the potential to inhibit the proliferation of human oral tumor cell lines (Zhang et al., 2008).

Strawberry as Gut Microbiome and Vascular Health Improver

There is a strong relationship between strawberry intake, gut microbiome, strawberry metabolites, and improved vascular health. The gut microbiome has a significant role in maintaining health and regulating metabolism (Satheesh et al., 2023). Digestive enzymes which are crucial for metabolizing dietary components, are less in humans (Kwon et al., 2023). There is a symbiotic relationship between dietary components and gut microbes. Studies indicate the vascular benefits of strawberry intake in humans. Strawberries are very rich in several bioactive compounds, beneficial sugars like glucose and galactose, and pelargonidin glycosides (Miller et al., 2022). According to recent studies, almost 90% of the strawberry anthocyanins make their way to the large intestine, where they are further metabolized by gut microbes (Rodriguez-Mateos et al.,2019). Anthocyanins, microbial metabolites, are capable of mediating several biological activities within the gut (Rodriguez-Mateos et al.,2019).

Figure 3

Response Mechanism of Dietary Strawberry Metabolism



Strawberry as an Anti-Aging Agent

Due to changes in the striatal dopamine system or occasionally in the cerebellum, several cognitive and motor functioning problems occur during aging. These problems and other neurodegenerative diseases may get worse when exposed to oxidative stress and inflammation for a long time. Regular strawberry intake can change the cell signaling to enhance neuron communication, neuron protection to stress shock, calcium buffering ability, elasticity, and stress signal pathways (Shukitt-Hale et al., 2008). Research shows that strawberries slow and reverse age-related problems in rats. Before exposing the rats to radiation to determine the effect of the berry diet, the rats were kept by scientists on a controlled strawberry diet for 56 days (Shukitt-Hale et al., 2007). The result revealed that strawberry intake protects against spatial problems. The study also suggests that strawberry phytochemicals may stop age-related, functional cognitive behavioral problems as well as central nervous system problems, hence have a positive impact on human neurodegenerative diseases as well.

Strawberry and Leukemia

Strawberries and some other types of berries are known for their anti-cancer benefits, as these berries contain methanol extracts, which are helpful in retarding the growth of several types of cancers like colon, prostate, oral, and breast cancer (Seeram, 2008). Research was conducted that reported that programmed cell death was observed in the cell lines of patients with extreme B-lineage risk, including both the cell line with translocation

of t (4;11) as well as in the cell line with no translocation due to curcumin, resveratrol, quercetin, and carnosol (Kellner and Zunino, 2004). The in vitro studies reported that quercetin, ellagic acid and kaempferol are known as the most effective phytochemicals of strawberry to kill leukemia cells in a cell culture system (Kellner and Zunino, 2004).

Synthesis of Key Findings

This review literature highlights strawberries as a nutritionally dense fruit and a source of many bioactive compounds with significant health benefits. This review literature emphasizes the advancement from a single benefit to the combined benefits of strawberry consumption to accelerate health. The main finding from this review aims to reveal that:

The polyphenols present in strawberries, like anthocyanins, catechins, ellagitannins, flavonoids and hydroxycinnamic acids, provide antioxidant, anti-inflammatory, chemopreventive, and cardioprotective activities. Many of these health benefits are a result of the combined action of multiple bioactive compounds rather than a single bioactive compound, highlighting the importance of whole strawberry consumption rather than isolated compound supplements.

The processing methods of strawberries significantly affect their bioactivity; the heat processing in industry generally reduces vitamin C, total phenolics, and anthocyanins, which results in reduced antioxidant activity.

USDA confirms that to sustain a healthy lifestyle, it is compulsory to take 2 servings of fruits, rich in antioxidants such as Strawberries per day

Strawberry consumption improves cardiovascular health by improving blood pressure, vascular function, lipid profiles and oxidative balance.

Despite all these promising findings about strawberry health benefits, there always remain several research gaps. In order to establish optimal intake requirements, the availability of specific phytochemicals and their interactions with human microbiota, more long-term controlled human research is needed.

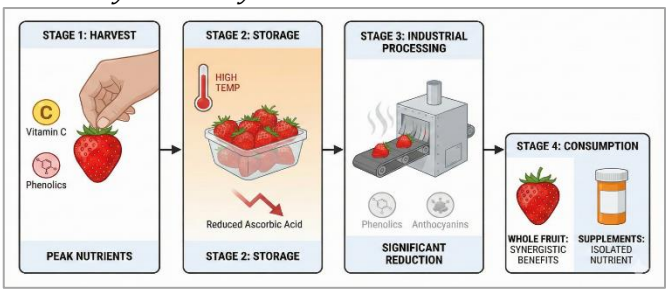
Challenges and Future Perspectives

Major challenges

Despite many strong pieces of evidence supporting the nutraceutical benefits of strawberries, there remain several hurdles that limit the full scientific understanding and practical application. Among these, the first one is the variation of strawberry phytochemical composition among different cultivars, harvest, maturity, post-harvest handling practices, and environmental conditions. This variability of phytochemical composition results in difficulty in standardizing bioactive content for various types of research or product development. Secondly, most of the previous research studies were in vitro assays, which sometimes fail to show the actual biological effects in humans. The metabolism and availability of phytonutrients like anthocyanins, flavonoids, and ellagitanins remain mostly misunderstood. At last the processing of strawberry into different types of food, insufficiently alter its vitamins and phenolic content, but the extent and effect of these losses are not fully explored, not only this the possible protective strategies to these losses are not fully explored yet.

Figure 4

Impact of Post-Harvest Handling and Processing on Strawberry Bioactivity



Future Directions

While significant changes have been made to know the potential of strawberry phytochemicals as a valuable source of nutrition for health improvement and to avoid disease, some of the gaps remain in our knowledge of biochemistry about these compounds.

Hence, future studies should aim to improve the knowledge about these complex compounds and their functions, and should aim to boost the knowledge related to these complex compounds and the roles and functions at the cellular and molecular level. The study analyzing different cultivars of strawberry shows great variation in bioactive compounds. Future work should focus on identifying the germplasm with high anthocyanin phenotypes to breed strawberries with high nutraceutical content. Many beneficial compounds, such as phenylethanol derivatives, phloridzin, and high-molecular-weight proanthocyanidins, have been identified but not properly studied and understood in terms of their bioactivity. Future directions should focus on the study of these compounds as well.

More in vivo studies are needed to clearly understand the role of strawberry phenolics in humans and how they influence apoptosis, DNA repair pathways, maintain oxidative stress, and provide neuroprotection. Human clinical trials are very important to check the efficacy of antioxidants, cognitive, and chemoprotective effects that were obtained in preclinical models.

Future work should be towards motivating healthy aging and preventing chronic diseases in humans, alongside improving the quality of life through new gene-nutrient interactions and health outcomes, ultimately enhancing human life.

CONCLUSION

The evidence presented by previous studies positions strawberries are more than a dietary fruit, defining their emerging role as a natural source of health-regulating compounds, their ability to prevent the occurrence of many diseases and overall human well-being. However, there always remain gaps in understanding their complete bioavailability, metabolism, and long-term health effects in humans. Continued multidisciplinary integrated approaches, advanced analytical methods and clinical evaluations are required to improve the scientific foundation needed to fully harness the functional benefits of strawberries.

REFERENCES

Aaby, K., Skrede, G., & Wrolstad, R. E. (2005). Phenolic composition and antioxidant activities in flesh and achenes of strawberries (*Fragaria ananassa*). *Journal of Agricultural and Food Chemistry*, *53*(10), 4032-4040. https://doi.org/10.1021/jf048001o

Aaby, K., Wrolstad, R. E., Ekeberg, D., & Skrede, G. (2007). Polyphenol composition and antioxidant activity in strawberry purees; Impact of achene level and storage. *Journal of Agricultural and Food Chemistry*, *55*(13), 5156-5166. https://doi.org/10.1021/jf070467u

Afzal, M., Redha, A., & AlHasan, R. (2019). Anthocyanins potentially contribute to defense against Alzheimer's disease. *Molecules*, *24*(23), 4255. https://doi.org/10.3390/molecules24234255

Andres-Lacueva, C., Shukitt-Hale, B., Galli, R. L., Jauregui, O., Lamuela-Raventos, R. M., & Joseph, J. A. (2005). Anthocyanins in aged blueberry-fed rats are found centrally and may enhance memory. *Nutritional Neuroscience*, *8*(2), 111-120. https://doi.org/10.1080/10284150500078117

Bailey, L. B., & Gregory, J. F. (1999). Folate metabolism and requirements. *The Journal of Nutrition*, *129*(4), 779-782. https://doi.org/10.1093/jn/129.4.779

Banc, R., Rusu, M. E., Filip, L., & Popa, D. (2023). The impact of Ellagitannins and their metabolites through gut microbiome on the gut health and brain wellness within the gut–brain Axis. *Foods*, *12*(2), 270. https://doi.org/10.3390/foods12020270

Beekwilder, J., Hall, R. D., & Ric Vos, C. D. (2005). Identification and dietary relevance of antioxidants from raspberry. *BioFactors*, *23*(4), 197-205. https://doi.org/10.1002/biof.5520230404

Bell, D. R., & Gochenaur, K. (2006). Direct vasoactive and vasoprotective properties of anthocyanin-rich extracts. *Journal of Applied Physiology*, *100*(4), 1164-1170. https://doi.org/10.1152/japplphysiol.00626.2005

Bhagwat, S., Haytowitz, D. B., & Holden, J. M. (2014). USDA database for the flavonoid content of selected foods, Release 3.1. *US Department of Agriculture: Beltsville, MD, USA*, 324-473.

Bibi, N., Naseer Hashmi, M. A., Naz, F., Mahmood, T., Ikram, R., Muhammad Daood, Muhammad Bilal, Ahmad, M., & Umair Nadeem, H. M. (2025). Modern breeding strategies for the identification of drought tolerance in wheat: A comprehensive review. *Indus Journal of Bioscience Research*, *3*(10), 235-244. https://doi.org/10.70749/ijbr.v3i10.2532

Chu, Y., Sun, J., Wu, X., & Liu, R. H. (2002). Antioxidant and Antiproliferative activities of common vegetables. *Journal of Agricultural and Food Chemistry*, *50*(23), 6910-6916. https://doi.org/10.1021/jf020665f

Crowe-White, K. M., Evans, L. W., Kuhnle, G. G., Milenkovic, D., Stote, K., Wallace, T., Handu, D., & Senkus, K. E. (2022). Flavan-3-ols and Cardiometabolic health: First ever dietary Bioactive guideline. *Advances in Nutrition*, *13*(6), 2070-2083. https://doi.org/10.1093/advances/nmac105

Edirisinghe, I., Banaszewski, K., Cappozzo, J., Sandhya, K., Ellis, C. L., Tadapaneni, R., Kappagoda, C. T., & Burton-Freeman, B. M. (2011). Strawberry anthocyanin and its association with postprandial inflammation and insulin. *British Journal of Nutrition*, *106*(6), 913-922. https://doi.org/10.1017/s0007114511001176

Food and Agriculture Organization (FAO). (2023). *FAOSTAT—Crops and livestock products*. https://www.fao.org/faostat/en/#data/QCL

D'Urso, G., Maldini, M., Pintore, G., D'Aquino, L., Montoro, P., & Pizza, C. (2016). Characterisation of fragaria vesca fruit from Italy following a metabolomics approach through integrated mass spectrometry techniques. *LWT*, *74*, 387-395. https://doi.org/10.1016/j.lwt.2016.07.061

Sammarco, G., Gallo, G., Vescio, G., Picciariello, A., De Paola, G., Trompetto, M., Currò, G., & Ammendola, M. (2020). Mast cells, microRNAs and others: The role of translational research on colorectal cancer in the forthcoming era of precision medicine. *Journal of Clinical Medicine*, *9*(9), 2852. https://doi.org/10.3390/jcm9092852

Miller, M. G., Thangthaeng, N., Rutledge, G. A., Scott, T. M., & Shukitt-Hale, B. (2021). Dietary strawberry improves cognition in a randomised, double-blind, placebo-controlled trial in older adults. *British Journal of Nutrition*, *126*(2), 253-263. https://doi.org/10.1017/s0007114521000222

Gao, Q., Dong, J., Cui, R., Muraki, I., Yamagishi, K., Sawada, N., Iso, H., & Tsugane, S. (2021). Consumption of flavonoid-rich fruits, flavonoids from fruits and stroke risk: A prospective cohort study. *British Journal of Nutrition*, *126*(11), 1717-1724. https://doi.org/10.1017/s0007114521000404

Giampieri, F., Alvarez-Suarez, J., Mazzoni, L., Forbes-Hernandez, T., Gasparrini, M., Gonzàlez-Paramàs, A., Santos-Buelga, C., Quiles, J., Bompadre, S., Mezzetti, B., & Battino, M. (2014). Polyphenol-rich strawberry extract protects human dermal fibroblasts against hydrogen peroxide oxidative damage and improves mitochondrial functionality. *Molecules*, *19*(6), 7798-7816. https://doi.org/10.3390/molecules19067798

Wang, H., Oo Khor, T., Shu, L., Su, Z., Fuentes, F., Lee, J., & Tony Kong, A. (2012). Plants vs. cancer: A review on natural phytochemicals in preventing and treating cancers and their Druggability. *Anti-Cancer Agents in Medicinal Chemistry*, *12*(10), 1281-1305. https://doi.org/10.2174/187152012803833026

Han, X., Shen, T., & Lou, H. (2007). Dietary polyphenols and their biological significance. *International Journal of Molecular Sciences*, *8*(9), 950-988. https://doi.org/10.3390/i8090950

Heo, H. J., & Lee, C. Y. (2005). Strawberry and its anthocyanins reduce oxidative stress-induced Apoptosis in PC12 cells. *Journal of Agricultural and Food Chemistry*, *53*(6), 1984-1989. https://doi.org/10.1021/jf048616l

Hollands, W., Brett, G. M., Dainty, J. R., Teucher, B., & Kroon, P. A. (2008). Urinary excretion of strawberry anthocyanins is dose dependent for physiological oral doses of fresh fruit. *Molecular Nutrition & Food Research*, *52*(10), 1097-1105. https://doi.org/10.1002/mnfr.200700372

Holt, R. R., Barile, D., Wang, S. C., Munafo, J. P., Arvik, T., Li, X., Lee, F., Keen, C. L., Tagkopoulos, I., & Schmitz, H. H. (2022). Chardonnay Marc as a new model for Upcycled Co-products in the food industry: Concentration of diverse natural products chemistry for consumer health and sensory benefits. *Journal of Agricultural and Food Chemistry*, *70*(48), 15007-15027. https://doi.org/10.1021/acs.jafc.2c04519

Huang, L., Xiao, D., Zhang, X., Sandhu, A. K., Chandra, P., Kay, C., Edirisinghe, I., & Burton-Freeman, B. (2021). Strawberry consumption, Cardiometabolic risk factors, and vascular function: A randomized controlled trial in adults with moderate Hypercholesterolemia. *The Journal of Nutrition*, *151*(6), 1517-1526. https://doi.org/10.1093/jn/nxab034

Ivey, K. L., Jensen, M. K., Hodgson, J. M., Eliassen, A. H., Cassidy, A., & Rimm, E. B. (2017). Association of flavonoid-rich foods

and flavonoids with risk of all-cause mortality. *British Journal of Nutrition*, *117*(10), 1470-1477. https://doi.org/10.1017/s0007114517001325

MILIVOJEVIĆ, J., MAKSIMOVIĆ, V., NIKOLIĆ, M., BOGDANOVIĆ, J., MALETIĆ, R., & MILATOVIĆ, D. (2011). Chemical and Antioxidant Properties of Cultivated and Wild Fragaria and Rubus Berries. *Journal of Food Quality*, *34*(1), 1-9. https://doi.org/10.1111/j.1745-4557.2010.00360.x

Vanamala, J., Tarver, C., & Murano, P. (2008). Obesity-enhanced colon cancer: Functional food compounds and their mechanisms of action. *Current Cancer Drug Targets*, *8*(7), 611-633. https://doi.org/10.2174/156800908786241087

Jacob, R. A., Spinozzi, G. M., Simon, V. A., Kelley, D. S., Prior, R. L., Hess-Pierce, B., & Kader, A. A. (2003). Consumption of cherries lowers plasma urate in healthy women. *The Journal of Nutrition*, *133*(6), 1826-1829. https://doi.org/10.1093/jn/133.6.1826

Karlińska, E., Masny, A., Cieślak, M., Macierzyński, J., Pecio, Ł., Stochmal, A., & Kosmala, M. (2021). Ellagitannins in roots, leaves, and fruits of strawberry (Fragaria × ananassa Duch.) vary with developmental stage and cultivar. *Scientia Horticulturae*, *275*, 109665. https://doi.org/10.1016/j.scienta.2020.109665

Kellner, C., & Zunino, S. J. (2004). Nitric oxide is synthesized in acute leukemia cells after exposure to phenolic antioxidants and initially protects against mitochondrial membrane depolarization. *Cancer Letters*, *215*(1), 43-52. https://doi.org/10.1016/j.canlet.2004.06.046

Khanizadeh, S., Tsao, R., Rekika, D., Yang, R., Charles, M. T., & Vasantha Rupasinghe, H. (2008). Polyphenol composition and total antioxidant capacity of selected Apple genotypes for processing. *Journal of Food Composition and Analysis*, *21*(5), 396-401. https://doi.org/10.1016/j.jfca.2008.03.004

Krga, I., & Milenkovic, D. (2019). Anthocyanins: From sources and bioavailability to cardiovascular-health benefits and molecular mechanisms of action. *Journal of Agricultural and Food Chemistry*, *67*(7), 1771-1783. https://doi.org/10.1021/acs.jafc.8b06737

Krikorian, R., Shidler, M., & Summer, S. (2023). Early intervention in cognitive aging with strawberry supplementation. *Nutrients*, *15*(20), 4431. https://doi.org/10.3390/nu15204431

Kwon, C., Ediriweera, M. K., & Kim Cho, S. (2023). Interplay between phytochemicals and the colonic microbiota. *Nutrients*, *15*(8), 1989. https://doi.org/10.3390/nu15081989

Lee, S., Choi, Y., Sung, J., Kim, Y., Jeong, H., & Lee, J. (2014). Protective effects of Black rice extracts on oxidative stress induced by tert-butyl Hydroperoxide in HepG2 cells. *Preventive Nutrition and Food Science*, *19*(4), 348-352. https://doi.org/10.3746/pnf.2014.19.4.348

Li, D., Wang, P., Luo, Y., Zhao, M., & Chen, F. (2015). Health benefits of anthocyanins and molecular mechanisms: Update from recent decade. *Critical Reviews in Food Science and Nutrition*, *57*(8), 1729-1741. https://doi.org/10.1080/10408398.2015.1030064

Määttä-Riihinen, K. R., Kamal-Eldin, A., & Törrönen, A. R. (2004). Identification and quantification of phenolic compounds in berries of*Fragaria*andRubusSpecies (Family rosaceae). *Journal of Agricultural and Food Chemistry*, *52*(20), 6178-6187. https://doi.org/10.1021/jf049450r

Mazur, W. M., Uehara, M., Wähälä, K., & Adlercreutz, H. (2000). Phyto-oestrogen content of berries, and plasma concentrationsand urinary excretion of enterolactone after asingle strawberry-meal in human subjects. *British journal of nutrition*, *83*(4), 381-387. https://doi.org/10.1017/S0007114500000489

Miller, J. C., Satheesh Babu, A. K., Petersen, C., Wankhade, U. D., Robeson, M. S., Putich, M. N., Mueller, J. E., O'Farrell, A. S., Cho, J. M., Chintapalli, S. V., Jalili, T., Symons, J. D., & Anandh Babu, P. V. (2022). Back cover: Gut microbes are associated with the vascular beneficial effects of dietary strawberry on metabolic syndrome-induced vascular inflammation. *Molecular Nutrition & Food Research*, *66*(22). https://doi.org/10.1002/mnfr.202270062

Nickel, T., Schmauss, D., Hanssen, H., Sicic, Z., Krebs, B., Jankl, S., Summo, C., Fraunberger, P., Walli, A. K., Pfeiler, S., & Weis, M. (2009). OxLDL uptake by dendritic cells induces upregulation of scavenger-receptors, maturation and differentiation. *Atherosclerosis*, *205*(2), 442-450. https://doi.org/10.1016/j.atherosclerosis.2009.01.002

Nowicka, A., Kucharska, A. Z., Sokół-Łętowska, A., & Fecka, I. (2019). Comparison of polyphenol content and antioxidant capacity of strawberry fruit from 90 cultivars of Fragaria × ananassa Duch. *Food Chemistry*, *270*, 32-46. https://doi.org/10.1016/j.foodchem.2018.07.015

Oyewole, A. O., Wilmot, M., Fowler, M., & Birch-Machin, M. A. (2013). Comparing the effects of mitochondrial targeted and localized antioxidants with cellular antioxidants in human skin cells exposed to UVA and hydrogen peroxide. *The FASEB Journal*, *28*(1), 485-494. https://doi.org/10.1096/fj.13-237008

Palacios, C., Joshipura, K., & Willett, W. (2009). Nutrition and health: Guidelines for dental practitioners. *Oral Diseases*, *15*(6), 369-381. https://doi.org/10.1111/j.1601-0825.2009.01571.x

Rahman, M., Rahman, M., & Islam, T. (2019). Improving yield and antioxidant properties of strawberries by utilizing microbes and natural products. *Strawberry - Pre- and Post-Harvest Management Techniques for Higher Fruit Quality*. https://doi.org/10.5772/intechopen.84803

Raman, G., Avendano, E. E., Chen, S., Wang, J., Matson, J., Gayer, B., Novotny, J. A., & Cassidy, A. (2019). Dietary intakes of flavan-3-ols and cardiometabolic health: Systematic review and meta-analysis of randomized trials and prospective cohort studies. *The American Journal of Clinical Nutrition*, *110*(5), 1067-1078. https://doi.org/10.1093/ajcn/nqz178

Rodriguez-Mateos, A., Istas, G., Boschek, L., Feliciano, R. P., Mills, C. E., Boby, C., ... & Heiss, C. (2019). Circulating anthocyanin metabolites mediate vascular benefits of blueberries: insights from randomized controlled trials, metabolomics, and nutrigenomics. *The Journals of Gerontology: Series A*, *74*(7), 967-976. https://doi.org/10.1093/gerona/glz047

Rothwell, J. A., Perez-Jimenez, J., Neveu, V., Medina-Remon, A., M'hiri, N., García-Lobato, P., ... & Scalbert, A. (2013). Phenol-Explorer 3.0: a major update of the Phenol-Explorer database to incorporate data on the effects of food processing on polyphenol content. *Database*, *2013*. https://doi.org/10.1093/database/bat070

Rudkowska, I., AbuMweis, S. S., Nicolle, C., & Jones, P. J. (2008). Cholesterol-lowering efficacy of plant sterols in low-fat yogurt consumed as a snack or with a meal. *Journal of the American College of Nutrition*, *27*(5), 588-595. https://doi.org/10.1080/07315724.2008.10719742

Satheesh Babu, A. K., Srinivasan, H., & Anandh Babu, P. V. (2023). Breaking bugs: Gut microbes metabolize dietary components and modulate vascular health. *Critical Reviews in Food Science and Nutrition*, *64*(33), 12411-12419. https://doi.org/10.1080/10408398.2023.2251616

Seeram, N. P. (2008). Berry fruits for cancer prevention: Current status and future prospects. *Journal of Agricultural and Food Chemistry*, *56*(3), 630-635. https://doi.org/10.1021/jf072504n

Seeram, N. P., Lee, R., Scheuller, H. S., & Heber, D. (2006). Identification of phenolic compounds in strawberries by liquid chromatography electrospray ionization mass spectroscopy. *Food Chemistry*, *97*(1), 1-11. https://doi.org/10.1016/j.foodchem.2005.02.047

Seeram, N. P., Adams, L. S., Zhang, Y., Lee, R., Sand, D., Scheuller, H. S., & Heber, D. (2006). BlackBerry, Black raspberry, blueberry, cranberry, red raspberry, and strawberry extracts inhibit growth and stimulate Apoptosis of human cancer cells in vitro. *Journal of Agricultural and Food Chemistry*, *54*(25), 9329-9339. https://doi.org/10.1021/jf061750g

Seeram, N. P., Lee, R., Scheuller, H. S., & Heber, D. (2006). Identification of phenolic compounds in strawberries by liquid chromatography electrospray ionization mass spectroscopy. *Food Chemistry*, *97*(1), 1-11. https://doi.org/10.1016/j.foodchem.2005.02.047

Seki, H., Ma, T., Murakami, H., Tsuchikawa, S., & Inagaki, T. (2023). Visualization of sugar content distribution of white strawberry by near-infrared hyperspectral imaging. Foods, 12(5), 931. https://doi.org/10.3390/foods12050931

Shukitt-Hale, B., Carey, A. N., Jenkins, D., Rabin, B. M., & Joseph, J. A. (2007). Beneficial effects of fruit extracts on neuronal function and behavior in a rodent model of accelerated aging. *Neurobiology of Aging*, *28*(8), 1187-1194. https://doi.org/10.1016/j.neurobiolaging.2006.05.031

Shukitt-Hale, B., Lau, F. C., & Joseph, J. A. (2008). Berry fruit supplementation and the aging brain. *Journal of Agricultural and Food Chemistry*, *56*(3), 636-641. https://doi.org/10.1021/jf072505f

Šic Žlabur, J., Bogdanović, S., Voća, S., & Skendrović Babojelić, M. (2020). Biological potential of fruit and leaves of strawberry tree (Arbutus unedo L.) from Croatia. Molecules, 25(21), 5102. https://doi.org/10.3390/molecules25215102

Stapleton, P. A., James, M. E., Goodwill, A. G., & Frisbee, J. C. (2008). Obesity and vascular dysfunction. *Pathophysiology*, *15*(2), 79-89. https://doi.org/10.1016/j.pathophys.2008.04.007

Stoner, G. D. (2009). Foodstuffs for preventing cancer: The preclinical and clinical development of berries. *Cancer Prevention Research*, *2*(3), 187-194. https://doi.org/10.1158/1940-6207.capr-08-0226

Tang, W. W., Bäckhed, F., Landmesser, U., & Hazen, S. L. (2019). Intestinal microbiota in cardiovascular health and disease. *Journal of the American College of Cardiology*, *73*(16), 2089-2105. https://doi.org/10.1016/j.jacc.2019.03.024

Törrönen, R., & Määttä, K. (2002). Bioactive substances and health benefits of strawberries. *Acta Horticulturae*, (567), 797-803. https://doi.org/10.17660/actahortic.2002.567.176

Tsuda, T. (2008). Regulation of Adipocyte function by anthocyanins; Possibility of preventing the metabolic syndrome. *Journal of Agricultural and Food Chemistry*, *56*(3), 642-646. https://doi.org/10.1021/jf073113b

Ubago-Guisado, E., Rodríguez-Barranco, M., Ching-López, A., Petrova, D., Molina-Montes, E., Amiano, P., Barricarte-Gurrea, A., Chirlaque, M., Agudo, A., & Sánchez, M. (2021). Evidence update on the relationship between diet and the most common cancers from the European prospective investigation into cancer and nutrition (EPIC) study: A systematic review. *Nutrients*, *13*(10), 3582. https://doi.org/10.3390/nu13103582

USDA. 2016. USDA national nutrient database for standard reference, Release 28. https://www.ars.usda.gov/Services/docs.htm?docid=8964

Vattem, D. A., Lin, Y., & Shetty, K. (2005). Enrichment of phenolic antioxidants and anti-*helicobacter pylori*Properties of cranberry pomace by solid-state Bioprocessing. *Food Biotechnology*, *19*(1), 51-68. https://doi.org/10.1081/fbt-200049065

Wang, L., & Stoner, G. D. (2008). Anthocyanins and their role in cancer prevention. *Cancer Letters*, *269*(2), 281-290. https://doi.org/10.1016/j.canlet.2008.05.020

Wang, S. Y., & Lin, H. (2000). Antioxidant activity in fruits and leaves of BlackBerry, raspberry, and strawberry varies with cultivar and developmental stage. *Journal of Agricultural and Food Chemistry*, *48*(2), 140-146. https://doi.org/10.1021/jf9908345

Warner, R., Wu, B.-S., MacPherson, S., & Lefsrud, M. (2021). A review of strawberry photobiology and fruit flavonoids in controlled environments. Frontiers in Plant Science, 12, 611893. https://doi.org/10.3389/fpls.2021.611893

Prior, R. L., Wu, X., & Cao, G. (2002). Absorption and metabolism of anthocyanins in elderly women after consumption of elderberry or blueberry. *The Journal of Nutrition*, *132*(7), 1865-1871. https://doi.org/10.1093/jn/132.7.1865

Yang, Y., Dong, J.-Y., Cui, R., Muraki, I., Yamagishi, K., Sawada, N., Iso, H., Tsugane, S., & Group, for the J. P. H. C. P. S. (2020). Consumption of flavonoid-rich fruits and risk of CHD: a prospective cohort study. *British Journal of Nutrition*, *124*(9), 1–8. https://doi.org/10.1017/S0007114520001993

Zhang, H., Cha, S., & Yeung, E. S. (2007). Colloidal graphite-assisted laser desorption/ionization ms and ms(n) of small molecules. 2. Direct profiling and ms imaging of small metabolites from fruits. *Analytical Chemistry*, *79*(17), 6575-6584. https://doi.org/10.1021/ac0706170

Zhang, Y., Seeram, N. P., Lee, R., Feng, L., & Heber, D. (2008). Isolation and identification of strawberry phenolics with antioxidant and human cancer cell Antiproliferative properties. *Journal of Agricultural and Food Chemistry*, *56*(3), 670-675. https://doi.org/10.1021/jf071989c

Zhang, Y., Seeram, N. P., Lee, R., Feng, L., & Heber, D. (2008). Isolation and identification of strawberry phenolics with antioxidant and human cancer cell Antiproliferative properties. *Journal of Agricultural and Food Chemistry*, *56*(3), 670-675. https://doi.org/10.1021/jf071989c

Zuelch, M. L., Radtke, M. D., Holt, R. R., Basu, A., Burton-Freeman, B., Ferruzzi, M. G., Li, Z., Shay, N. F., Shukitt-Hale, B., Keen, C. L., et al. (2023). Perspective: Challenges and future directions in clinical research with nuts and berries. Advances in Nutrition, 14(5), 1005–1028. https://doi.org/10.1016/j.advnut.2023.07.010