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From Plant to Science Unveiling Catechins as an Antioxidants Treasure: Bibliometric analysis

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Abstract

Catechins a group of natural phenolic compounds belonging to the flavonoids or the hydrogenated flavones or anthocyanidins families. They occur together with other phenols in many types of plants such as green tea, grapes, and cocoa. They are involved in the brown coloration of bruised and cut surfaces (e.g., apples) catalyzed by phenol oxidases. They play an important role in plant defense mechanisms and exhibit numerous biological activities beneficial to human health, including antioxidant, anti-inflammatory, and antimicrobial properties. This study provides a comprehensive overview of catechin, focusing on its botanical sources, chemical structure, physicochemical properties, and biological effects. Particular attention is given to its biosynthesis through the type III polyketide synthase (PKS III) pathway. In addition, various extraction techniques are discussed, with emphasis on the QuEChERS method for its efficiency, simplicity, and reduced solvent consumption. Owing to its diverse biological activities, catechin has promising applications in various fields, including food, pharmaceutical, and cosmetic industries. This work highlights the importance of catechin as a bioactive compound and its potential for future applications. Given the highest number of Scopus publications on catechin, a bibliometric analysis was conducted using Scopus and VOSviewer.

Keywords: *Catechins, Flavonoids, Antioxidant activity, Biosynthesis, QuEChERS, HPLC analysis; Bibliometric analysis*

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1. Introduction

Catechins are natural phenolic compounds belonging to the flavonoid's family (Makowski *et al.*, 2024), a large group of plant secondary metabolites widely distributed in fruits, vegetables, and beverages derived from plants (Scota *et al.,* 2025; Savina *et al.*, 2023; Alamgir 2018). Among flavonoids, catechin is one of the most abundant and biologically active compounds, particularly present in green tea (Camellia sinensis) (Ding *et al.,* 2026), grapes (Acharya *et al.*, 2026), cocoa

(Huanca-Ccompe *et al.*, 2026), and various medicinal plants (Xu *et al.*, 2026). Due to its chemical structure rich in hydroxyl groups, catechin exhibits strong antioxidant activity (Liu, 2004), enabling it to neutralize free radicals and reduce oxidative stress in biological systems. In plants, catechin plays an important role in defense mechanisms against environmental stress (Martin, 2006), pathogens (Pandey & Rizvi, 2009), and ultraviolet radiation (Wang, Chen, Yu, 2011). It is synthesized through the flavonoid biosynthetic pathway, which involves several enzymatic steps starting from phenylalanine and leading to the formation of flavan-3-ols such as catechin and epicatechin. A key enzyme involved in this pathway is the type III polyketide synthase (PKS III), which catalyzes the formation of chalcone intermediates that serve as precursors for various flavonoids. In addition to its role in plants, catechin has attracted considerable scientific interest due to its numerous biological and pharmacological properties (Alam *et al.,* 2022). Several studies have demonstrated that catechin exhibits antioxidant, anti-inflammatory, antimicrobial, anticancer, and cardioprotective activities (Van Acker *et al.*, 1996). These properties contribute to its beneficial effects on human health, including the prevention of chronic diseases such as cardiovascular disorders, diabetes, and certain types of cancer. Because of these beneficial properties, catechin has become an important compound in several scientific and industrial fields. It is widely used in food science as a natural antioxidant, in pharmaceuticals for its therapeutic potential, and in cosmetics for its protective effects on the skin. Consequently, the extraction, purification, and analysis of catechin from natural sources have become important research topics (Tsao, 2010). Various extraction techniques have been developed to isolate catechin from plant matrices, including conventional solvent extraction and modern approaches such as the QuEChERS method, which offers advantages in terms of simplicity, efficiency, and reduced solvent consumption. The present work aims to provide a comprehensive overview of catechin, including its plant sources, chemical structure, physicochemical properties, and biological activities. Particular attention is given to its biosynthesis through the PKS III pathway as well as to modern extraction and analytical techniques (Alara *et al.*, 2021). Understanding these aspects is essential to highlight the importance of catechin as a bioactive compound with significant applications in medicine, food science, chemistry, and environmental research. **Figure 1a**, shows the evolution of publications about catechins from 1841 to 2025, by a total of 38 236 articles to be reduced to 37,000 articles from 1980 to 2025 (**Figure 1b**). The number of articles reaches more than 2760 in 2025. In **Figure 2**, among the top countries working on the catechin topic, China is the leader. The US, Japan, India … are also in the wide profilers, testimony the importance of catechins in various domains as indicated in **Figure 3**. Agriculture, biochemistry, and chemistry (>41%) to cultivate, extract, and characterize the compounds for different applications in Medicine, pharmacology, and nursing domains.

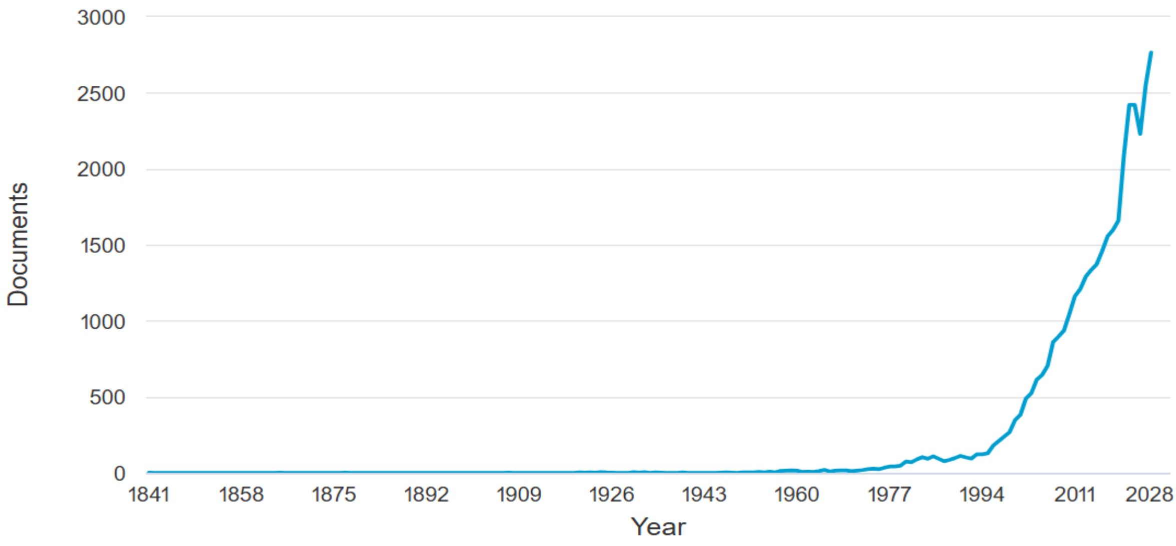


Figure 1a: Evolution on catechins articles from Scopus-Elsevier (1841-2025)

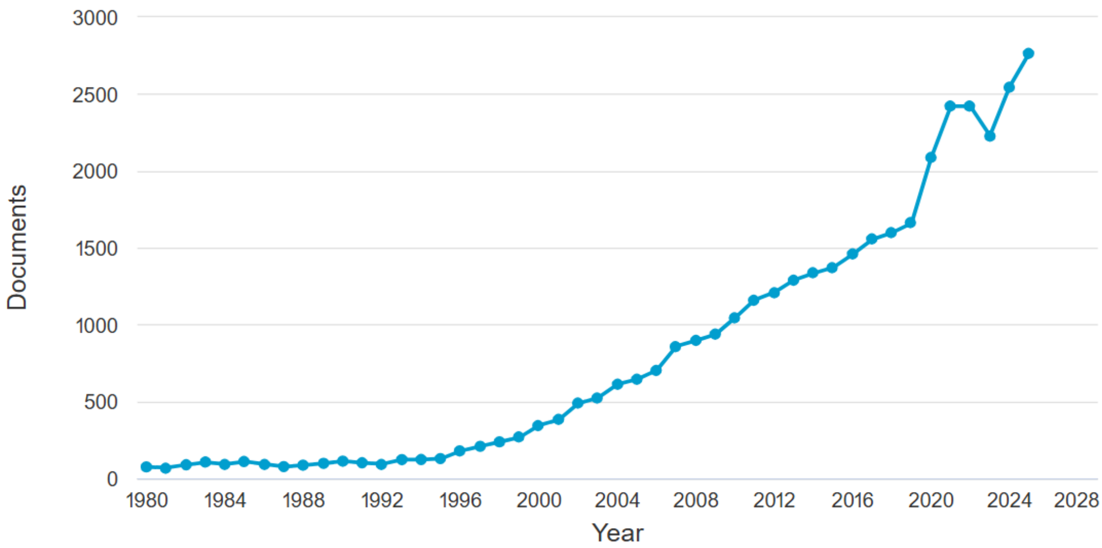


Figure 1b: Evolution on catechins articles from Scopus-Elsevier (1980-2025)

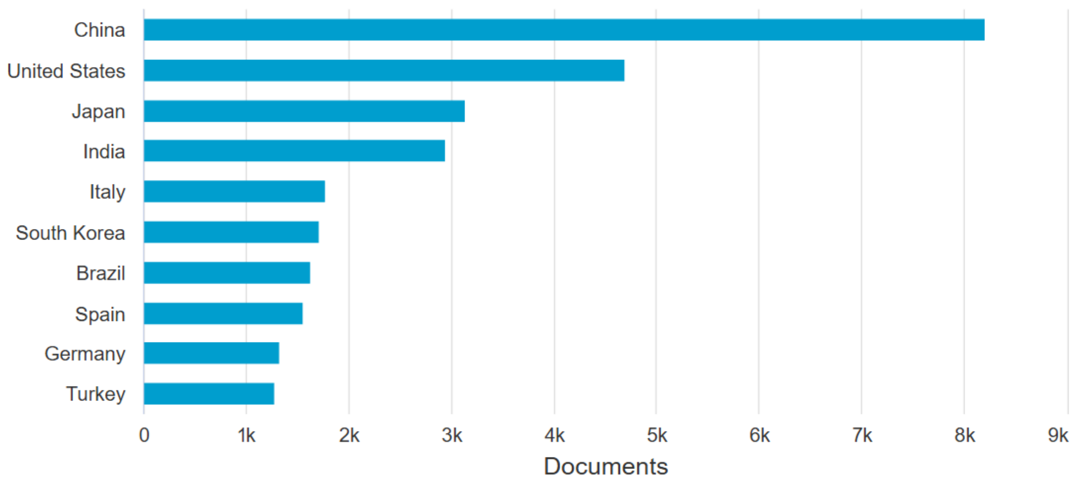


Figure 2: Top countries working on catechins from Scopus-Elsevier (1841-2026)

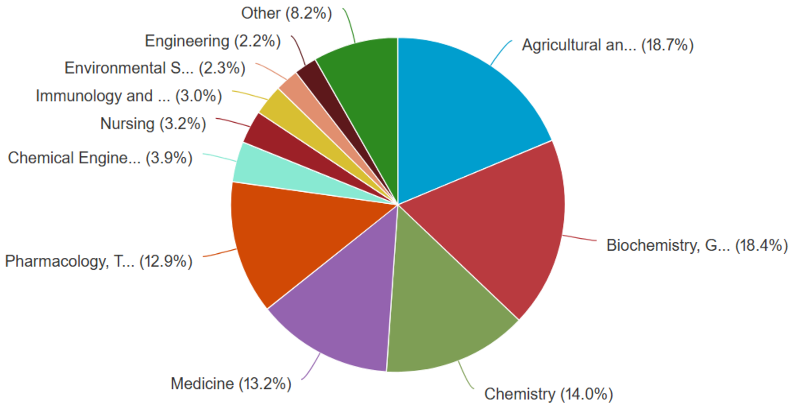


Figure 3: Fields of application from Scopus- Elsevier

VOSviewer was used to visualize the network of collaboration among countries/regions, institutions, authors, and journals, as well as the co-occurrence of keywords and the co-citation of authors. On the map, the various nodes correspond to countries/regions, authors, journals, and author keywords (Bazzi *et al.*, 2023; Hammouti *et al.*, 2025; Merzouki *et al.*, 2025). The size of the nodes indicates the number of publications, frequency of occurrence, or number of citations; the colors reflect different groups or periods; the thickness of the lines indicates the strength of the link (Kachbou *et al.*, 2021; Salghi *et al.*, 2025; Nandiyanto *et al.*, 2026). Network visualization presenting 87 countries by colored nodes show that the largest orange node of China (8200 articles), the mustard nodes of the US (4672 articles) and Japan (3125 articles), the blue one of India (2926 articles) (**Figure 4**).

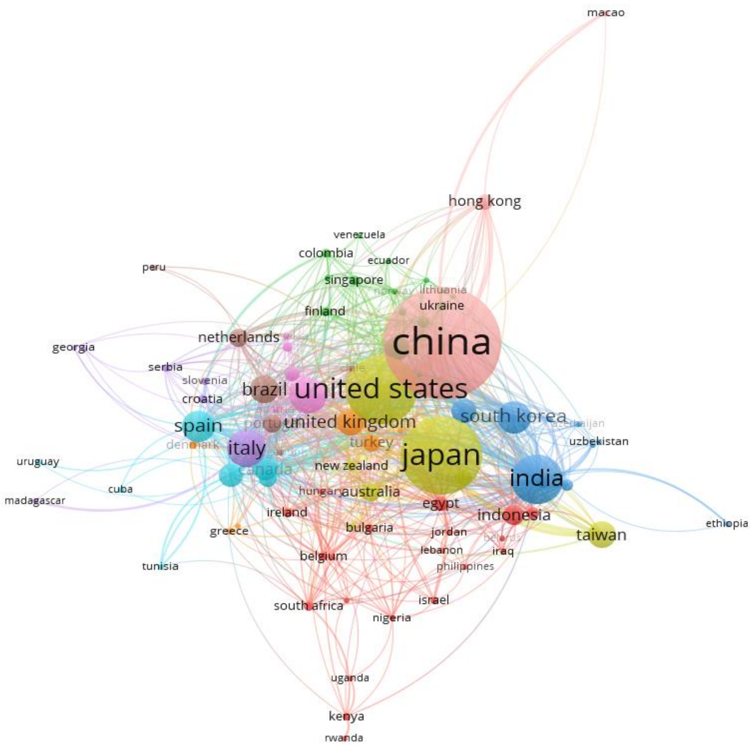


Figure 4: Network visualization of VOSviewer

In an overlay visualization (**Figure 5**), the color of a node indicates a specific property of that node related to its publication time (Laita *et al.*, 2024; Snoussi *et al.*, 2026). Nodes represented by light yellow colors are recently published. The dark colors represent the US, India, UK and Japan, while China with the light-yellow color is currently of interest.

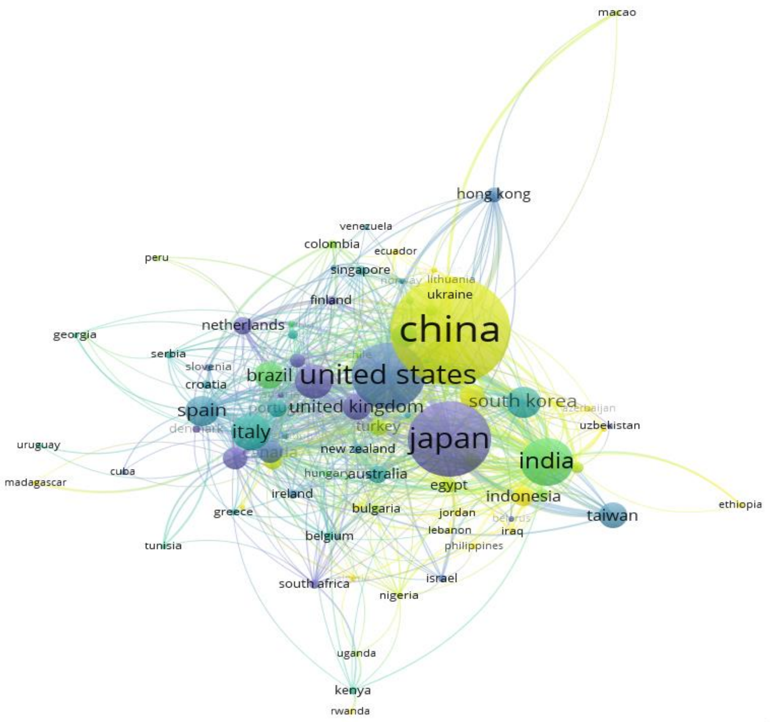


Figure 5: Overlay visualization of VOSviewer

Figure 6 shows the most productive authors in the field of catechins, ranked by number of publications. Hara, Y. ranks first with the highest number of documents (approximately 91 publications), followed by Liu, Z. and Yang, C.S. a who also have a significant scientific output (64 and 62 articles, respectively).

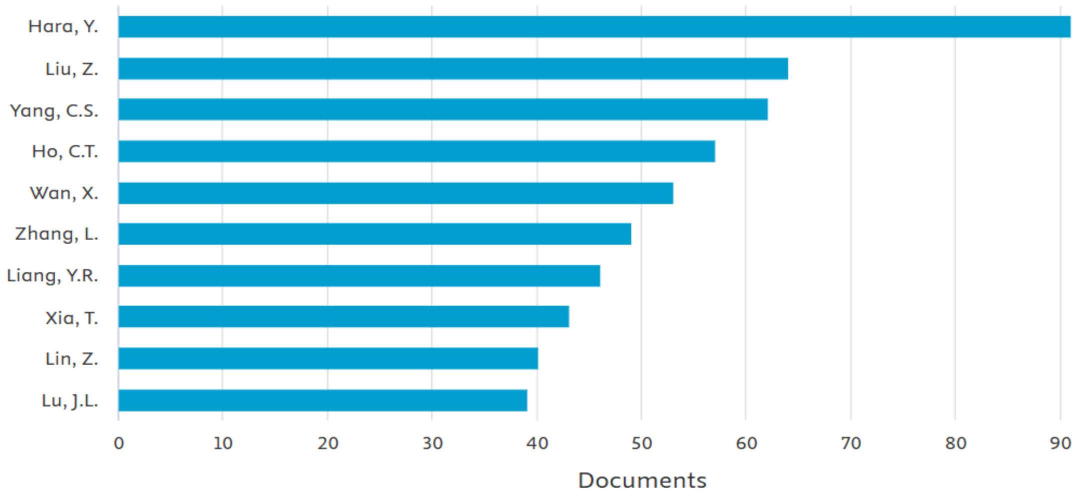


Figure 6: Top authors working on catechins from Scopus Elsevier.

2. The origin of catechins

Catechins are polyphenols found in certain foods, including green tea and chocolate (Rao, 2025; Raby, *et al.,* 2025). They therefore have phenolic nuclei. More specifically, catechins belong to the flavonoid family, we can say that they are flavanols (Malhotra, *et al.*, 2026; Martinelli, *et al.*, 2026; Cook and Samman, 1996). The catechin molecules also contribute to the bitterness and astringency of the foods in which they are found (tea, cocoa, coffee, wine, etc.) (Drewnowski, 2001). When an apple is cut, it tends to change color: this browning is linked to the oxidation of the catechins in the apple. Catechins in tea and chocolate 200 ml of green tea contains approximately 100 mg of catechins. In black tea, catechins are oxidized during fermentation. The main catechin in green tea is epigallocatechin gallate (EGCG), which is believed to be responsible for the health benefits of green tea. For example, EGCG is thought to be involved in the cardioprotective effect of green tea; it also helps reduce the risk of type 2 diabetes. Given its health benefits, EGCG is also marketed in the form of dietary supplements (Bonetti, *et al.* 2026; Koonyosying, *et al.,* 2025). In 2018, the EFSA issued an opinion on the harmful effects of catechins on the liver. The health authority considers that the consumption of catechins in green tea is safe, but that more than 800 mg/day of EGCG in the form of dietary supplements should be avoided. Chocolate and cocoa contain catechins, particularly epicatechin. Catechins account for around 10% of the polyphenols in chocolate. They are easily absorbed by the intestine. Epicatechin is one of the active ingredients in dark chocolate. It promotes endothelial function, insulin sensitivity and blood platelet response, and reduces blood pressure (Al Awawdeh *et al.,* 2026; Rego, *et al.,* 2026, Bitari, *et al.*, 2023 and 2024).

3. History of Catechin

Michiyo Tsujimura (her photo below), she was born in 1888 in what is now the Japanese city of Okinawa, in Saitama Prefecture. She studied at the Tokyo Women's Normal School and graduated in **1909.** She later joined the biochemical sciences department of the Tokyo Women's Secondary School. It was there that she discovered her interest in scientific research, a field that had previously been dominated by men. She met other pioneering women, including Kono Yasui, a renowned cell biologist and biochemist who became the first Japanese woman to earn a doctorate in science and who deeply inspired Tsujimura. After graduating in **1917**, Tsujimura took science courses at pioneering women's institutes. But her enormous interest in learning led her to take a further step by joining Hokkaido Imperial University, where female students were not accepted. She was able to enter the university as an assistant in the Food and Nutrition Laboratory of the Department of Agricultural Chemistry, a job for which she received no pay. There, she devoted herself to the study of silkworms and their nutrition. And so, little by little, she began to gain recognition. Vitamin C but it was not until a few years later, in **1923**, that she found her true passion in worms when she joined Riken, Japan's huge and renowned natural science research institute. She joined the laboratory studying chemistry and nutrition in agriculture and worked closely with Umetaro Suzuki, a scientist famous for discovering and successfully extracting vitamin B1 from rice bran. Tsujimura was particularly interested in green tea, a popular drink in Japan, China, and other Asian countries at the time (and still today), but one that had been incredibly understudied.

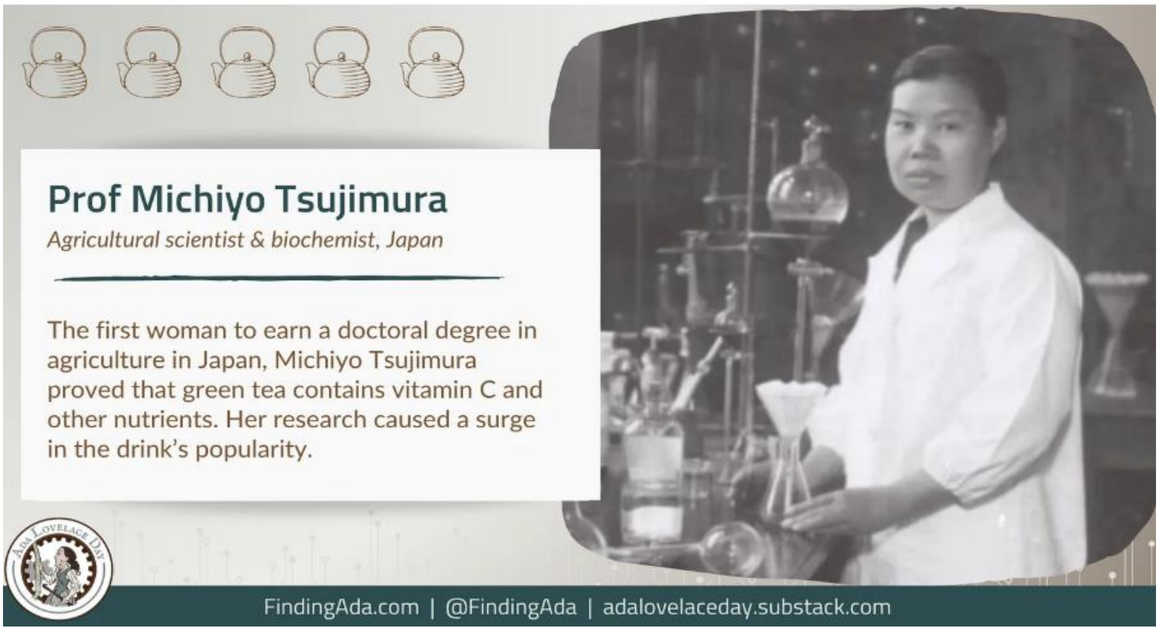


Photo of Michiyo Tsujimura : 1888-1969 (BBC, 2021)

In **1924**, thanks to a joint investigation with his colleague Seitaro Miura, Tsujimura discovered the high vitamin C content in the leaves used to prepare the infusion. According to Ochanimuzu University in Japan, this discovery led to a surge of interest in green tea on the other side of the world, in the West, particularly in the United States. And with it came an increase in exports of this beverage from Japan to North America. But his research did not stop there. In **1929**, the Japanese scientist succeeded in isolating and extracting a flavonoid called catechin, a powerful natural antioxidant that, among other things, helps prevent cell damage and is responsible for the bitter taste of tea. The following year, Tsujimura succeeded in extracting catechin in crystal form. She did the same with tannin, another antioxidant component of green tea. According to Ochanomizu University, this research required "a lot of patience" because it was necessary to boil a large amount of green tea several times to obtain a small amount of crystals. But the scientist knew that patience was a key principle in her work. "Chemistry is not for those who want to see results in a short period of time,"she once said. She then published her thesis on both discoveries (vitamin C and catechin), entitled "On the Chemical Components of Green Tea," which made her the first woman to obtain a doctorate in agriculture in her country in **1932**. However, her interest in green tea continued, and in **1934** she succeeded in isolating gallocatechin, another flavonoid compound beneficial to health. In **1935**, she patented her method of extracting vitamin C crystals from plants. Today, this process is used on a large scale around the world and is available in pharmaceutical form through oral dietary supplements. Ten years later, Tsujimura was appointed professor at Ochanimuzu University, where she became the first woman to hold the position of dean of the school of home economics. After retiring from Ochanomizu University in **1955**, she taught at Jissen Women's University until the mid-**1960**s. A year before her death in 1968, the scientist looked back on her career as a researcher and told her students: "My research work was full of difficulties, but it was very enjoyable." "Finding no regrets in my life was my greatest happiness," she added. Until her last days, Tsujimura enjoyed long walks with her dog. She finally passed away in Toyohashi on June 1, **1969** at the age of 81 (Cioanca *et al.*, 2024).

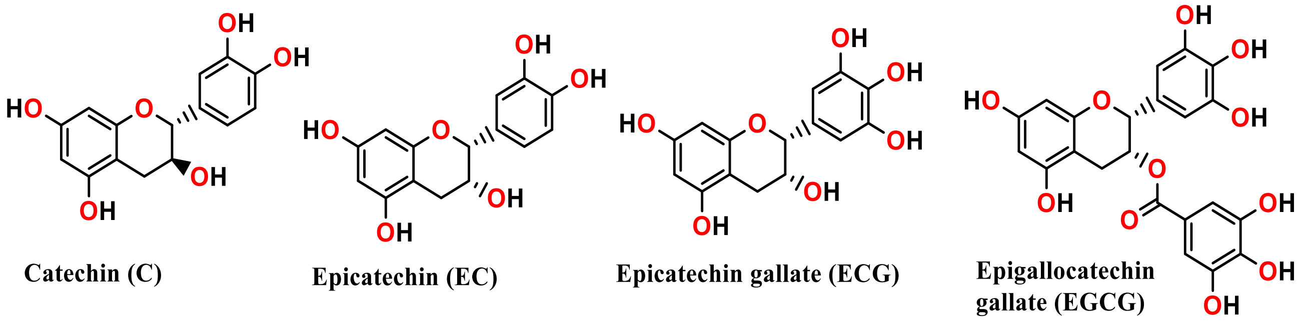
4. Natural sources of catechins

4.1. Plants rich in catechins: Catechins are mainly found in several plant species, including: Green tea (*Camellia sinensis):* This is one of the most concentrated sources, with a high content of pigallocatechin gallate (EGCG), a powerful antioxidant. Fresh leaves contain catechins in proportions that vary depending on the variety and cultivation methods (Zaveri, 2006; Bettuzzi *et al.*, 2006; Song, *et al.*, 2005). Cocoa (*Theobroma cacao*): Unroasted cocoa beans contain mainly (−)-epicatechin and procyanidins. These compounds are responsible for many of the beneficial properties associated with dark chocolate (Della Pelle *et al.*, 2020; Gras *et al.*, 2021; Maldonado & Figueroa, 2023). Nuts, Apples, grapes, and blueberries are other examples of important sources of catechins and their derivatives (Crozier *et al.*, 2009).

4.2. Variability depending on environmental conditions: Catechin concentrations in plants can vary depending on several factors: Climate and soil, which increase exposure to light and nutrient-rich soil, promote greater accumulation of catechins (Carloni *et al.*, 2013; Li *et al.*, 2022). Agricultural practices, organic farming methods tend to maintain higher levels of polyphenols, in catechins (Yao *et al.*, 2005).

5. Chemical Structure

Catechin is a flavanol, a subclass of flavonoids characterized by a complex chemical structure composed of a chromane ring with several hydroxyl groups attached. Its chemical formula is $C_{15}H_{14}O_6$, and it is distinguished by its ability to trap free radicals, contributing to its powerful antioxidant properties. The presence of two asymmetric carbons (positions 2 and 3 of the central heterocycle) gives catechin several stereoisomeric configurations (**Scheme 1**).



Scheme 1: structure of catechin and its four main forms

In addition to their basic forms, catechins form derivatives such as gallates and procyanidins: The galloylation of catechins, as in epigallocatechin gallate (EGCG) (Debnath *et al.*, 2021), enhances their antioxidant activity. Procyanidins: These catechin polymers, such as procyanidins B1 and B2, are often found in red wine and berries (**Scheme 1**).

6. Synthesis method

Bellow (**Figure 7**) we show catechin biosynthsis pathway: The biosynthesis of catechin begins with a starting unit of 4-hydroxycinnamoyl-CoA, which undergoes chain extension through the addition of three malonyl-CoA molecules via a PKSIII pathway. 4-hydroxycinnamoyl-CoA is biosynthesized from L-phenylalanine via the shikimate pathway. L-phenylalanine is first delaminated by phenylalanine ammonia lyase (PAL), forming cinnamic acid, which is then oxidized to 4-hydroxycinnamic acid by cinnamate 4-hydroxylase. Chalcone synthase then catalyzes the condensation of 4-hydroxycinnamoyl-CoA with three molecules of malonyl-CoA to form chalcone. The chalcone is then isomerized to naringenin by chalcone isomerase, which is oxidized to eriodictyol by flavonoid 3′-hydroxylase, and then oxidized to taxifolin by flavanone 3-hydroxylase. Taxifolin is then reduced by dihydroflavanol 4-reductase and leucoanthocyanidin reductase to yield catechin. Leucoanthocyanidin reductase (LCR) uses 2,3-trans-3,4-cis-leucoanthocyanidin to produce (+)-catechin and is the first specific enzyme in the proanthocyanidin (PA) pathway. Its activity has been measured in the leaves, flowers, and seeds of several legumes such as Medicago sativa, Lotus japonicus, Lotus uliginosus, Hedysarum sulfurescens, and Robinia pseudoacacia. The enzyme is also present in Vitis Vinifera (grapes) (Dewick, 2009).

7. Physicochemical properties of catechin

Catechin is a flavan-3-ol flavonoid that has been extensively studied for its beneficial effects on human health. Its physicochemical properties play a fundamental role in its biological activity, bioavailability, and pharmaceutical and food applications.

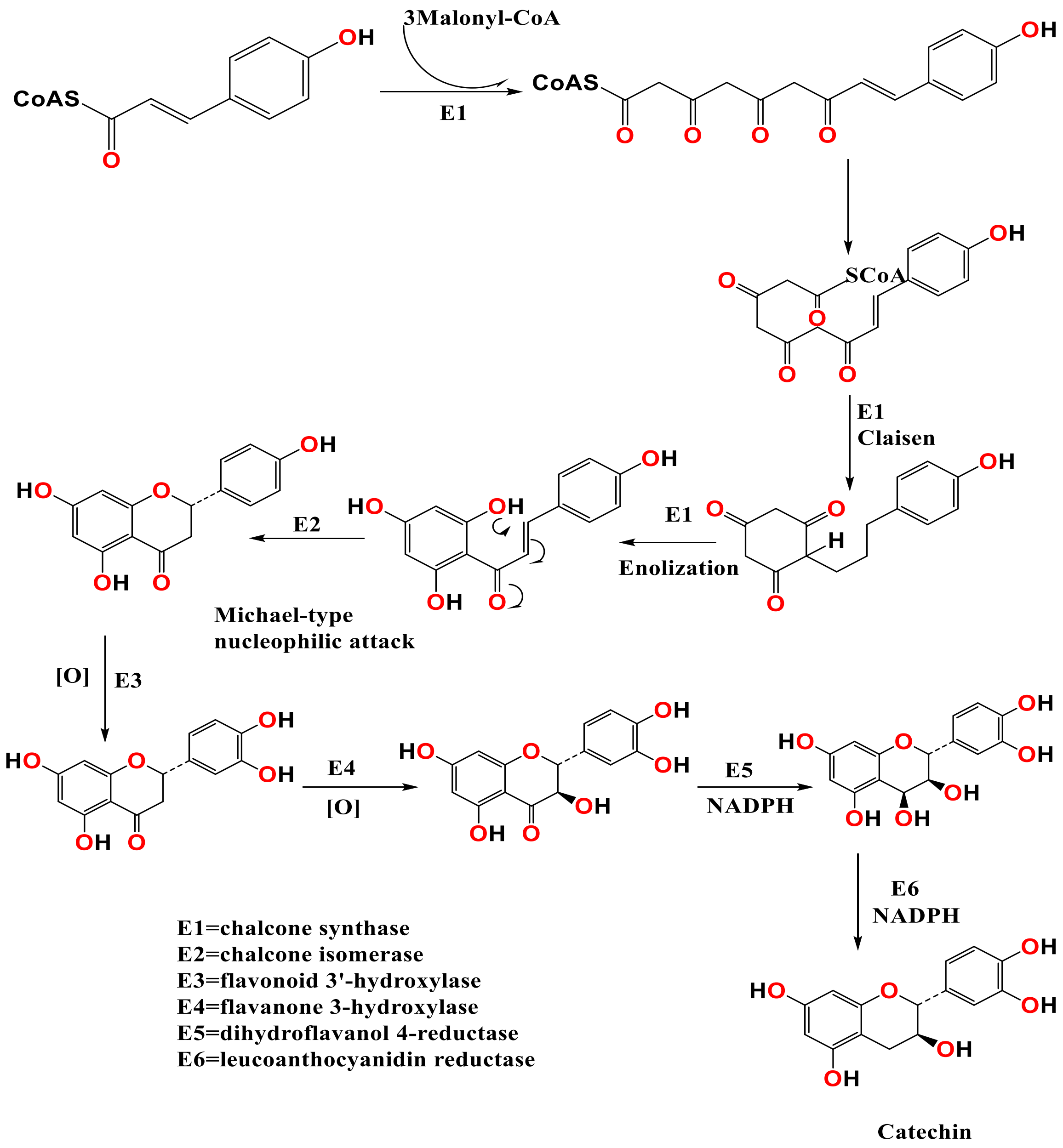


Figure 7: Catechin biosynthesis pathway

From a structural point of view, catechin has a molecular formula of $C_{15}H_{14}O_6$ and a molar mass of 290.27 g/mol**.** It comes in the form of a white to yellowish crystalline powder that is slightly bitter. The molecule has three aromatic rings (labeled A, B, and C), several hydroxyl groups (–OH) of which confer high polarity and a strong affinity for polar solvents such as hot water, methanol, or ethanol. However, its solubility in cold water is limited, which can influence its intestinal absorption. The melting point of catechin is around 214 °C, although it can Varies slightly depending on purity and isomerism. In terms of stability, catechin is sensitive to light, heat, and oxygen. It tends to oxidize in solution, especially in basic environments, which often justifies the use of protective or encapsulating excipients in its formulation (Dixon *et al.*, 2025).

8. Biological properties and health benefits

Catechin is known for its role in neutralizing free radicals, which contribute to oxidative stress. This stress is involved in cellular aging and the development of chronic diseases, such as ardiovascular disease and certain cancers. Thanks to their chemical structure, which is rich in hydroxyl groups, catechins act as effective free radical scavengers, reducing oxidative damage to lipids, proteins, and DNA (Dixon *et al.*, 2025). Cardiovascular benefits: Catechins, particularly those found in green tea such as epigallocatechin gallate (EGCG), play a crucial role in cardiovascular health. They contribute to: Reducing bad cholesterol (LDL): Catechins limit LDL oxidation, a key factor in the formation of atherosclerotic plaques. Improving endothelial function: They promote vasodilation, thereby reducing blood pressure. Preventing blood clots: Their antithrombotic effect helps prevent cardiovascular events (Aggett *et al.,* 2018). Anti-inflammatory and antimicrobial effects: Catechins also have anti-inflammatory properties by inhibiting the production of proinflammatory cytokines. These effects are particularly beneficial in the management of chronic inflammatory diseases such as arthritis and intestinal disorders. Their antimicrobial action has been demonstrated against several pathogens, including Helicobacter pylori, which causes stomach ulcers, and certain viruses, such as influenza viruses.

Other health impacts: Catechins also offer benefits in other areas: Reduced risk of diabetes: They improve insulin sensitivity and help regulate blood sugar levels. Support for the immune system: Their immunomodulatory action strengthens the body's natural defenses. Neuroprotective effect: Studies suggest that they may protect against neurodegenerative diseases, such as Alzheimer's, thanks to their ability to reduce inflammation and oxidative stress in the brain (Dixon *et al.*, 2025). Analytical techniques for quantifying Catechins: Catechins, as complex chemical compounds, require advanced laboratory techniques for their analysis. Several analytical methods are used to identify and quantify catechins, including: High-performance liquid chromatography (HPLC): HPLC is the most commonly used technique for analyzing catechins due to its accuracy and sensitivity. It allows the different catechins present in a sample to be separated, identified, and quantified. UV-vis detectors are often used to measure their concentration. This technique allows for accurate identification of catechins based on their specific molecular eight, offering increased sensitivity to detect even low concentrations. Catechins are separated according to their chemical properties, such as their polarity, on a chromatographic column. HPLC allows the individual identification of different forms of catechins (catechin, epicatechin, EGCG, etc.) and the measurement of their concentrations in a complex Matrix (Aggett *et al.,* 2018). UV-Vis spectrophotometry: This method is used to estimate the total catechin content: Principle: Catechins absorb UV light at a specific wavelength, which allows their concentration to be determined. Limitations: Although fast, this technique lacks the precision to differentiate between individual isomers (Aggett, *et al.,* 2018).

9. The QuEChERS method for catechin analysis

The QuEChERS method (an acronym for Quick, Easy, Cheap, Effective, Rugged, and Safe) is an extraction technique developed in 2003, initially for the analysis of pesticide residues in food products. Thanks to its simplicity, low cost, and high efficiency, it has been widely adapted for the extraction of many organic compounds, including **catechins**, from complex plant matrices (such as tea, fruit, or plant extracts). This method alone does not allow quantification, but it is often used as a preliminary step to chromatographic analysis (particularly by HPLC or LC-MS/MS) (Oualdi, *et al.*, 2023; 2024).

Principle of the QuEChERS method. The method is based on two main steps: Liquid extraction: The sample (ground) is mixed with acetonitrile, often acidified. Salts are then added (typically $MgSO_4$) to: Promote the separation of the aqueous and organic phases. Improve the efficiency of the extraction. Catechins, which are soluble in the organic phase, migrate into the acetonitrile. Solid-phase dispersion cleaning (d-SPE), The supernatant containing the catechins is purified using specific sorbents (such as PSA, C18, or activated carbon), This removes impurities such as pigments, sugars, fatty acids, etc. The result is a purified extract ready for analysis by chromatography. Practical steps: Here is a typical protocol for extracting catechins from a tea sample: Weigh the sample (approximately 10g of tea) in a centrifuge tube. Add 10 ml of acetonitrile. Stir vigorously for 1 to 2 minutes. Add the salt mixture ($MgSO_4$). Centrifuge to separate the phases. Transfer the supernatant to a tube containing the cleaning sorbents (e.g., 150 mg PSA + 900 mg $MgSO_4$). Shake again and centrifuge. Filter the final supernatant for HPLC injection (**Figure 8**).

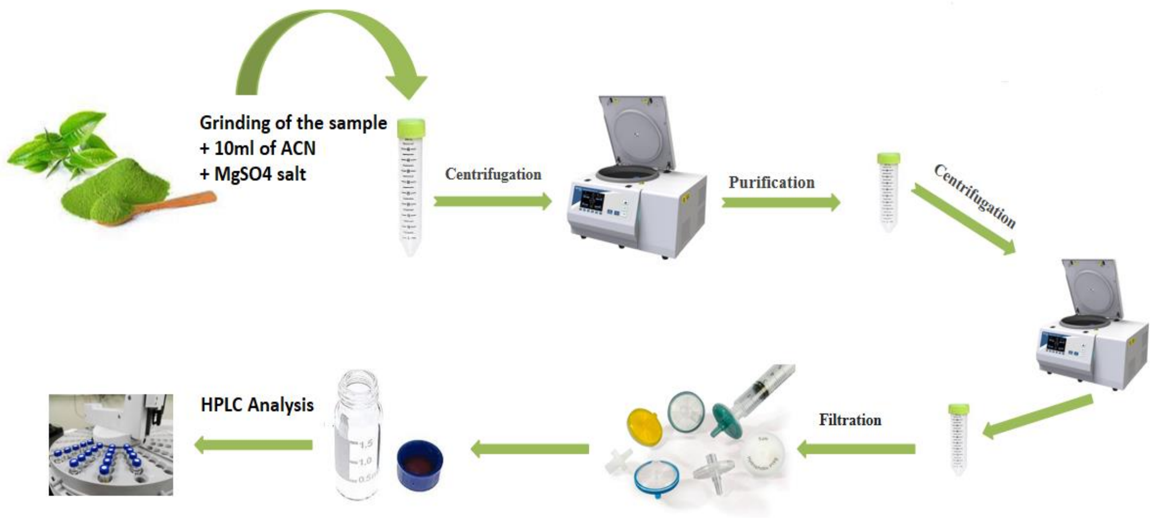


Figure 8: Extraction using the QuEChERS method

10. The multiple applications of catechin

The diversity of research conducted on catechins reflects their multidisciplinary potential. The graph below illustrates the distribution of publications by scientific field, confirming their importance in biochemistry, agriculture, medicine, chemistry, and many other sectors as indicated **Figure 3**. We can see the major domain of applications of catechins in Biochemistry, genetics, and molecular biology (18.7%), in Agricultural and biological sciences (18.5%), in Chemistry (14.1%), in Medicine (13.4%), in Pharmacology, toxicology, and pharmaceuticals (13.1%), in Chemical engineering (3.8%), in Nursing (3.3%), in Immunology and microbiology (2.9%), in Environmental sciences (2.2%), in Engineering (2.2%) and other domains with (7.9%).

Conclusion

Catechin is an important natural compound, widely present in several plants such as green tea, cocoa, and fruits. It is distinguished by its unique chemical structure and numerous beneficial properties, including antioxidant, anti-inflammatory, and antimicrobial properties. Thanks to scientific research, we now have a better understanding of its biosynthesis, its different forms, and the methods used to extract and quantify it. Techniques such as HPLC chromatography and UV-Vis spectrophotometry are essential for the accurate analysis of this molecule. Today, catechin is used in a variety of fields, including medicine, chemistry, biology, the environment, and the pharmaceutical industry. Its many uses show that it remains a molecule of great interest for future research and innovation.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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