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Research on the Biological and Bioactive Functions of Tea Polyphenols

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ABSTRACT
Tea polyphenols, as one of the most important bioactive components in tea, have received extensive attention and research in recent years. This article reviews the biological sources, chemical structures, and extraction methods of tea polyphenols, and focuses on their bioactive functions in antioxidant, anti - inflammatory, anti - tumor, blood glucose and lipid regulation, cardiovascular and cerebrovascular protection, and neuroprotection. Through in - vitro and in - vivo experimental data, the action mechanisms of tea polyphenols and their application prospects in the food and pharmaceutical fields are analyzed. The research shows that tea polyphenols have a wide range of biological activities and are expected to become research and development targets for new functional foods and drugs.

KEYWORDS
Tea polyphenols; Antioxidant; Anti - inflammatory; Anti - tumor; Blood glucose and lipid regulation; Cardiovascular and cerebrovascular protection; Neuroprotection

1 Introduction

Tea, as a beverage with a long - standing history, its unique health benefits have always attracted much attention. Tea polyphenols (TP) are the most important bioactive components in tea, accounting for about 20% - 35% of the dry weight of tea. Tea polyphenols are a class of complex compounds, mainly including catechins, flavonoids, phenolic acids, etc. Among them, catechin compounds (such as epicatechin, epigallocatechin gallate, etc.) have the highest content and the strongest activity.

In recent years, with the increasing demand for functional foods and drugs, the research on the biological and bioactive functions of tea polyphenols has been continuously deepened. A large number of scientific studies have shown that tea polyphenols have significant biological activities such as antioxidant, anti - inflammatory, anti - tumor, and blood glucose and lipid regulation, and are expected to become an important source of new drugs and functional foods.

This article aims to review the biological sources, chemical structures, extraction methods, and main bioactive functions of tea polyphenols, focus on exploring their action mechanisms in antioxidant, anti - inflammatory, anti - tumor, etc., as well as their application prospects in the food and pharmaceutical fields. At the same time, through literature reviews and experimental data, it provides a theoretical basis and technical support for the further research, development, and utilization of tea polyphenols.

2 Chemical Structures and Extraction Methods of Tea Polyphenols

2.1 Chemical Structures

Tea polyphenols are the general term for polyphenolic substances in tea. They are white amorphous powders, soluble in water and ethanol, etc., accounting for about 18% - 36% of the dry matter of tea. According to different chemical structures, they can be simply divided into catechins, flavonols, phenolic acids, anthocyanins, etc., and about 30 kinds have been discovered so far. Epigallocatechin gallate (EGCG) is a polyphenolic compound with a relatively high content. It belongs to flavanols. The flavanol skeleton in its structure has physiological activities such as antioxidant and anti - inflammatory effects, and the gallate group enhances the antioxidant capacity.

Theanine is a special amino acid with the chemical formula C_7H_{14}N_2O_3. It has health - care functions such as lowering blood pressure, sedation, antioxidant, and inhibiting the growth of tumor cells.

Caffeine belongs to alkaloids and has effects such as stimulating the nervous system, accelerating the heart rate, and promoting metabolism.

Catechins are a class of polyphenolic substances in tea polyphenols and have physiological activities such as antioxidant, anti - tumor, and antiviral effects.

Amino acids and proteins: Amino acids are the basic structures that make up proteins. Proteins account for about 25% - 35% of the dry matter content in fresh tea leaves, and less than 2% can be dissolved in tea soup. However, the amino

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acids produced by hydrolysis contribute significantly to the taste of tea soup.

Enzymes are special proteins that catalyze the changes of substances in tea like catalysts. For example, polyphenol oxidase can oxidize tea polyphenols to form o - quinones, and further produce theaflavins, thearubigins, and theabrownins. In addition, tea also contains components such as water and volatile oils. The contents and proportions of these chemical components vary depending on the type and variety of tea.

2.2 Extraction Methods

The extraction methods of tea polyphenols mainly include solvent extraction, water extraction, ultrasonic extraction, microwave extraction, supercritical fluid extraction, etc. Among them, solvent extraction and water extraction are the most commonly used methods. Solvent extraction uses organic solvents (such as ethanol, acetone, etc.) for extraction and is suitable for industrial production; water extraction utilizes the water - solubility of tea polyphenols and obtains extracts through hot - water extraction. Ultrasonic extraction and microwave extraction have the advantages of high extraction efficiency and short time, but the equipment cost is relatively high; supercritical fluid extraction is suitable for occasions with high requirements for extraction conditions.

3 Bioactive Functions of Tea Polyphenols

3.1 Antioxidant Activity

Tea polyphenols, as the general term for polyphenolic substances in tea, have significant antioxidant activity and are a powerful natural antioxidant. They mainly exert antioxidant effects through the following mechanisms:

3.1.1 Scavenging free radicals

Free radicals are highly active and can trigger lipid peroxidation reactions in cell membranes, causing cell damage. Tea polyphenols can quickly combine with free radicals to form stable compounds, inhibit further reactions of free radicals, protect the cell membrane structure, and reduce cell damage.

3.1.2 Inhibiting lipid peroxidation reactions

Lipids can undergo oxidation reactions under the action of free radicals, generating harmful lipid peroxides. Tea polyphenols can inhibit this reaction, reduce the generation of lipid peroxides, not only protect the cell membrane but also alleviate the inflammatory reactions caused by lipid peroxides.

3.1.3 Promoting cell repair

Tea polyphenols can activate antioxidant enzyme systems such as superoxide dismutase (SOD) and glutathione peroxidase (GPx) in cells, enhance the antioxidant capacity of cells; they can also promote the repair of intracellular DNA and reduce gene mutations caused by oxidative stress.

3.1.4 Synergistic antioxidant effect

Tea polyphenols can act synergistically with other antioxidants such as vitamin C, vitamin E, and glutathione to enhance the antioxidant effect.

Numerous experimental studies have shown that many pharmacological activities of tea polyphenols, such as anti - tumor, anti - aging, and blood lipid regulation, are closely related to their antioxidant properties. Different types of tea have different tea polyphenol contents due to different processing techniques. According to research data, the contents of tea polyphenols in green tea, oolong tea, and black tea decrease in turn.

3.2 Anti - inflammatory Activity

Tea polyphenols, as the main bioactive components in tea, have significant anti - inflammatory activity, which is specifically manifested as follows:

3.2.1 Inhibiting the production and release of inflammatory factors

Its main components, such as catechins, flavonoids, and phenolic acids, can inhibit the production and release of

inflammatory factors such as interleukin - 1 (IL - 1) and tumor necrosis factor - α (TNF - α), reducing the inflammatory reaction. For example, in inflammatory diseases such as arthritis, it can relieve symptoms such as joint pain and swelling.

3.2.2 Regulating inflammatory - related signaling pathways

It can regulate signaling pathways such as nuclear factor - κB (NF - κB). This pathway plays a key role in the regulation of inflammatory reactions. Tea polyphenols reduce the expression of inflammatory - related genes by inhibiting its activation, thereby alleviating inflammation.

3.2.3 Antioxidant - synergistic anti - inflammation

Tea polyphenols have strong antioxidant properties. They can scavenge free radicals, reduce the level of oxidative stress, and reduce the inflammatory reactions caused by oxidative stress. Because oxidative stress is closely related to inflammation, excessive free radicals can promote the production of inflammatory factors and the activation of inflammatory cells.

3.2.4 Regulating the functions of immune cells

It regulates the activities of immune cells such as macrophages and lymphocytes, reducing the release of inflammatory mediators. While enhancing the immune function of the body, it avoids inflammatory damage caused by excessive immune responses.

Research shows that tea polyphenols have a certain relieving effect on inflammatory diseases such as enteritis and arthritis and have potential application value in the medical and health - care fields. However, the specific anti - inflammatory mechanisms and effects of tea polyphenols still need to be further clarified through more research.

3.3 Anti - tumor Activity

Tea polyphenols have significant anti - tumor activity, which is mainly reflected in the following aspects:

3.3.1 Inducing apoptosis of tumor cells

Tea polyphenols can activate the apoptotic signaling pathway in cells, prompting tumor cells to undergo apoptosis. For example, by upregulating the expression of the pro - apoptotic protein Bax and simultaneously downregulating the expression of the anti - apoptotic protein Bcl - 2, changing the ratio of the two, cytochrome C is released from the mitochondria into the cytoplasm, activating the caspase cascade reaction, and ultimately leading to the apoptosis of tumor cells. It can also damage the mitochondrial membrane potential of tumor cells, increase its permeability, release apoptosis - related factors, and trigger cell apoptosis.

3.3.2 Inhibiting the proliferation of tumor cells

Tea polyphenols can block the tumor cell cycle, causing cells to stagnate in specific stages such as the G1 phase or S phase, preventing cells from entering the division phase, thereby inhibiting the proliferation of tumor cells. It can also interfere with the DNA synthesis and repair process of tumor cells, affect the stability of the genetic material of tumor cells, and make cells unable to divide and proliferate normally.

3.3.3 Inhibiting tumor angiogenesis

The growth and metastasis of tumors depend on new blood vessels to provide nutrients and oxygen. Tea polyphenols can inhibit the expression and activity of angiogenesis - related factors such as vascular endothelial growth factor (VEGF), reduce the proliferation and migration of vascular endothelial cells, and thus inhibit tumor angiogenesis. It can also affect the degradation and remodeling of the extracellular matrix by regulating the activity of matrix metalloproteinases (MMPs), disrupting the micro - environment for tumor angiogenesis.

3.3.4 Enhancing the immune function of the body

Tea polyphenols can activate immune cells such as T lymphocytes, B lymphocytes, macrophages, and natural killer cells, enhancing their activities and functions, enabling them to better recognize and kill tumor cells. It can also promote immune cells to secrete cytokines such as interleukins and interferons. These cytokines can regulate the immune

response and enhance the anti - tumor immune response of the body.

3.3.5 Chemopreventive effect

Tea polyphenols can act at multiple stages of tumorigenesis, including initiation, promotion, and progression. Through mechanisms such as antioxidant and free - radical scavenging, it reduces the damage of carcinogens to cellular DNA and reduces the risk of tumor occurrence.

3.4 Blood Glucose and Lipid Regulation Activity

Tea polyphenols can regulate the metabolism of blood glucose and lipids and reduce the risk of diabetes and cardiovascular diseases. Research shows that tea polyphenols can inhibit the activity of α - glucosidase, delay the absorption and utilization of carbohydrates, and thus reduce blood glucose levels. At the same time, tea polyphenols can also promote the oxidation and decomposition of fatty acids and the excretion of cholesterol, reducing blood lipid levels.

Animal experiments have shown that tea polyphenols can improve the glucose and lipid metabolism of diabetic mice and reduce blood glucose and lipid levels. Clinical studies have also found that long - term tea drinking can reduce the incidence and mortality of diabetes and cardiovascular diseases. In addition, tea polyphenols can also improve symptoms of metabolic syndrome such as insulin resistance and obesity, providing new ideas for the prevention and treatment of diabetes and cardiovascular diseases.

3.5 Cardiovascular and Cerebrovascular Protection

Tea polyphenols have significant cardiovascular and cerebrovascular protection functions and can prevent and treat a variety of cardiovascular and cerebrovascular diseases. Research shows that tea polyphenols can inhibit platelet aggregation and thrombosis formation, improve hemorheological properties; they can also dilate blood vessels, lower blood pressure, and protect vascular endothelial cells from damage. In addition, tea polyphenols can inhibit myocardial cell apoptosis and fibrosis and improve cardiac function.

Animal experiments have shown that tea polyphenols can reduce the severity of heart diseases such as myocardial ischemia - reperfusion injury and myocardial infarction; they can also prevent the occurrence and development of vascular diseases such as hypertension and atherosclerosis. Clinical studies have also found that long - term tea drinking can reduce the incidence and mortality of cardiovascular and cerebrovascular diseases. The cardiovascular and cerebrovascular protection function of tea polyphenols is mainly attributed to its regulatory effects on the functions of vascular smooth muscle cells, endothelial cells, myocardial cells, etc., and its improvement of hemorheological properties.

3.6 Neuroprotection

Tea polyphenols have neuroprotective effects and can reduce the degree of nervous system damage and neurodegenerative diseases. Research shows that tea polyphenols can inhibit the apoptosis and necrosis of neurons, promote the regeneration and repair of neurons; they can also inhibit neuroinflammatory reactions and oxidative stress reactions, protecting neurons from damage. In addition, tea polyphenols can improve neurotransmitter transmission and synaptic plasticity, enhancing the function of the nervous system.

Animal experiments have shown that tea polyphenols can reduce the severity of neurodegenerative diseases such as cerebral ischemia - reperfusion injury and Parkinson's disease; they can also improve learning and memory abilities and cognitive functions. Clinical studies have also found that long - term tea drinking can reduce the incidence and progression rate of neurodegenerative diseases. The neuroprotective effect of tea polyphenols is mainly attributed to its promotion of neuron survival, regeneration, and repair, as well as its inhibition of neuroinflammatory reactions and oxidative stress reactions.

4 Application Prospects of Tea Polyphenols

As a natural functional ingredient, tea polyphenols have broad application prospects in the food and pharmaceutical fields. In the food industry, tea polyphenols can be used as antioxidants, preservatives, and fresh - keeping agents to improve the stability and safety of food; they can also be used as functional food additives to enhance the nutritional value and health benefits of food. In the pharmaceutical field, tea polyphenols can be used as drug precursors or auxiliary components for the prevention and treatment of diseases such as tumors, diabetes, and cardiovascular and cerebrovascular diseases.

In addition, tea polyphenols can be used in combination with other functional ingredients (such as vitamins, minerals,

etc.) to exert synergistic effects and improve health benefits. For example, the combination of tea polyphenols and vitamin C can enhance the antioxidant effect; the combination with dietary fiber can improve the balance of the intestinal micro - ecosystem; the combination with calcium can enhance bone health, etc.

5 Conclusion

As the main bioactive substances in tea, tea polyphenols exhibit a wide range of important biological and bioactive functions. In terms of antioxidant activity, it is a powerful antioxidant that can scavenge free radicals, inhibit the activity of oxidases, and protect cells from oxidative stress damage. In anti - tumor function, it can inhibit the proliferation of tumor cells, induce their apoptosis, and block tumor angiogenesis. In lipid - lowering function, it is manifested as regulating lipid metabolism and anti - atherosclerosis. At the same time, tea polyphenols have antibacterial and antiviral abilities, which can inhibit the growth of bacteria and the replication of viruses. In addition, it also has other functional activities such as anti - diabetes and neuroprotection. Its action mechanisms involve capturing free radicals, regulating intracellular signaling pathways, directly acting on target molecules, and regulating gene expression. These studies show that tea polyphenols have great potential application value in the medical and health - care fields and are worthy of further in - depth research, development, and utilization.

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