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Literature Review of The Analytical Detection and Physiological Functions of Vitamin C

Wang Kehan ,

Yao Yiming,

Shi Zhan

Shenzhen (Nanshan) Concord College of Sino-Canada, Shenzhen, 518000, China
Corresponding author: shizhan@ccsc.com.cn

Abstract:
Vitamin C (L-ascorbic acid) is an very important water-soluble vitamin with the highest daily requirement in human being, playing crucial physiological roles in immune regulation, antioxidant activity, collagen synthesis, and iron absorption. This paper systematically reviews several special properties of vitamin C with particular emphasis on analyzing the current research status of vitamin C detection technologies both domestically and internationally. These include traditional 2,6-dichlorophenolindophenol titration, ultraviolet spectrophotometry, and high-performance liquid chromatography, with comparative analysis of their respective advantages, disadvantages, and application scenarios. Furthermore, this paper addresses key controversies in current research, such as the “pro-oxidant” effect of vitamin C under specific conditions and the safety of long-term high-dose intake. Finally, future research directions are proposed, suggesting that detection technologies will evolve towards miniaturization and intelligence, functional studies will focus more on molecular mechanism exploration, and dietary strategies need to integrate innovative food engineering technologies, providing theoretical references for achieving precise nutrition and effective dietary supplementation of vitamin C.Furthermore,this paper discusses several controversies in contemporary research,including the “pro-oxidative”effect of vitamin C under specific conditions and the safety of long-term high-does intake.Finally,potential future research directions are proposed herein:detection techniques of vitamin C will advance toward miniaturization and intelligence ; functional studies will place greater emphasis on investigations into molecular mechanisms; and dietary strategies should integrate innovative food technologies-all of which aim to provide theoretical references for the realization of precision nutrition and effective dietary supplementation of vitamin C.

Keywords: Vitamin C; physiological function; detection technology;

1. Introduction

Vitamin C, also known as L-ascorbic acid, is the water-soluble vitamin with the simplest molecular structure, the most unstable biochemical properties, the highest daily requirement in humans, and the most concentrated dietary distribution among the vitamin family. It is closely related to human health and has historically been praised as the "universal vitamin," playing an important role in ensuring the normal metabolic functions of the human body[1]. According to recent Chinese National Nutrition Survey data, the daily dietary intake of vitamin C among Chinese residents has shown a declining trend over the years, dropping from 129mg/day in 1982 to approximately 90mg/day in 2002 [1-4]. This phenomenon has raised widespread concern regarding its dietary adequacy. At the same time, with the advancement of analytical technologies, higher demands have been placed on the accurate and rapid determination of vitamin C content in fruits, vegetables, and their processed products. Therefore, this paper aims to systematically review the research progress on the physiological functions and detection technologies of vitamin C both domestically and internationally, clarify existing controversies, and explore future development trends, in order to provide a comprehensive reference for scientific research and practical applications in related fields.

2. Physiological Functions and Research Status of Vitamin C

2.1 Physiological Functions of Vitamin C

Vitamin C plays numerous and important roles in human physiology, mainly summarized in the following ten aspects:

1. Enhancing immune function: Vitamin C can promote the formation of antibodies in the human body and increase the phagocytic ability of white blood cells, thereby enhancing the body's resistance to bacteria and viruses [1].
2. Prevention and treatment of iron-deficiency anemia: Since the human body can only absorb divalent iron (Fe^{2+}), the strong reducing property of vitamin C can reduce trivalent iron ions (Fe^{3+}) in food to more absorbable divalent iron ions (Fe^{2+}), promoting iron absorption in the intestine [1].
3. Prevention and treatment of megaloblastic anemia: Vitamin C can protect folic acid from oxidative damage and reduce it to biologically active tetrahydrofolate, playing a dual role in protection and activation of folic acid[1].
4. Prevention and treatment of scurvy: Ensuring adequate dietary intake of vitamin C is the fundamental method for preventing and treating scurvy caused by severe vitamin C deficiency [1].
5. Promotion of steroid metabolism and collagen formation: Vitamin C can activate prolyl hydroxylase and lysyl hydroxylase, and is an essential cofactor in the hydroxylation process of steroids. At the same time, it can promote effective synthesis of collagen and accelerate the metabolism of cholesterol into bile acids[1-3].
6. Maintaining normal function of bones and teeth: It forms an acidic medium in the digestive tract, promoting the absorption of dietary calcium and its deposition in bones[1].
7. Indirect maintenance of cell membrane integrity: As a strong reducing agent, vitamin C can reduce oxidized glutathione to reduced glutathione under the action of glutathione reductase, and reduced glutathione can eliminate peroxides, thereby eliminating their damage to cell membranes [1-3].
8. Detoxification effect: It has a mitigating effect on common toxic substances such as lead compounds, arsenic compounds, benzene, and bacterial toxins [1-2].
9. Anti-aging effect: By inhibiting the formation of harmful substances such as free radicals and lipid peroxides in the body, it slows down the aging process of the human body[1-7].
10. Anti-cancer effect: It can block the nitrosation process, inhibit the formation of strong carcinogen nitrosamines, and promote collagen to surround cancer cells, showing anti-cancer effects[1].

2.2 Current Status of Vitamin C Detection Technology

There are various methods for detecting vitamin C, each with its own characteristics, and their development reflects the progress of analytical techniques.

Traditional chemical titration methods: The 2,6-dichlorophenolindophenol titration method is representative[1-9]. This method uses the principle of redox color change of dyes, is simple and fast to operate, and is one of the national standard methods. However, its endpoint judgment is easily interfered by the color of the sample itself. Although improved methods such as xylene extraction colorimetry can be used, there are still certain limitations. Iodometric method is also based on redox reactions, but the accuracy of endpoint judgment in dark samples is poor [9].

Instrumental analysis methods:

Ultraviolet spectrophotometry: Based on the maximum absorption peak of vitamin C near 243nm and its instability in alkaline environment, quantitative analysis is carried out by measuring the absorbance difference at 243nm between the sample and the alkali-treated sample[5-6]. This

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method is simple, rapid, accurate, and highly sensitive (detection limit can reach 0.014μg/mL), especially suitable for the determination of dark samples, avoiding the problem of difficult endpoint identification in titration methods [5-6-9]. Studies by Zheng Jingping and Ma Hongfei have verified the good linear relationship and recovery rate of this method [5-6].

High-performance liquid chromatography (HPLC): It has the advantages of high separation efficiency, short analysis time, and is particularly suitable for unstable substances, but the instrument is relatively expensive [9].

Other methods: Fluorescence spectrophotometry, electrochemical methods, and capillary electrophoresis are also applied to the determination of vitamin C, each with its own applicable scenarios[5-9].

Rapid and frontier detection technologies: Flow injection analysis (FIA) greatly increases the analysis speed (up to 120 samples/hour) [9]. In addition, with the development of micro-spectrometers, optical fiber technology, and sensors, the detection of vitamin C is moving towards on-site, online, and portable directions.

3. Controversies and Issues in Research

Although research has been relatively thorough, there are still some controversies and unresolved issues regarding vitamin C.

Issues of applicability and standardization of detection methods: Different methods (such as titration and UV methods) may produce different results due to different principles. The elimination of interference factors such as dark samples and coexisting reducing substances still needs optimization [5-9]. How to select the most suitable method for different matrix samples and achieve standardization and comparability of results is a challenge in practical analytical work.

The double role of vitamin C as "pro-oxidant": While vitamin C is a strong antioxidant in most cases, in the presence of transition metal ions (such as Fe^{3+}, Cu^{2+}), it may produce hydroxyl radical through Fenton reactions, showing pro-oxidant effects [7]. This duality makes its biological effects complex under high-dose applications and requires careful evaluation.

Safety and dependency of long-term high-dose intake: Although vitamin C is water-soluble and short-term high-dose intake usually does not cause serious side effects, studies have shown that long-term daily intake exceeding 1g may increase the risk of kidney or urinary tract stones and may lead to metabolic dependency, with deficiency symptoms appearing once normal dosage is resumed[1-3]. Therefore, the definition of "optimal dosage" for both general and special populations still needs more evidence-based evidence.

4. Future Research Directions and Methodological Prospects

Based on the current research status and controversies, future research on vitamin C can be carried out in the following directions:

Innovation and integration of detection technologies: Future detection technologies will pay more attention to miniaturization (such as handheld spectrometers based on CCD/PDA) and muti-colormetric sensor based on composited metal material which maybe more rapid and sensitive for vitamin C detection[11], intelligence (combining artificial intelligence for spectral data analysis and model prediction), and online monitoring (for food processing process monitoring)[8] and also the nanotechnology(mutilayered graphene nanosheets for the sensitive and selective detection of vitamin C)[10] Developing multi-component combined technologies that can simultaneously and rapidly detect vitamin C, vitamin E, and other nutrients will be an important trend.

In-depth exploration of physiological function mechanisms: Using molecular biology and omics technologies to further reveal the mechanisms of vitamin C in cell signaling pathways and gene expression regulation. In-depth study of its synergistic antioxidant network with other nutrients such as vitamin E and selenium [7], as well as precise intervention strategies under specific pathological conditions.

Coordination between dietary assurance and food engineering technology: In response to the unstable characteristics of vitamin C, develop new protection technologies such as embedding and micro-encapsulation to improve its stability during food processing and storage. Combined with changes in residents' dietary patterns, design functional foods and optimize nutrition fortification strategies, and improve public awareness of scientific vitamin C supplementation through public nutrition education.

5. Conclusion

As an indispensable micro-nutrient, vitamin C's complex physiological functions and precise analytical detection have always been research hots-pots in the fields of nutrition and food science. Currently, people's understanding of its physiological functions is relatively systematic, and detection methods have also developed from traditional titration to rapid and precise instrumental analysis. However, issues such as its "pro-oxidant" potential and the safety of long-term high-dose use still need to be treated with caution. In the future, through interdisciplinary integration, vigorously promoting the development of detection technology towards intelligence and miniaturization, deepening research on its physiological function mechanisms at the molecular level, and innovating dietary assurance technology, will provide a more solid scientific foundation for promoting public health and achieving precision nutrition.

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