

Research on Mechanisms for Enhancing Nutritional Safety in Fresh Food from an Industrial Chain Perspective

Yurong Yun

*School of Finance and Economics, Hainan Vocational University of Science and Technology, Haikou
Hainan, China*

**Corresponding Author*

Abstract: As consumers increasingly prioritise health and food quality, nutritional safety in fresh produce has progressively become a central concern in the development of the food industry. This paper adopts an industrial chain perspective to systematically analyse key factors affecting nutritional safety throughout the production, processing, distribution and consumption stages of fresh food. It identifies persistent shortcomings in China's current systems concerning nutritional safeguards at source, processing technology controls, cold chain logistics infrastructure, and nutritional information disclosure. Building upon this foundation, it is proposed that a multi-faceted nutritional security mechanism should be established through four key approaches: developing nutrition-oriented agriculture, enhancing processing standardisation, improving intelligent cold chain systems, and strengthening consumer nutrition education. This study aims to provide theoretical underpinnings and practical guidance for enhancing nutritional safety standards within China's food supply chain and advancing high-quality development in the food industry.

Keywords: Fresh Food; Nutritional Safety; Industrial Chain; Cold Chain Logistics; Food Processing

1. Introduction

With increasing consumer concern regarding food safety and nutritional health, the issue of nutritional safety in fresh agricultural products has gradually emerged as a critical societal concern. According to the China Fresh Food Market Development Report (2023), the market size of fresh food products has exceeded the one-trillion-yuan threshold and is projected to expand further, reaching approximately two

trillion yuan by 2025. Against this backdrop, ensuring the stability, resilience, and safety of food supply systems has become a central issue in discussions of food security and sustainable development.

In recent years, agricultural supply chains have faced mounting challenges arising from natural disasters, geopolitical uncertainty, and regional conflicts. These factors have exposed structural weaknesses in terms of supply chain stability, product quality, operational efficiency, and overall competitiveness. At the same time, consumer awareness of nutritional value and food safety standards for fresh produce remains relatively limited, rendering the nutritional safety of fresh agricultural products particularly vulnerable and increasingly significant.

Accordingly, there is a pressing need to adopt a systematic and integrated approach to safeguarding food supply systems by enhancing industrial chain coordination and improving cold chain logistics performance. Optimizing these mechanisms is essential for preserving the nutritional integrity of fresh produce throughout production, storage, and distribution processes. Such efforts not only support the sustainable development of the food industry but also provide an effective pathway for improving public health outcomes and strengthening consumer trust.

1.1 Theoretical Significance

This research project adopts an industrial chain perspective to explore how to safeguard the nutritional content and safety of food throughout production, distribution, storage, and processing. It focuses on enhancing the nutritional safety standards of fresh produce by optimising each stage and fostering cross-sector collaboration, thereby providing theoretical underpinnings for modern food industry management. Moreover, this study explores how optimising each stage and fostering cross-industry collaboration can

enhance the nutritional safety of fresh food products. This approach may advance the development of supply chain synergy theory and provide theoretical underpinnings for modern food industry management. Additionally, this research project integrates big data and intelligent technology applications to explore how technological means can enhance comprehensive food traceability and management, thereby providing theoretical support for technological innovation in food safety.

1.2 Practical Significance

Food nutrition and safety have always been a focal point of societal concern, directly impacting the health and safety of the general public. Therefore, researching mechanisms to enhance the safety level of the food industry's industrial chain and supply chain is of significant importance for safeguarding public food safety. The security of industrial and supply chains impacts economic development: The food industry chain encompasses multiple segments including agriculture, processing, and distribution, with supply chain security directly affecting the healthy development of the food sector. By examining mechanisms to enhance supply chain security levels, we can foster a virtuous cycle and healthy development within the food industry chain, thereby driving economic growth. Moreover, this research project will drive the upgrading and enhanced efficiency of the food industry chain. By investigating food safety mechanisms, it will contribute to elevating the safety standards and management levels across the entire food supply chain, propelling the industry towards high-quality development while bolstering its competitiveness and capacity for sustainable growth.

2. Current State of Research at Home and Abroad

With the rapid development of the fresh food market, food safety and nutritional security issues have gradually become a hot topic in domestic research. In recent years, relevant domestic studies have primarily focused on areas such as food safety, cold chain logistics, and green agriculture.

In the field of food nutrition for fresh produce, domestic research has primarily focused on cold chain logistics and food quality assurance. Xiao

Hang and Li Nan contend that preserving the nutritional content of fresh produce relies not only on quality control in agricultural production but also necessitates stringent nutritional protection measures throughout cold chain logistics and processing stages. Particularly within supply chain management, safeguarding food nutrients from degradation represents a significant current research focus [1,2]. Wang Chunhua upholds a people-centred approach and scientific lifestyle philosophy, innovatively integrating food nutrition theory with scientific exercise to explore the health maintenance model anticipated by people in the new era. This endeavour aims to provide theoretical and practical guidance for enhancing public health literacy [3]. However, despite some progress in applying food nutrition principles domestically, approximately 80% of fresh produce still fails to benefit fully from cold chain logistics. This results in inadequate safeguards for food quality and significant levels of wastage.

Overseas scholars predominantly focus on the comprehensive management and technological innovation of fresh food products. Kaur et al. noted that the nutritional composition of fresh produce is influenced by environmental factors such as storage temperature, humidity, and light exposure. Consequently, cold chain management must not only ensure food safety but also employ technical measures to preserve its nutritional content [4]. Feng et al. emphasise that through refined supply chain management, such as optimising temperature control during transportation and the configuration of cold chain facilities, the nutritional value and quality of fresh foodstuffs can be significantly enhanced [5].

Research on the nutritional safety of fresh food in China remains fragmented, lacking a systematic theoretical framework. He Jing and Song Xiufeng, recognising the complexity of food supply and demand networks, introduced blockchain technology and reputation incentive mechanisms. They quantified reputation management and automated the incentive mechanism through blockchain smart contracts. This approach not only facilitates information exchange and value interoperability between heterogeneous blockchains within food supply and demand networks but also offers novel perspectives for advancing value information exchange within these networks [6,7]. Li Ping, adopting a retailer perspective and grounded in

trust theory, conducted three consumer experiments to investigate the impact of blockchain-based food traceability systems on consumer patronage intentions. The study concludes that food retailers should actively adopt such systems while complementing their implementation with appropriate advertising strategies. Furthermore, governments can enhance food safety governance by vigorously promoting the retail application of these systems [8].

Although some exploration has been undertaken domestically in this area, systematic research remains insufficient. Regarding the management of fresh food safety standards abroad, Miller et al. (2019) note that cold chain logistics not only extends food shelf life but also maximises the preservation of nutritional content. Temperature and humidity control prove particularly crucial during the transportation of fruit and vegetables.^[9] European and American countries widely employ Internet of Things (IoT) technology and big data systems to monitor cold chains in real time, ensuring food quality and safety.^[10] These technological measures have driven the intelligent and transparent transformation of food supply chains worldwide. In summary, domestic research has predominantly focused on the fundamental theories and applications of food safety and cold chain logistics, lacking systematic approaches. Particularly concerning the integration of nutritional safety with supply chain optimisation, relevant studies remain relatively underdeveloped. By contrast, overseas research has already delved deeply into cold chain technology, supply chain coordination and intelligent monitoring, achieving significant results in practical applications. Domestic technological implementation in these areas still lags behind, particularly concerning the informatisation management and intelligent applications of cold chain logistics. Therefore, there is an urgent need domestically to enhance the construction of cold chain facilities, standardised management, and technological innovation, thereby improving the safety and nutritional standards of the fresh food industry.

3. Analysis of the Industrial Chain Links in the Nutritional Safety of Fresh Food Products

With the continuous expansion of the fresh food market and consumers' growing demand for nutritional health, nutritional safety has become

a crucial component within the food safety system. However, nutritional safety is not determined by any single link in the chain, but rather constitutes a systemic issue that permeates the entire food supply chain. The nutritional composition of fresh produce is influenced from the outset by factors such as the natural environment and agricultural inputs at the production stage. Upon entering processing, distribution and retail channels, it is further affected by numerous elements including temperature control, processing techniques and transport efficiency. By the time it reaches consumers, its nutritional value has been shaped by the combined effects of multiple factors. Therefore, adopting a holistic industry chain perspective to systematically map the mechanisms by which each critical stage impacts nutritional safety is an essential prerequisite for enhancing the nutritional quality of fresh produce and safeguarding public health.

3.1 Production Process: Ensuring Quality at Source and Laying the Foundation for Nutrition

The nutritional safety of fresh produce hinges primarily on quality control during production, which constitutes the most fundamental and critical stage within the entire supply chain. The nutritional content of raw materials, the consistency of their quality, and the safety of production environments directly determine the nutritional standards of fresh food.

3.1.1 Insufficient germplasm resources and nutrition-oriented breeding

The nutritional value of agricultural products is largely determined by their genetic characteristics, with the foundations for this process being laid during the germplasm selection and breeding stages. For a considerable period, China's agricultural sector has prioritised 'high yields, disease resistance, and stable production' as its primary objectives, neglecting systematic breeding and long-term accumulation of nutritional components. During the breeding process of many common crops, nutritional indicators such as vitamins, minerals, and proteins have not been central considerations. Consequently, the nutritional content of varieties circulating in the market varies considerably, with nutritional density sometimes sacrificed in the pursuit of appearance and yield.

In contrast, certain agriculturally advanced nations abroad have commenced promoting

“nutrition-directed breeding”, enhancing crops' inherent nutritional content through genetic modification. Examples include increasing iron and zinc levels in rice and boosting lycopene concentrations in tomatoes. This approach not only fortifies the nutritional foundation of primary products but also establishes favourable conditions for preserving nutrients during subsequent processing and distribution.

3.1.2 Extensive production methods

At present, agricultural production in China remains predominantly based on traditional methods, with widespread overuse of chemical fertilisers, pesticides, and ripening agents, which adversely affects the nutritional stability and safety of agricultural products. Particularly in fruit and vegetable crops, the excessive pursuit of growth rates and yields may result in inadequate nutrient absorption, reduced mineral content, and disproportionately high water content. This renders the nutritional value of such produce artificially inflated yet fundamentally deficient. Moreover, within the farming process, the use of animal feed additives, antibiotics and growth promoters also exerts a potential influence on the nutritional composition of meat, eggs and aquatic products. Moreover, from an ecological perspective, the long-term reliance on chemical inputs has exacerbated issues such as soil depletion and water eutrophication. This has resulted in unstable sources of nutrients for agricultural products and reduced absorption efficiency, thereby fundamentally constraining improvements in nutritional quality.

3.1.3 Absence of nutritional safety standards

In the actual agricultural production process, China has yet to establish a systematic nutritional evaluation system for agricultural products. Current agricultural product standards primarily focus on safety, while the formulation of indicators for key nutritional components such as vitamins, proteins, polyphenols, and minerals remains severely inadequate. The absence of a unified testing system and grading standards not only limits the market recognition of nutritionally superior products but also prevents the formation of a market competition mechanism centred on ‘nutritional quality’.

At the same time, agricultural operations in our country remain predominantly smallholder-based, characterised by fragmented production and varying levels of technical proficiency. Most farming households lack nutritional awareness,

professional training and scientific guidance, often relying on experience in cultivation methods, harvesting timing and fertiliser management. This makes it difficult to scientifically manage and regulate the nutritional levels of agricultural products. Smallholder farmers, constrained by limited capital and technical expertise, struggle to adopt modern agricultural equipment or digital management systems. Their capacity for collecting, tracing, and analysing nutritional data remains markedly inadequate. This not only hinders their participation in high-quality supply chains but also, to a certain extent, lowers the overall nutritional safety standards across the entire industry chain.

3.2 Processing Stage

The processing stage, as a pivotal link in the industrial chain, directly influences the integrity and safety of nutritional components during the commercialisation and standardisation of raw agricultural products. Reasonable and scientific processing not only extends the shelf life of food but also preserves its nutritional value to the greatest extent possible. However, in actual production, the processing stage continues to face multiple challenges, including significant nutrient loss and the absence of standards, which constrain improvements in nutritional safety across the entire supply chain.

3.2.1 Nutrient loss during primary processing

Primary processing refers to the treatment of raw materials through washing, peeling, cutting, sterilisation, and pre-packaging, without altering the fundamental form of the foodstuff. Although this stage does not demand high technical expertise, improper handling can easily lead to nutrient loss. Taking fruit and vegetables as an example, excessive soaking causes water-soluble nutrients such as vitamin C and B vitamins to leach out in significant quantities, diminishing their health benefits. Furthermore, once cut and exposed to air, produce undergoes oxidation reactions that deplete antioxidant compounds including polyphenols and carotenoids. In China, some small and micro-scale processing enterprises lack awareness of nutritional preservation. With rudimentary processing equipment and non-standardised operational practices, the degradation of food nutritional composition during primary processing is a common occurrence. Moreover, issues such as the quality of washing water and environmental

hygiene conditions may introduce new safety hazards, further undermining the effectiveness of nutritional security measures.

3.2.2 The conflict between deep processing techniques and the degradation of nutritional components

With the rise of emerging consumer demands for pre-prepared meals and ready-to-eat dishes, the proportion of deep-processed fresh food products has increased year on year. Techniques such as quick-freezing, drying, deep-frying, and seasoning/pickling are now widely applied to vegetables, fruits, poultry, and aquatic products. However, whilst pursuing palatability, convenience and market adaptability, deep processing often entails the destruction of nutritional components. High-temperature frying causes heat-sensitive nutrients such as vitamin E and unsaturated fatty acids to break down; repeated freezing and thawing may lead to protein denaturation and moisture loss, affecting both texture and nutrient absorption; the high salt content and preservatives added during the pickling process not only dilute nutritional density but may also pose health risks. Furthermore, to enhance colour and extend shelf life, some manufacturers add artificial colourings, colour-retaining agents and other additives. While these practices remain within legal boundaries, they dilute or even obscure the food's 'natural nutritional composition', thereby affecting consumers' accurate assessment of its nutritional value.

3.2.3 Nutrition-oriented processing standards and regulatory framework

The current regulatory framework for food processing in China predominantly focuses on safety and hygiene aspects, with notably insufficient attention paid to nutritional preservation. Particularly within small and medium-sized enterprises, systematic standards for nutrient retention control remain largely absent. Parameters such as vitamin retention rates and protein denaturation rates should be established as quality benchmarks during processing; however, in practice, most enterprises have yet to implement such technical specifications. Concurrently, the absence of labelling systems and incentive mechanisms for "high-nutrient retention" products has dampened enterprises' willingness to invest in nutritional preservation, while high-quality nutritional products struggle to command a premium in the marketplace. Nutritional information accessible

to consumers is often incomplete or ambiguous, while processing enterprises lack traceability management capabilities regarding changes in nutritional content, further undermining the market's ability to guide nutritional safety.

3.3 Distribution Chain

The distribution stage is a critical phase in ensuring the nutritional safety of fresh produce from source to table, with the cold chain logistics system playing a decisive role throughout this process. Following harvesting and processing, if fresh foodstuffs fail to maintain a stable low-temperature environment during transportation, storage, and distribution, their internal nutritional structure becomes highly susceptible to alteration. This can result in the loss of nutrients or the spoilage of the food. At present, the development of China's cold chain logistics system remains uneven, with the following issues persisting:

Firstly, cold chain logistics coverage remains at a relatively low level, particularly in central and western regions and rural markets. There is an insufficient provision of refrigeration facilities, cold storage, and cold chain transport vehicles, with a significant volume of fresh produce still being transported at ambient temperatures. Data indicates that over 30% of fresh produce undergoes distribution without a fully integrated cold chain system, resulting in a significant decline in their nutritional and bioactive components. Secondly, there exists a significant issue of "cold chain breaks" during refrigerated transport. Temperature fluctuations frequently occur during cargo handling, vehicle waiting periods, and final-mile delivery stages. Particularly during high-temperature seasons or long-distance journeys, such instability in temperature control can lead to the degradation of vitamins, antioxidants, and active enzymes within foodstuffs. Furthermore, repeated freezing and thawing can cause protein denaturation and moisture loss, directly affecting food quality and nutritional absorption efficiency. Insufficient levels of informatisation and intelligent management also represent a significant shortcoming in the current cold chain distribution process. Some enterprises still rely on manual monitoring of transport conditions, lacking dynamic monitoring systems based on the Internet of Things (IoT), big data, and real-time temperature and humidity recording. Consequently, they are unable to achieve fully

visualised and traceable temperature control management throughout the entire process.

Moreover, the absence of a unified cold chain standard system is also a significant factor hindering the assurance of nutritional safety. The industry currently lacks standardised requirements for temperature, humidity and other parameters during the transportation and storage of different categories of fresh produce. Coupled with regulatory blind spots, this has led to considerable arbitrariness in enterprises' implementation of cold chain operations, making it difficult to enforce nutritional control measures.

4. Upgrade Path

Addressing the vulnerabilities and systemic issues in the nutritional safety of fresh food products across production, processing, distribution and consumption in China, efforts should be made to enhance nutritional safety capabilities throughout the entire supply chain. This requires a multi-faceted approach encompassing policy support, standardisation, technological innovation and consumer education. The ultimate goal is to achieve comprehensive nutritional protection and information transparency throughout the entire process, from farm to fork.

4.1 Strengthen Governance at Source to Promote Green, Nutrition-Oriented Agricultural Development

To fundamentally safeguard the nutritional safety of fresh food, it is essential to address the issue at its agricultural source. Efforts should be intensified to develop and promote nutrition-enriched crop varieties, incorporating nutritional content into the assessment framework for agricultural research. This will encourage the cultivation of high-quality varieties rich in vitamins, minerals and functional components. Concurrently, we shall vigorously advance the development of green and ecological agriculture, reducing reliance on high-residue pesticides and chemical fertilisers, enhancing soil ecological functions, and improving the nutritional absorption foundation of agricultural products. The government may employ measures such as financial subsidies, technical guidance, and insurance mechanisms to guide farmers towards adopting scientific cultivation and breeding practices, thereby establishing a source-based production mechanism centred on nutritional

value.

4.2 Advancing Technological Upgrades and Standardisation in Processing Operations

Processing stages represent high-risk areas for nutrient depletion, necessitating scientific and nutrition-focused handling through technological upgrades and the establishment of standardised systems. On the one hand, enterprises are encouraged to adopt advanced technologies such as low-temperature processing, modified atmosphere preservation, vacuum packaging, and non-thermal sterilisation to enhance nutrient retention capabilities. On the other hand, standards for nutrient retention rates during fresh food processing are to be formulated and implemented, incorporating nutritional indicators such as vitamin loss and protein denaturation rates into the food quality evaluation system. Concurrently, efforts will be made to advance the establishment of a nutritional information disclosure system, with packaging displaying the retention status of key nutrients to enhance consumers' ability to recognise a product's nutritional value.

4.3 Establishing an Intelligent cold Chain Logistics System to Ensure the Stable Delivery of Nutrients

Strengthening the cold chain logistics system is key to addressing risks in the distribution of nutritional products. The deployment of cold chain infrastructure in central, western and rural regions should be accelerated, particularly in major agricultural production areas and around agricultural wholesale markets, with the construction of standardised cold storage facilities and low-temperature distribution centres. Advance the intelligent development of cold chain logistics by extensively deploying the Internet of Things, big data analytics, and temperature-humidity monitoring systems to achieve end-to-end temperature control and traceability. Refine the industry's cold chain standards framework by specifying optimal parameter requirements for transporting, storing, and distributing diverse fresh produce categories. Enhance the enforceability and implementation rate of these regulations to prevent nutritional quality fluctuations caused by cold chain interruptions.

4.4 Enhancing Consumers' Nutritional Literacy and Promoting Shared Governance

of Nutritional Safety within Society

As the ultimate recipients of nutritional safety, consumers' levels of awareness and behavioural habits directly influence the direction of optimisation across the entire nutritional supply chain. Efforts should be made to enhance public awareness and discernment regarding nutritional safety through diverse approaches, including science communication campaigns, media guidance, and nutrition education programmes in schools. Establish a nationally unified standard for nutritional labelling of fresh food products and promote a 'nutritional grading labelling' system to guide consumers towards making more informed food choices. Concurrently, leverage the oversight functions of industry associations, third-party testing bodies and media outlets to establish a tripartite nutritional safety governance framework comprising government regulation, corporate self-discipline and public participation. This will foster a positive market environment characterised by nutritional transparency and healthier food offerings.

5. Summary

This paper adopts an industrial chain perspective to systematically analyse nutritional safety issues encountered in the production, processing, distribution and consumption of fresh foodstuffs. It identifies multiple shortcomings in China's fresh food sector concerning nutritional control at source, preservation of nutrients during processing, stability of cold chain logistics, and consumer nutritional awareness. These deficiencies constrain the effective transmission of nutritional value throughout the entire food supply chain. Research indicates that enhancing the nutritional safety of fresh food requires a four-pronged approach: establishing a nutrition-oriented agricultural system, advancing processing technologies and standards, improving intelligent cold chain logistics systems, and elevating consumer nutritional literacy. This will foster a multi-stakeholder collaborative mechanism for nutritional safety assurance, featuring comprehensive oversight throughout the entire production chain. Future research may further strengthen empirical analysis by constructing quantitative models of nutrient loss, delving deeper into the pathways through which different product categories and supply chain segments impact nutritional content. Concurrently, it should advance the integration

of food nutrition safety research with digital technologies and nutritional science, thereby enhancing the scientific rigour and practical guidance value of such studies. This will provide theoretical underpinnings and policy recommendations for establishing a safer, healthier, and more efficient food industry system.

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