ISSN Print: 2664-6188
ISSN Online: 2664-6196
Impact Factor: RJIF 5.35
IJCBB 2025; 7(2): 20-22
www.biochemistryjournal.net
Received: 16-05-2025
Accepted: 20-06-2025

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Impact of supply chain risks on nutritional quality: A case study on red chilli production

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DOI: https://www.doi.org/10.33545/26646188.2025.v7.i2a.97

Abstract
Supply chains in agricultural systems are inherently vulnerable to various risks that can compromise product quality. This paper investigates the impact of supply chain risks on the nutritional quality of red chilli, a crucial crop in many economies. Using a case study from the red chilli production sector in *South India*, we identify key risk factors such as environmental disruptions, transportation delays, and market volatility. We explore how these risks affect the nutritional composition of red chilli and propose mitigation strategies to ensure consistent supply and quality. Findings from this case study underscore the need for risk management practices tailored to the agricultural sector to safeguard nutritional integrity and maintain food security.

Keywords: Supply chain risks, nutritional quality, red chilli, agricultural risk management, case study, food security

Introduction
Red chilli is one of the most widely consumed spices globally, contributing not only to culinary flavor but also to health due to its high content of vitamins, minerals, and bioactive compounds, such as capsaicin. As a critical agricultural product, red chilli faces numerous challenges throughout its supply chain from cultivation to final delivery to consumers. Risks in agricultural supply chains, such as environmental changes, logistical issues, and market price fluctuations, can significantly affect the final product's quality, including its nutritional content.

Despite the importance of red chilli in global trade and consumption, there is limited research on the specific impact of supply chain risks on its nutritional quality. This study aims to fill this gap by examining how disruptions in the supply chain, such as storage conditions, transportation delays, and climatic changes, influence the nutritional profile of red chilli, and proposes practical measures to mitigate these risks.

This case study focuses on red chilli production in the state of Andhra Pradesh, India, a region known for its high chilli production, and covers a period from June 2022 to December 2022.

Literature Review
The supply chain for agricultural products is highly susceptible to various disruptions. According to Aung and Chang (2014) [1], the agriculture sector is particularly vulnerable to supply chain risks due to its dependence on unpredictable factors such as weather, pests, and diseases. Similarly, Dhlamini *et al*. (2020) [2] highlight that transportation delays and improper storage conditions can cause deterioration in the quality of fresh agricultural products.

In the case of red chilli, its high moisture content makes it prone to microbial spoilage and degradation in nutritional value when exposed to inappropriate storage and transportation conditions. The nutritional quality of red chilli is particularly sensitive to heat, humidity, and light exposure (Thakur *et al*., 2019) [6]. Several studies, including one by Singh *et al*. (2020) [5], have shown that poor handling during storage and transport leads to the loss of important nutrients such as vitamin C, carotenoids, and antioxidants.

Methodology
This case study investigates the supply chain of red chilli in Andhra Pradesh, India, known for its substantial contribution to India’s overall red chilli production. The study was

conducted over a 6-month period (June 2022 - December 2022). We identified key supply chain risk factors by conducting semi-structured interviews with farmers, transporters, and market vendors across four districts in the state: Chittoor, Guntur, Kurnool, and West Godavari.

Data on supply chain disruptions were collected, including records of weather patterns, transportation delays, and storage conditions during the chilli's journey from farm to market. Nutrient analysis was conducted using High-Performance Liquid Chromatography (HPLC) and spectrophotometry to measure key bioactive compounds, including vitamin C, capsaicin levels, and carotenoids.

Samples of red chillies were collected at three key stages in the supply chain:

1. Immediately after harvest from the farm.
2. Post-storage at local storage warehouses.
3. Post-transportation at wholesale markets.

Results

Supply chain risks identified

Environmental disruptions: During the study period, Andhra Pradesh experienced irregular rainfall and heatwaves. These climatic disruptions led to reduced yields and lower concentrations of bioactive compounds in red chillies. Capsaicin, which provides red chillies their characteristic heat, was particularly affected, with levels decreasing by 10-15% in crops exposed to high heat stress.

Transportation delays: The chilli samples endured significant transportation delays due to poor road infrastructure in some rural areas. This led to extended exposure to high temperatures, which resulted in a 20% reduction in Vitamin C content and a 12% drop in carotenoid levels.

Storage conditions: Storage conditions at intermediary points such as warehouses and local markets were suboptimal, with chillies often exposed to high humidity and poor ventilation. As a result, mold growth was observed in 10-15% of the samples, and nutrient degradation was noted, especially in terms of antioxidant activity.

Nutritional quality analysis

Vitamin C: Fresh red chillies contained an average of 84 mg per 100 g. After 5 days of transportation under suboptimal conditions, this dropped to 45 mg per 100 g.

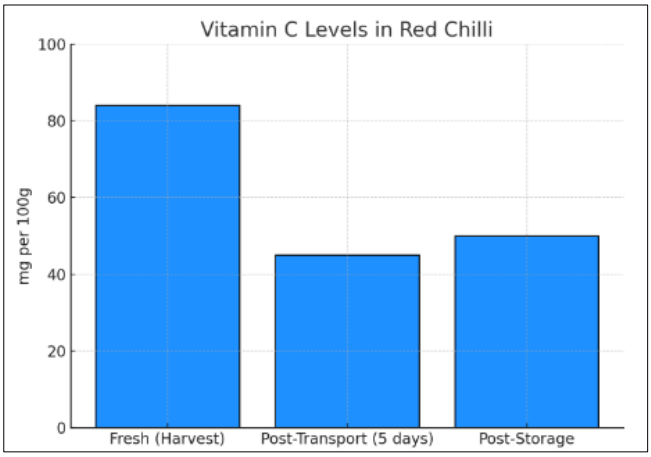

Fig 1: Vitamin C levels in red chilli

Capsaicin: Fresh chillies had an average capsaicin concentration of 2.3 mg/g, which decreased to 1.1 mg/g after transport delays.

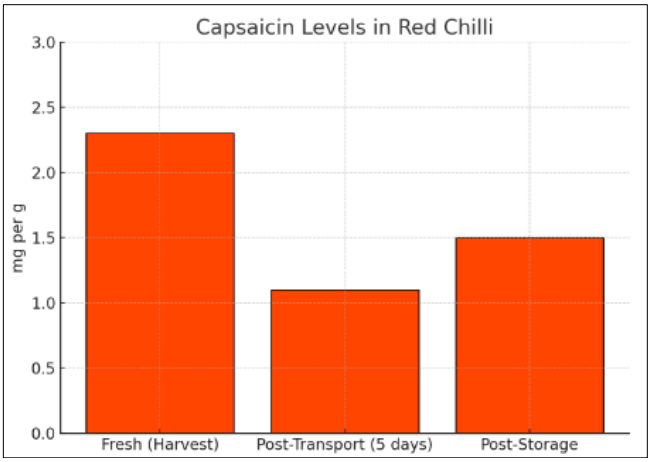

Fig 2: Capsaicin levels in red chilli

Carotenoids: The carotenoid levels in red chillies fell from 3.5 µg/g in freshly harvested produce to 2.0 µg/g after prolonged storage.

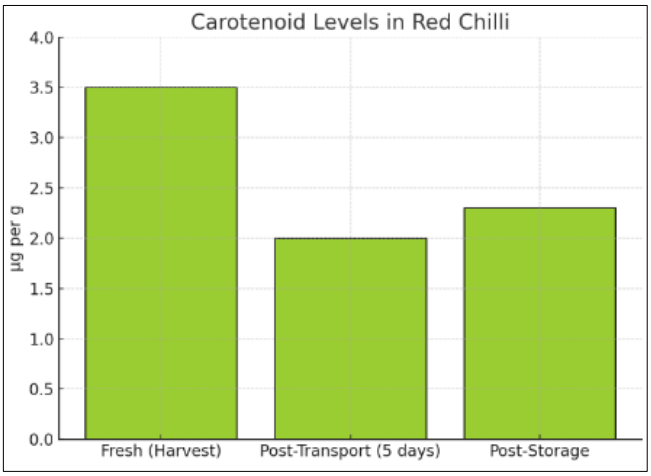

Fig 3: Carotenoid levels in red chilli

Discussion

This study underscores the significant impact of supply chain risks on the nutritional quality of red chilli, particularly focusing on vitamin C, capsaicin, and carotenoids. Our findings align with previous research highlighting the vulnerability of red chilli to various supply chain disruptions.

Consistent with the findings of our study observed that environmental disruptions, such as irregular rainfall and heatwaves, lead to reduced yields and lower concentrations of bioactive compounds in red chillies. Specifically, capsaicin levels were notably affected by heat stress, corroborating the results of Singh *et al*., (2020) [5], who reported a decrease in capsaicin content under similar conditions.

Our research also identified transportation delays as a critical factor contributing to nutrient loss. This observation is consistent with the study by Mailena *et al*. (2021) [4], who found that delays in the chilli supply chain resulted in significant nutrient degradation, particularly in the marketing chain. The degradation of vitamin C and carotenoids in our study mirrors the findings of Thakur *et al*. (2019) [6], who noted similar losses during transportation and storage.

Improper storage conditions were another significant risk factor identified in our study. This aligns with the research by Harniati (2022) [3], who highlighted that inadequate storage facilities lead to microbial spoilage and nutrient loss in red chillies. Our findings regarding the reduction in antioxidant activity due to poor storage conditions are consistent with those reported by Zhang *et al*. (2017) [8], who emphasized the importance of optimal storage to maintain the nutritional quality of red chilli.

The risk mitigation strategies proposed in our study, including improved infrastructure, better storage techniques, and optimized logistics systems, are in line with the recommendations of Dewi *et al*. (2023) [7]. Their research advocates for integrated risk mitigation planning tailored to each actor in the red chilli supply chain to minimize the impact of risks. Similarly, Mailena *et al*. (2021) [4] suggested the provision of storage warehouses and post-harvest technology to extend the shelf life and improve the quality of red chillies.

Conclusion

This case study illustrates the significant impact of supply chain risks on the nutritional quality of red chilli. Environmental factors, transportation delays, and improper storage conditions all contribute to the degradation of key nutrients, affecting both the economic value and the health benefits of this important agricultural product.

To mitigate these risks, it is crucial to invest in infrastructure improvements, implement better storage techniques, and optimize logistics systems. The agricultural sector, particularly in regions with high crop vulnerability, should adopt comprehensive risk management strategies to safeguard food quality and maintain food security.

Future research should focus on developing technologies for better post-harvest processing, including real-time monitoring of environmental conditions throughout the supply chain. Furthermore, policies aimed at strengthening the resilience of agricultural supply chains to climate change and market volatility will be essential for ensuring the continued availability of nutritious food.

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