

Vietnam's pepper industry in transition: A review of production, processing and market dynamics of black and white pepper

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Abstract

The aim of this study was to review the current status of pepper production in Vietnam, with particular attention to regional cultivation patterns, the classification and distinguishing characteristics of black and white pepper, major processing technologies and value-chain structure, recent global market dynamics and trade trends, and the principal challenges affecting the sector. Vietnam has maintained a dominant position in the global pepper industry, supported by its large production base, strong export performance, and growing integration into international spice value chains. However, the sector is undergoing a substantial transition as it faces increasing pressure to improve product quality, processing efficiency, market responsiveness, and long-term sustainability. The methods used involved a comprehensive review of recent scientific literature, industry reports, and trade-related sources to synthesize current knowledge on pepper production, processing systems, market developments, and sectoral constraints in Vietnam. The results showed that pepper production in Vietnam is strongly concentrated in the Central Highlands and the Southeast region, while black and white pepper differ markedly in harvest maturity, processing methods, physicochemical properties, and commercial value. The results also showed that processing technologies, ranging from primary drying and cleaning to deep processing and quality standardization, play an increasingly important role in product differentiation and export competitiveness. In addition, recent trade patterns indicate that Vietnam remains highly influential in global pepper markets, although export performance is increasingly shaped by market diversification, stricter regulatory requirements, and pronounced price volatility. The review contributes to a deeper understanding of the structural, technological, and market-related factors shaping the development of Vietnam's pepper industry. It highlights that the future competitiveness of the sector will depend not only on maintaining production volume, but also on strengthening post-harvest technology, quality assurance, traceability, environmental sustainability, and resilience to market and climate-related risks. A more integrated and value-oriented development strategy is therefore essential for sustaining Vietnam's leadership in the global pepper sector.

Keywords: Black pepper; *Piper nigrum*; Pepper value chain; Price volatility; Processing technologies; Trade trends; White pepper

1 Introduction

Pepper (*Piper nigrum* L.) is one of the most widely traded spice commodities globally, with Vietnam maintaining a dominant position in both production and export over the past two decades. The country's leadership is supported not only by large-scale cultivation but also by increasing integration into global value chains, expanding processing capacity, and gradual alignment with international quality and safety standards [1, 2]. However, the evolution of the Vietnamese

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pepper sector reflects a broader transition from volume-driven expansion toward a more complex system shaped by market requirements, regulatory pressures, and sustainability concerns.

This transformation is strongly associated with regional specialization. Pepper cultivation in Vietnam is primarily concentrated in the Central Highlands and the Southeast region, which together form the core production belt of the country. While the Central Highlands dominates in terms of cultivation area and agro-ecological suitability, the Southeast plays a complementary role through its established processing infrastructure and proximity to major export logistics hubs. In addition, smaller regions such as Phú Quốc Island and Quảng Trị Province contribute to product differentiation by offering distinct sensory characteristics and origin-linked value, highlighting the growing importance of geographical identity in the global spice market [3].

Despite its global prominence, the Vietnamese pepper industry faces multiple interconnected challenges, including price volatility, soil degradation, disease pressure, and increasing competition for land due to industrialization and urban expansion. At the same time, stricter international standards on food safety and traceability require continuous improvements in post-harvest processing and quality control. In this context, a comprehensive reassessment of the sector is needed to better understand how production systems, regional characteristics, processing practices and market dynamics interact, and how these factors collectively shape the long-term sustainability and competitiveness of Vietnam's pepper industry.

2 Production status of pepper in Vietnam

The success of Vietnam's pepper industry is deeply rooted in the country's unique geography and favorable agro-ecological parameters. Cultivation is not uniform across the nation but is strategically concentrated in regions that offer the precise combination of volcanic soil, tropical climate, and water availability required for pepper to thrive.

2.1 Regional distribution and key production hubs

2.1.1 The Central Highlands

Pepper cultivation in Vietnam exhibits a high degree of geographical concentration, forming a production structure that is both efficient and vulnerable. Current estimates indicate that the Central Highlands and Southeast region jointly contribute over 90% of national output, with total cultivation area of the Central Highlands ranging from 120,000 to 130,000 ha and production fluctuating between 180,000 and 200,000 tons annually [2]. This spatial clustering has enabled Vietnam to achieve economies of scale and maintain its position as the world's leading exporter; however, it also amplifies systemic risks associated with climate variability, disease outbreaks, and market shocks. The Central Highlands (Tây Nguyên) remains the primary epicenter of Vietnam's pepper production, accounting for an estimated 60-65% of the total national output [2]. The region's dominance is anchored in its unique agro-ecological foundation, characterized by mineral-rich basaltic soils, moderate elevations (500-800 m), and a distinct monsoonal climate [4]. According to the latest 2025-2026 statistical data, Lâm Đồng (Đắk Nông) Province has solidified its position as the leading hub, managing a vast cultivation area of 34,500 hectares with an output of 110,000 tons, followed by Đắk Lắk Province (28,000 ha; 80,000 tons) and Gia Lai Province (8420 ha; 26,600 tons) (Table 1). Beyond raw volume, the region is spearheading a profound structural transformation from quantity-driven expansion to quality-oriented systems. Lâm Đồng (Đắk Nông) Province, has particularly emerged as a pioneer for sustainable and organic pepper, with a rapidly increasing number of households achieving GlobalGAP and international organic certifications to meet stringent European standards [4]. This transition is essential for moving away from traditional intensive farming toward traceable and export-compliant supply chains. However, the Central Highlands faces existential environmental and biological threats. Decades of intensive monoculture have led to severe soil degradation and a precarious decline in groundwater levels, which are critical for irrigation during the dry season [5]. Furthermore, the region remains highly vulnerable to soil-borne pathogens, specifically *Phytophthora* spp. foot rot and *Fusarium* spp. wilt, which continue to threaten long-term productivity [6]. To maintain its global leadership, the region must prioritize integrated pest management (IPM) and climate-smart agricultural practices to mitigate these growing ecological stressors.

2.1.2 The Southeast regions

The Southeast region stands as a cornerstone of Vietnam's pepper industry, contributing approximately 30-35% of the national output. This region forms a vital production corridor alongside the Central Highlands, driven by major hubs such as Đồng Nai (Bình Phước) Province, and Hồ Chí Minh City (Bà Rịa-Vũng Tàu). According to recent data, Đồng Nai (Bình Phước) Province maintains an extensive cultivation area of approximately 17,000 hectares with production of about 22,500 tons, while Hồ Chí Minh City (Bà Rịa-Vũng Tàu) with approximately 10,370 hectares contributes an estimated 25,000 tons to the annual supply (Table 1). Although the agro-ecological conditions here are slightly less

optimal than the volcanic soils of the Central Highlands, the Southeast compensates through its superior post-harvest processing infrastructure and sophisticated logistical advantages. A defining feature of this region is its proximity to the Cái Mép-Thị Vải port complex, a strategic deep-water gateway that facilitates direct export routes to Europe and North America [7]. This proximity allows for tighter value chain integration and reduces the "farm-to-port" lead time, which is essential for maintaining the chemical and microbiological integrity of high-value products like white pepper. However, the region is currently grappling with intense land-use competition. Rapid industrialization and urban expansion, particularly in provinces like Đồng Nai which currently manages ~21,500 hectares are exerting significant pressure on agricultural land, often constraining the potential for future horizontal expansion (Table 1).

2.1.3 Specialty regions

Beyond these major production corridors, niche regions such as Phú Quốc Island and Quảng Trị Province contribute marginally (<3% of total output) but are strategically important for product differentiation and premium market positioning. Phú Quốc pepper is best understood as a niche island specialty rather than a bulk commercial pepper. It is described to have hard peppercorns and a distinctly spicy, tangy taste, while also emphasizing its close linkage with tourism, where pepper farms and pepper products are integrated into local visitor itineraries and souvenir markets. However, its market development appears uneven: sales are reported to be seasonal, oriented mainly toward domestic tourists, and constrained by weak branding, simple product presentation, and the circulation of counterfeit goods. This specialty image is broadly consistent with technical studies on Phú Quốc white pepper, whose essential oil is dominated by limonene, 3-carene, and sabinene, suggesting a terpene-rich aromatic profile [8]. By contrast, Quảng Trị pepper is increasingly distinguishable through a clearer sensory-territorial identity. Recent sensory and GC-MS research characterizes Quảng Trị pepper by fatty and pungent notes, with a rich, full-bodied profile associated with creamy aroma persistence, while broader studies on Vietnamese traditional products position Quảng Trị pepper as a place-linked community brand with long term commercial and cultural value. Overall, Phú Quốc pepper may be framed as a tourism-driven specialty product with spicy and tangy appeal, whereas Quảng Trị pepper is more convincingly presented as a terroir-linked specialty pepper valued for its deeper, fuller, and more persistent sensory profile [8].

Table 1 Geographical distribution of major pepper cultivation regions in Vietnam. The Central Highlands (Đắk Lắk, Đắk Nông, Gia Lai) and Southeast region (Bình Phước, Đồng Nai, Bà Rịa - Vũng Tàu) form the primary production corridor, accounting for over 90% of national output. Smaller specialty regions such as Phú Quốc and Quảng Trị contribute limited volumes but play a critical role in supplying high-value niche markets with distinctive quality attributes

Region	Province	Area (ha)	Production (tons)	References
Central Highlands	Đắk Lắk	~28,000	~80,000	[10]
	Lâm Đồng (Đắk Nông)	~34,500	~110,000	[2]
	Gia Lai	~8,420	~26,600	[11]
Southeast	Đồng Nai (Bình Phước)	~17,000	~22,500	[2]
	Đồng Nai (Đồng Nai)	~21,500	~45,000	[12]
	Hồ Chí Minh City (Bà Rịa-Vũng Tàu)	~10,370	~25,000	[2]
Specialty regions	Phú Quốc	~500	~1,200	[13]
	Quảng Trị	~2,000	~2,700	[2]

Overall, while Vietnam's pepper industry benefits from strong regional specialization and high production efficiency, its heavy reliance on a limited number of agro-ecological zones raises concerns regarding sustainability, climate resilience, and supply stability. Future development strategies should therefore prioritize diversification of production areas, adoption of sustainable cultivation practices, and strengthening of regional value chains to mitigate systemic risks.

2.2 Soil, climate, and adaptive farming strategies

The success of Vietnam's pepper industry is deeply rooted in the synergy between favorable pedoclimatic conditions and regional adaptive farming strategies. Pepper cultivation is predominantly distributed across diverse agro-ecological zones, where soil characteristics and climate patterns play a deterministic role in crop performance and chemical composition. Recent evaluations of physicochemical indicators across major growing areas have demonstrated that environmental factors significantly influence the quality profiles of black pepper, including parameters such as moisture

content, piperine levels, and ash content [14]. These regional variations necessitate a precision-based approach to monitoring to ensure that products from different soil types meet stringent international trade benchmarks. To mitigate the challenges posed by varying climates and soil degradation, the selection of high-performing varieties has emerged as a core adaptive strategy. Research on four prominent black pepper varieties across three target provinces revealed that growth and productivity are highly dependent on the interaction between genetic potential and local environmental stressors. The study emphasizes that site-specific variety selection is crucial for maximizing yields and ensuring the stability of production cycles under fluctuating monsoonal conditions. This varietal adaptation is not only essential for biological resilience but also for maintaining the consistency of the sensory and chemical attributes required by the global market [3]. Furthermore, as the industry transitions toward quality-oriented growth, technological adaptation in origin tracking and quality control has become indispensable. The integration of advanced analytical tools, such as near-infrared (NIR) spectroscopy combined with chemometrics, allows for the rapid and non-destructive identification of the geographical origin of Vietnamese black pepper [15]. This capability represents a sophisticated adaptive strategy to protect geographical indications and enhance the transparency of the supply chain. By aligning traditional farming practices with modern analytical monitoring and strategic variety deployment, Vietnam continues to refine its cultivation systems to address environmental constraints and evolving regulatory demands in the global spice trade.

The exceptional productivity of Vietnamese pepper vines is intrinsically linked to the presence of nutrient-rich red basaltic soils and a predictable tropical monsoon climate. Formed from prehistoric volcanic activity, these soils possess a porous structure and high organic matter content that facilitate deep root development while preventing the waterlogging that often triggers devastating fungal infections like *Phytophthora* spp. The climate is characterized by two distinct phases: a monsoon season from May to November that supports vegetative growth and fruit set, followed by a dry period from December to April which provides the necessary biological stress for flower bud initiation. Regional variations in soil, climate, and management practices have led to distinct differences in pepper quality and chemical composition, highlighting the importance of regional identification and origin tracing for export and quality certification [15]. However, as the industry navigates the current decade, erratic weather patterns have necessitated a rapid transition toward more resilient farming practices. Farmers are increasingly adopting regenerative agroforestry models, which utilize living support trees to create a shaded microclimate, maintain soil moisture, and reduce chemical dependency. These adaptive strategies not only protect the crops from thermal stress but also align with the European Union Deforestation Regulation (EUDR), reinforcing Vietnam's commitment to sustainable and traceable agricultural supply chains.

3 Product classification - black pepper and white pepper

Pepper products are generally classified into two major commercial types: black pepper and white pepper, both derived from the same fruit but processed using different harvesting stages and post-harvest treatments. The differences in maturity at harvest and processing methods lead to distinct physical characteristics, flavor profiles, and market positioning.

3.1 Black pepper production and characteristics

Black pepper remains the most commercially significant and widely consumed spice globally, derived from unripe berries harvested at a critical physiological stage when they are nearly mature - fully developed in size and firm to the touch, yet still green. Harvesting at this specific juncture is vital as it preserves the maximum concentration of volatile oils and alkaloids, ensuring the peppercorns retain their characteristic pungent aroma and heat [1]. The chemical profile of Vietnamese black pepper is particularly esteemed in the international food industry due to its high density of bioactive compounds, including essential oils, phenolic substances, and alkaloids. Among these, piperine stands as the primary alkaloid responsible for the spice's signature pungency. Recent physicochemical evaluations of pepper from major Vietnamese growing regions like Đắk Lắk and Quảng Trị have identified piperine concentrations ranging typically from 4.2% to 5.3%, though superior cultivars and optimized processing can push these levels higher, reaching up to 9% in specialized batches [14]. Beyond flavor, these compounds are increasingly scrutinized for their pharmacological properties, including antioxidant and anti-inflammatory benefits, which has further bolstered the demand for high-purity Vietnamese extracts in the pharmaceutical and nutraceutical sectors.

Vietnam currently solidifies its position as the global powerhouse of the pepper trade, accounting for 57.5% of global pepper export volume [2]. In 2025, the industry achieved a historic milestone, with export turnover reaching a record-breaking 1.66 billion USD despite a slight decline in total output volume. This paradox - higher revenue from lower supply - is attributed to a significant surge in global demand paired with a supply crunch in other major producing nations like Brazil and Indonesia. Major importing regions, led by the United States, the European Union, and the United

Arab Emirates, have shown a growing preference for Vietnamese pepper that meets stringent "clean-label" and sustainable certifications. To maintain this competitive edge, Vietnamese exporters are rapidly investing in deep-processing technologies, such as steam sterilization and cryo-grinding, to satisfy the rigorous maximum residue limits (MRLs) and food safety standards imposed by Western markets [2]. Reflecting this global supply-demand imbalance, farm-gate prices in Vietnam have entered a high-value cycle in the 2024-2026 period. After years of stagnation, domestic prices skyrocketed from approximately 80,000 VND per kilogram in early 2024 to peaks of 180,000 VND per kilogram by mid-year, eventually stabilizing at a robust range of 145,000 to 160,000 VND per kilogram throughout 2025 and into early 2026. Experts anticipate that prices will remain elevated through the 2026 harvest season, as domestic production is forecast to decrease by another 15% to 20% due to climate-driven yield fluctuations and the aging of existing plantations [16]. This economic environment has provided a much-needed boost to rural livelihoods in the Central Highlands, encouraging farmers to reinvest in sustainable, high-yield cultivation practices that ensure the long-term viability of Vietnam's most vital spice export.

3.2 White pepper production and characteristics

In contrast to the standard production of black pepper, white pepper represents a specialized segment of the Vietnamese spice industry, characterized by its distinct processing methodology and refined flavor profile. The production cycle begins with the harvest of fully ripe berries, identifiable by their bright red or yellow coloration, which indicates a higher sugar content in the mesocarp compared to the green berries used for black pepper. Harvesting at this advanced stage of maturity is essential for the subsequent decortication process, as the softened outer skin is more easily separated from the inner seed. This selective harvesting requires more intensive labor and precise timing, as over-ripe berries risk falling from the vine or being damaged by pests, while under-ripe berries result in a lower-quality white peppercorn with a persistent greyish tint [17]. Because the removal of the outer skin results in a weight loss of approximately 25% to 30% compared to black pepper, and because the labor and water costs are substantially higher, white pepper consistently commands a significantly higher price point on the global stage. Throughout the 2025 and early 2026 seasons, Vietnamese white pepper has maintained a price premium of roughly 30% to 40% over its black counterpart, with export prices often exceeding USD 8,000 per ton. Vietnam's strategic shift towards increasing the proportion of white pepper in its export basket is a response to growing demand from high-end culinary markets in Japan, Germany, and the United States, where it is preferred for its aesthetic purity in light-colored sauces and its more nuanced, less pungent heat [18].

From a market perspective, the Vietnamese white pepper sector is transitioning from volume-based export toward higher-value processing and quality improvement. The rising export price, coupled with relatively stable or declining production, indicates a shift toward premiumization and deeper processing, including fermentation and refined products. This trend is expected to continue in 2026, with export revenues projected to surpass previous records due to persistently high prices and strong international demand. Overall, white pepper plays a strategic role in enhancing the value chain of Vietnam's pepper industry, contributing significantly to export earnings and positioning the country as a key supplier of high-quality spices in the global market.

4 Processing technologies

4.1 Traditional versus industrial processing

Post-harvest processing is a critical step influencing the quality, safety, and market value of black pepper. After harvesting, pepper berries are typically subjected to drying to reduce moisture content and prevent microbial deterioration during storage. In many producing regions, open sun drying remains the most common traditional method, where pepper berries are spread in thin layers and exposed to sunlight for several days until the moisture content is sufficiently reduced. This method is widely adopted because of its low cost and simplicity; however, it strongly depends on weather conditions and may lead to uneven drying or contamination [19]. To improve processing efficiency and product quality, mechanical drying systems such as fixed-bed or hot-air dryers have increasingly been investigated and applied in pepper processing. Experimental studies on convective drying of black pepper have demonstrated that controlled drying conditions allow better regulation of heat and mass transfer processes, thereby improving drying efficiency and enabling process optimization for industrial applications [20]. Processing methods can also influence the physicochemical quality of pepper products. Research comparing different processing techniques has shown that blanching followed by sun-drying can improve quality attributes such as essential oil and oleoresin content, which are important indicators of pepper flavor and commercial value [21]. After drying, additional industrial steps are often implemented to ensure product safety and quality consistency. These may include cleaning, grading, and further processing into value-added products such as ground pepper, essential oils, and oleoresins used in the food industry.

Efficient post-harvest handling and processing are therefore essential to maintain pepper quality and meet the increasingly strict requirements of the international spice market [22].

4.2 Quality control and standards

Quality control and regulatory compliance are essential to ensure the safety and export competitiveness of white pepper. Standards set by the American Spice Trade Association define key quality parameters such as moisture, purity, and microbial limits, serving as an important benchmark for international trade. At the same time, exporters must comply with the stringent European Union on pesticide residues, requiring strict control of cultivation and post-harvest practices. Microbial safety is particularly critical due to traditional soaking processes, necessitating improved hygiene and decontamination methods to prevent contamination by pathogens such as *Salmonella* spp. In addition, monitoring of heavy metals (e.g. Pb, Cd, As) and aflatoxins is mandatory to meet food safety requirements, as these contaminants can arise from environmental exposure and improper storage. Overall, integrated control of chemical and microbiological hazards is crucial for maintaining product quality and accessing high-value markets [23, 24, 25].

5 Global market dynamics and trade trends

5.1 Global demand dynamics and major pepper import markets

Vietnam's pepper export market is broad in geographic reach but still anchored by a limited number of major destinations. In 2025, the country exported about 247,482 tons of pepper worth USD 1.66 billion, the highest export value ever recorded for the sector. Although export volume declined slightly from the previous year, export earnings rose sharply because of higher international prices. The United States remained Vietnam's largest single market, importing 55,082 tons and accounting for 22.3% of total exports, while other major destinations included the United Arab Emirates, China, India, and Germany. This pattern indicates that Vietnam's pepper trade is no longer concentrated only in traditional end-use markets, but it is increasingly distributed across a mix of direct consumption markets, re-export hubs, and regional distribution centers [16].

From a value-chain perspective, Vietnam's pepper export market is becoming more differentiated in both destination profile and market requirements. In the first nine months of 2025, the United States, Germany, and India were the three largest markets by export value, accounting for 24.7%, 8.1%, and 6.1% of total export turnover, respectively. Over the same period, export value to Germany increased by 43.4%, while exports to India rose by 64.3%, reflecting expanding opportunities beyond the dominant US market. At the same time, the sector is under growing pressure to comply with stricter sustainability, food safety, and traceability standards in high-value destinations such as the EU and the US. As a result, the competitiveness of Vietnamese pepper in export markets increasingly depends not only on supply volume and price, but also on the industry's ability to meet regulatory expectations and deliver more standardized, higher-value products [26].

5.2 Global price volatility

Global pepper prices have shown pronounced volatility in recent years, shifting from pandemic-era demand weakness to sharp upward corrections once supply tightened. The International Pepper Community (IPC) noted that global demand was subdued in 2020 because of COVID-19, yet by early 2021 the Vietnamese market had already become highly unstable: black pepper prices rose by about 40% within three weeks after Tet, and the IPC explicitly described this movement as "unpredictable" and potentially disconnected from normal market fundamentals. This early rebound highlighted how strongly pepper prices can react not only to consumption trends, but also to inventory behaviour, supply expectations, and speculative holding by growers and traders [27].

Price volatility intensified further in 2024 and 2025 as the market entered a period of tighter supply. In April 2024, farm-gate pepper prices in Vietnam had risen to roughly VND 96,500 - 98,000 per kilogram, while the average export price for the year to date reached USD 4,189 per ton, up 36.8% year on year; according to Vietnam Pepper and Spice Association (VPSA), this increase was linked to low supply, a stronger US dollar, transport disruptions associated with global conflicts, and speculation. By 2025, the IPC characterized the global pepper market as operating under structurally tight conditions, with limited carry-over stocks and rising production, compliance, and logistics costs. Consistent with this assessment, Vietnam's 2025 pepper export volume declined by about 1.2%, but export value surged by 26%, while average export prices rose to USD 6,607 per ton for black pepper and USD 8,629 per ton for white pepper, both more than 30% above 2024 levels. Together, these developments suggest that recent global pepper price volatility has been driven by an interaction of supply constraints, low inventories, logistics costs, regulatory pressures, and short-run speculative behaviour rather than by demand shifts alone [28, 29].

6 Current challenges

Despite its strong global market position, the pepper industry faces several critical challenges that threaten the long-term sustainability of production. One of the most significant issues is price instability, which is driven largely by fluctuations in global supply and demand. Rapid expansion of cultivation during periods of high market prices often leads to oversupply, causing sharp price declines and financial pressure on farmers. Such market volatility has been widely reported in studies analyzing the sustainability of black pepper production systems [30]. Another major challenge is overexpansion of cultivation areas, which has contributed to soil degradation and reduced productivity in certain regions. Intensive monoculture systems combined with excessive fertilizer application can degrade soil health and increase the prevalence of soil-borne diseases, threatening the long-term sustainability of pepper plantations [31]. Pest and disease outbreaks are also a serious constraint in pepper cultivation. Among them, foot rot disease caused by *Phytophthora capsici* is considered one of the most destructive diseases affecting black pepper worldwide. This pathogen infects roots, stems, leaves, and fruits, often leading to rapid plant mortality and significant yield losses [32]. The disease is particularly problematic in tropical production regions in which high humidity and poor drainage favor pathogen development. In addition to plant health issues, concerns about food safety and contamination are increasing. Studies have shown that black pepper can be contaminated by pathogens such as *Salmonella* spp. during harvest and post-harvest handling, and such contamination may persist through processing if adequate control measures are not implemented [33]. Furthermore, the pepper industry faces growing sustainability and climate challenges. Changes in rainfall patterns, extreme weather events, and rising temperatures can negatively affect pepper growth, flowering, and yield stability. These environmental pressures highlight the need for improved crop management practices, disease-resistant varieties, and sustainable production systems to maintain the long-term viability of pepper cultivation [34].

7 Conclusion

In conclusion, Vietnam continues to maintain a dominant position in the global pepper market, particularly as a major producer and exporter of pepper products. However, to sustain this leadership in an increasingly competitive and regulated environment, a structural transformation of the industry is essential. This includes shifting from volume-driven production toward quality-oriented and value-added approaches, alongside improvements in traceability, processing technology, and supply chain integration. Future growth of the sector will largely depend on the adoption of sustainable practices and the development of high-value products, enabling Vietnam to strengthen its competitiveness and resilience in the global spice market.

Compliance with ethical standards

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Author contributions

- Phu Hong Le: conceptualization, administrative support, critical revision
- Phuc Nguyen Thien Le: manuscript structuring, manuscript writing (original draft), revision
- Anh Ngoc Nguyen: manuscript structuring, manuscript writing (review and editing)
- Phuong Thi Hai Le: literature collection, proofreading
- All authors read and approved the final manuscript

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