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Grain Trade: A Literature Review and Research Outlook

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ABSTRACT

Grain trade plays a critical role in global grain security and the balance of grain supply and demand across countries. As globalization progresses, the complexity and diversity of grain trade have become increasingly prominent. Its significance extends beyond the economic sphere, directly impacting social stability and international relations. The dynamic development of grain trade is influenced by a variety of factors, including climate change, international economic policies, technological advancements, and geopolitics. At the same time, the complexity of global grain supply chains, the uncertainty of international trade policies, and the frequent occurrence of extreme climate events pose significant challenges to the smooth operation of grain trade. In recent years, there has been growing attention in the international community on how to achieve the sustainable development of grain trade by optimizing policies, strengthening international cooperation, and promoting technological innovation. This study systematically reviews the existing literature on grain trade, providing a comprehensive summary of the research landscape, covering factors influencing grain trade, development trends, supply chain management, and risk management. The goal is to provide a systematic analysis and insights for both academics and policymakers, as well as directions and references for future research. Additionally, the study explores how grain trade has maintained resilience amid global crises such as the COVID-19 pandemic and climate change, and offers strategic recommendations for achieving global grain security. This research aims to further promote the sustainable development of grain trade systems and provide strong support for global grain security and socioeconomic stability.

KEYWORDS

Grain Trade; Globalization; Grain Security; Climate Change; Supply Chain Management

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1. Introduction

Grain trade is a vital component of the global economy, playing an irreplaceable role in ensuring grain security, balancing supply and demand, and supporting agricultural economic development (Abbott, 1979; Y. Chen et al., 2015). As globalization and trade liberalization deepen, the complexity and diversity of grain trade have grown increasingly prominent. Grain trade involves not only balancing supply and demand between countries but also navigating external factors such as climate change, economic policies, geopolitical risks, and technological advancements (Ahn et al., 2023; Liu et al., 2023; S. Yu et al., 2024). Understanding the dynamic changes, challenges, and future directions of grain trade has thus become a key concern for governments and academic communities worldwide.

Globalization has significantly altered patterns of grain production and consumption, reshaping the scale and structure of international grain trade. In recent years, global grain trade has grown at an annual rate of nearly 5%, reflecting its critical role in modern economies (B. Chen et al., 2020). This growth highlights resource endowment differences among countries, making the international circulation of grain essential for balancing global supply and demand (Ozturk, 2020). However, climate change has introduced a pressing challenge. Rising temperatures and frequent extreme weather events increasingly affect grain production, leading to severe shortages in countries reliant on imports. For instance, recurrent droughts in Africa have disrupted food security, while increased production costs due to climate instability have diminished grain competitiveness on international markets (Falkendal et al., 2021).

The institutional framework of globalization, including the establishment of the World Trade Organization (WTO) and free trade agreements, has provided essential platforms for grain trade. Particularly for developing countries, international trade offers opportunities to access technology, capital, and markets (Sadłowski et al., 2023). However, the global grain trade system also faces significant challenges. The increasing complexity of supply chains exposes regions to shortages or surpluses during unexpected events like natural disasters or political conflicts (W. Yu & Bandara, 2017). Additionally, the volatility of climate conditions directly impacts yield and quality, further complicating trade dynamics. Trade policies and geopolitical uncertainties, such as rising protectionism and trade barriers, exacerbate instability in international markets (H. Wang et al., 2024).

Against this multifaceted backdrop, this study aims to provide a systematic review of grain trade by addressing the following key questions: What are the main influencing factors of grain trade? What are the development characteristics of grain trade? How can policy measures and technological innovations promote the sustainable development of grain trade? By synthesizing relevant literature, this paper seeks to provide a comprehensive analytical framework to better understand the evolution, current state, and future prospects of grain trade. This review offers valuable insights for academics and policymakers, helping them address the complex challenges in this field and formulate strategies to enhance sustainability. Grain trade represents not merely the movement of agricultural products across borders but also a reflection of broader dynamics, including agricultural efficiency, policy environments, and technological progress. This study contributes to bridging theoretical and practical perspectives, offering actionable guidance for navigating the intricate landscape of grain trade.

2. Theoretical Insights and Key Literature on Grain Trade

The theoretical foundations of grain trade can be traced back to the development of classical international trade theory. The earliest theory comes from Adam Smith's theory of absolute advantage, which suggests that countries can maximize economic benefits by focusing on the production of goods in which they have an absolute advantage and engaging in exchange. This theory provides a fundamental explanation for grain trade—countries should concentrate on producing agricultural products in which they have a comparative efficiency to maximize profits.

However, the theory of absolute advantage fails to explain how countries without an advantage in producing all goods can still participate in trade. To address this, David Ricardo's theory of comparative advantage was proposed, offering an answer for a broader international trade model (Krugman, 1993). According to the theory of comparative advantage, even if a country has disadvantages in producing all goods, it can still benefit from trade by specializing in products in which it has a relatively smaller disadvantage.

This theory has significant applications in agriculture. Some countries are naturally suited to produce specific grain crops due to favorable climate, soil conditions, and water resources, while other countries may be at a disadvantage in these aspects. Through international grain trade, these countries can specialize in the production of more suitable agricultural products and exchange their excess with others (Baldwin & Harrigan, 2011). For instance, Brazil, with its vast land and favorable climate, is well-suited for growing soybeans and corn, exporting them for economic benefit, while desert countries in the Middle East, due to land and water constraints, rely on imports to meet domestic demand.

With the development of international trade theory, the Heckscher-Ohlin model provided a more specific analytical tool for grain trade. This model emphasizes that the differences in resource endowments between countries are key factors in determining trade patterns (Panagariya, 2000). In the context of grain trade, differences in resource endowments primarily manifest in the availability of land, labor, and capital. Countries rich in land resources, such as Argentina and Canada, are typically grain exporters, as these nations dominate the international market by producing and exporting large quantities of grains and other agricultural products. In contrast, countries with scarce natural resources but high population density, such as Japan and Singapore, rely on grain imports to ensure domestic food security. This resource-based international division of labor has driven the cross-border movement of grain and the formation of a global production model (Chipman, 1965).

However, classical trade theory does not fully explain many phenomena in modern grain trade. With the emergence of new trade theory, research on grain trade has expanded. New trade theory emphasizes the role of economies of scale, imperfect competition, and product differentiation in influencing trade (Brandis, 1968). In grain trade, economies of scale are particularly important—large-scale agricultural production and highly integrated supply chain management enable some multinational agribusinesses to significantly reduce unit production costs, enhancing their competitiveness in the international market (Powell, 1991). For example, large agricultural enterprises in the United States rely on economies of scale, utilizing modern machinery, precision irrigation, and chemical inputs to keep production costs low, thus maintaining a high level of export competitiveness on the global market.

Building upon this, the new-new trade theory highlights the importance of firm heterogeneity. Firm heterogeneity refers to the significant differences between firms in terms of production efficiency, technological capabilities, and management levels, which directly affect their ability to participate in international trade. In grain trade, firms with higher technological levels and efficient management capabilities tend to cope better with production and market risks, thus gaining a competitive edge (Mutz & Kim, 2017). For instance, in global grain production, some multinational firms mitigate risks and reduce transportation costs by establishing production bases in different countries. This model has demonstrated strong supply chain resilience during global crises such as the COVID-19 pandemic (Graf et al., 2012).

Beyond traditional economics, research on grain trade also intersects with various disciplines. One important field is climate economics, which focuses on the impact of climate change on grain production and trade. Climate change is considered one of the key factors influencing modern grain production and trade patterns (S. Zhou et al., 2017). Rising temperatures, changing precipitation patterns, and the increased frequency of extreme weather events are all having profound effects on global grain production (J. Sun et al., 2023). For example, according to reports from the Food and Agriculture Organization (FAO), droughts caused by climate change have severely

impacted grain yields in sub-Saharan Africa, forcing many countries to rely on imports to meet domestic demand. Moreover, climate change has intensified the instability of global grain prices, severely disrupting grain trade (Huang et al., 2011).

Policy economics also plays a significant role in influencing grain trade. Governments often use agricultural subsidies, tariffs, quotas, and export restrictions to regulate their domestic grain markets and ensure national grain security (Smith & Glauber, 2020). For example, the U.S. provides substantial agricultural subsidies through the Farm Bill to support domestic farmers and enhance their competitiveness in the international market. Similarly, the European Union's agricultural subsidies and Common Agricultural Policy (CAP) greatly influence the grain production and trade behavior of member states (Yin et al., 2024). However, these policy measures can also lead to unfair competition in international markets and even spark trade disputes and conflicts (T.-T. Sun et al., 2021).

Meanwhile, changes in international trade policies and geopolitical factors also play a crucial role in grain trade. In recent years, with the instability of international political landscapes, many countries have implemented export restrictions to ensure domestic grain security. For example, Russia and Ukraine are major wheat exporters, but due to geopolitical conflicts, these countries often impose export bans, leading to supply shortages and price fluctuations in the international grain market. While these export restriction policies may secure domestic grain supplies in the short term, they undermine the stability and efficiency of the international grain market in the long term and increase the uncertainty of global grain supply (Yang & Zhang, 2021).

Grain security is one of the core issues in grain trade. Grain security involves the availability, affordability, utilization, and stability of grain, with international trade playing a critical role in each of these dimensions. Through grain trade, grain can be transported from surplus-producing regions to areas with high demand, optimizing the global allocation of grain resources (Ozturk, 2020). However, while international trade enhances grain security, it can also increase the dependency of some countries on grain imports, especially those with scarce natural resources or limited grain production capacity (Noland, 2018). This dependency makes these countries more vulnerable to international market fluctuations, particularly when grain prices rise or exporting countries impose restrictive policies (Crowley et al., 2018).

Additionally, grain trade in the context of globalization faces the challenge of promoting economic growth while achieving sustainable development. The carbon emissions generated during grain production and long-distance transportation are significant sources of global greenhouse gas emissions (Zhang et al., 2022). As such, how to ensure grain supply while reducing the carbon footprint and environmental pollution has become an important topic in current grain trade research. Many researchers suggest that developing green agriculture, optimizing logistics routes, and using renewable energy can help reduce the environmental costs of grain production and trade, thereby achieving sustainable development in grain trade (Cariou et al., 2023).

In summary, the theoretical foundations of grain trade encompass traditional comparative advantage theory, the Heckscher-Ohlin model, new trade theory, and new-new trade theory, while also incorporating interdisciplinary perspectives such as climate economics and policy economics. Thus, it can be seen that these theories and studies collectively provide valuable insights into the complexity of grain trade and its important role in the global economy. Based on this understanding, further analysis reveals that future research should focus on the impacts of climate change, policy adjustments, and technological advances on grain trade. This approach will enable a more comprehensive understanding of the development paths and challenges of grain trade in the context of globalization.

3. Characteristics and Trends in Grain Trade

The development characteristics of grain trade exhibit diversity, complexity, and dynamic change, driven by the forces of globalization. Grain trade is no longer a mere exchange of commodities; it is deeply influenced by multiple

factors such as technology, markets, policies, and environmental conditions. The following is a detailed analysis of the major development characteristics of grain trade.

First, the geographical scope of grain trade continues to expand. With the deepening of globalization, grain trade has gradually shifted from regional exchanges to a global economic activity. The grain supply chain has become globalized, with the flow of grain between countries no longer limited by geographic proximity but facilitated by highly complex global supply chains that enable cross-continental trade (Kabo-Bah & Bannor, 2024; Olabisi et al., n.d.). The grain supply chain linking North America to Asia has become a crucial nexus in the international market. This global mobility has helped address food shortages in many countries, particularly those with unfavorable natural conditions, where grain imports have become an essential means of balancing domestic supply and demand. For example, countries like China and India, with large populations and relatively limited land resources, meet their growing demand by importing crops such as soybeans and wheat from grain exporters like the United States and Brazil. This flow of grain allows nations to mitigate domestic supply-demand fluctuations and improve overall grain security.

Second, the types of participants in grain trade have become increasingly diverse, with multinational corporations playing a particularly prominent role. In the context of globalization, multinational grain trade companies, through modern logistics systems and strong financial backing, have gradually come to dominate the international grain market (He et al., 2020). The concentration of the global grain market continues to rise, with large multinational companies becoming more influential within the global supply chain. These companies not only control the production, processing, and distribution of grain but also consolidate global grain resources through mergers, acquisitions, and partnerships, thereby improving the overall efficiency of the supply chain (Xie et al., 2020). For instance, multinational giants like Cargill, Bunge, and Louis Dreyfus ensure the smooth flow of grain from production areas to consumer markets by integrating production and logistics. However, the involvement of multinational corporations, while improving the efficiency of grain supply, also raises concerns about monopolies and market control. Due to high market concentration, some multinational companies have significant influence over grain pricing in the global market, and during periods of international market volatility, this concentration can exacerbate price instability, threatening grain security in developing countries (W. Wang et al., 2024).

Third, the digitalization of grain trade is becoming increasingly significant, with advancements in information technology reshaping the organization and trading methods of grain trade. Grain trade is gradually transitioning from traditional offline transactions to electronic and digital platforms. The application of e-commerce and blockchain technology in grain trade has made transactions more transparent, convenient, and efficient. Blockchain technology, for example, can track the entire process of grain from production to consumption, ensuring supply chain transparency, reducing information asymmetry, and increasing consumer confidence in grain security (Hu et al., 2024). The rise of digital trade platforms also provides new opportunities for small and medium-sized enterprises to enter the international grain market, thereby partially breaking the traditional monopoly of large companies in grain trade (Li et al., 2024). Additionally, the use of Internet of Things (IoT) technology for real-time monitoring of the grain supply chain has significantly reduced losses during storage and transportation, enhancing the overall efficiency of the supply chain (Lee et al., 2023).

Fourth, regional cooperation in grain trade has grown stronger, with enhanced regional mechanisms providing robust support for cross-border grain flow. Regional organizations, such as ASEAN and the European Union, have promoted the movement of grain between member states by developing unified agricultural policies and reducing trade barriers within regions, thereby improving overall regional grain security. For example, the European Union's Common Agricultural Policy, through agricultural subsidies and market regulation measures, has not only ensured stable grain supply within the EU but has also played a crucial role in responding to external trade shocks (Piesse et al., 2005). The strengthening of regional cooperation reflects the necessity for countries to collaborate within

regions to manage fluctuations in the global grain market amidst globalization and geopolitical instability (Fulton et al., 1998). Regional cooperation enables effective responses to sudden grain supply crises while fostering greater coordination in national grain security policies, thereby enhancing the resilience of the regional grain market (Skevas & Grashuis, 2020).

Moreover, the development of grain trade has been accompanied by significant challenges related to environmental and social sustainability. The expansion of global grain production and trade has intensified pressures on critical resources such as water and arable land, particularly in regions facing water scarcity, where large-scale agriculture could lead to groundwater depletion (Xia et al., 2022). Additionally, long-distance transportation of grain contributes to carbon emissions, conflicting with global climate goals (Liu et al., 2023). Addressing these challenges requires minimizing environmental impacts while expanding trade. Strategies such as adopting green agriculture, sustainable farming practices, and optimizing logistics routes can significantly reduce the ecological footprint of grain trade (Novo et al., 2009). For instance, using clean energy for transportation and sustainable technologies in production can mitigate resource wastage, fostering the sustainable development of global grain trade.

Finally, the development characteristics of grain trade also highlight issues of social inequality and limited inclusiveness. The expansion of grain trade has enabled some developed countries and multinational corporations to reap substantial profits by controlling market resources and supply chains, while small farmers in producer countries, particularly in developing nations, often fail to benefit (Porteous, 2020). Due to market concentration and intense competition, small farmers in developing countries have relatively weak bargaining power in the grain supply chain, often having to sell their products at low prices, while the added value is predominantly captured by multinational corporations from developed countries. To address this issue, many scholars and policymakers suggest increasing financial support for small farmers, enhancing technical training, and promoting fair trade practices to improve the position of small farmers in the grain supply chain, thereby fostering social inclusivity in grain trade (Rivera-Padilla, 2020).

In conclusion, the development characteristics of grain trade reflect multiple facets, including globalization, multinational corporate dominance, digital transformation, enhanced regional cooperation, and challenges related to environmental and social sustainability. Thus, it can be seen that these characteristics not only underscore the importance and complexity of grain trade within the global economic system but also reveal the multifaceted challenges and opportunities in addressing environmental, social, and economic sustainability. Based on this development trend, further analysis reveals that future research can continue to explore how policy innovations and technological advances may promote the sustainable and inclusive development of grain trade. Such efforts are critical to better addressing the pressing challenges of global grain security.

4. Prospects and Strategic Pathways for Grain Trade

The future development pathways of grain trade need to be explored from multiple dimensions, including policy support, technological innovation, international cooperation, supply chain management, and sustainability. As globalization deepens and factors such as climate change and geopolitical instability influence the global economy, the future of grain trade is fraught with both challenges and opportunities. The following is a detailed discussion of the future development pathways of grain trade.

First, policy support is a critical safeguard for the development of grain trade. Governments need to promote the liberalization and facilitation of international grain trade by formulating trade policies, reducing tariffs, and eliminating non-tariff barriers, all while ensuring national grain security (Brown et al., 2020; Qian et al., 2020). The design of grain trade policies must be coordinated on multiple fronts to ensure the stability of grain supply, while also considering social fairness and environmental sustainability (Nuhu et al., 2021). For instance, the European

Union's Common Agricultural Policy has played a crucial role in improving Europe's self-sufficiency in grain by providing agricultural subsidies, improving infrastructure, and optimizing market conditions, while also addressing global fluctuations in grain supply (Carillo, 2021). Additionally, some developing countries are increasingly turning to policy interventions to ensure the stability and diversity of grain imports to cope with the volatility of global markets.

Second, technological innovation plays an essential role in the future development of grain trade. The application of modern agricultural technologies and advancements in information technology can significantly improve the efficiency of grain production and circulation (W. Wang et al., 2024). For example, precision agriculture technologies, utilizing data analysis, automated tools, and drones, enable farmers to monitor the cultivation process in real-time, optimizing agricultural production, reducing resource waste, and increasing grain yield per unit of land (Mercier, 1999). In grain supply chain management, blockchain technology enhances transparency by recording and tracking every link in the chain from production to sale, ensuring the quality and reliability of grain sources (van Meijl & van Tongeren, 1998). Moreover, IoT technology can monitor conditions such as temperature and humidity during grain storage and transportation in real time, thus reducing losses in the logistics and warehousing process.

Beyond production technologies, modern logistics technologies are also key to the future of grain trade. The development of cold chain logistics has made grain supply chain management more efficient, especially for perishable agricultural products in cross-border transport. Cold chain technologies significantly reduce grain losses and increase trade efficiency (Wilson et al., 2004). For instance, India has strengthened its cold chain infrastructure in recent years, improving its export capacity for dairy products and fruits, which has significantly enhanced its competitiveness in the global grain market (Yin et al., 2024). Further technological innovation and infrastructure development in logistics are necessary to ensure the efficient flow of grain.

International cooperation is another key factor for achieving the sustainable development of grain trade. Since grain issues are global in nature, they require cooperative efforts between countries to address them effectively. International organizations, such as the World Trade Organization (WTO) and the Food and Agriculture Organization (FAO), can facilitate multilateral cooperation by establishing effective international trade rules and agreements to reduce trade barriers and ensure the free flow of grain (Nuhu et al., 2021). Furthermore, regional trade agreements play an important role in strengthening international cooperation. Through collaboration within regions, more efficient grain distribution can be achieved, mitigating imbalances in supply and demand caused by climate or disaster-related factors (Svanidze & Götz, 2019). For example, ASEAN countries have reduced internal tariff barriers through free trade agreements, enhancing the mobility of grain and improving regional grain security. Strengthening international cooperation can also help by sharing agricultural technologies and experiences, thus enhancing the production capacity of member states and ultimately achieving global grain security (Xia et al., 2022).

The future development of grain trade must also focus on optimizing supply chain management. The complexity of the grain supply chain makes it vulnerable to various risks, such as natural disasters, political conflicts, and logistics disruptions. Therefore, building a resilient supply chain management system is crucial for ensuring the sustainable development of grain trade (Huang et al., 2011). By enhancing coordination and information sharing among supply chain links, and improving the ability to respond to emergencies, the loss of grain during transportation and storage can be minimized (L. Zhou & Turvey, 2014). For instance, establishing regional grain reserve centers can effectively alleviate the risk of supply disruptions caused by sudden events. These reserves can help ensure grain supply during natural disasters or political instability, preventing drastic market price fluctuations. Additionally, the digitalization of supply chains can improve the efficiency of grain circulation, as real-time monitoring and information sharing make the supply chain more flexible and controllable (Yin et al., 2024).

Sustainable development in grain trade is a critical issue that must be addressed in the future. The expansion of grain trade needs to strike a balance between environmental and social sustainability, particularly in response to climate change and resource constraints. The sustainability of grain trade becomes especially important when considering the environmental impact of agricultural production and the carbon emissions associated with long-distance transport (Y. Chen et al., 2015). Agriculture is a significant source of greenhouse gas emissions, and long-distance transportation of grain further exacerbates carbon emissions. Therefore, reducing the carbon footprint of grain trade is a necessary direction for future development (Bacon et al., 2014). Low-carbon agricultural practices, energy-efficient logistics, and optimized transportation routes can all contribute to reducing the environmental impact of grain trade (Maiyar & Thakkar, 2020). For example, using renewable energy vehicles for grain transportation and developing localized agriculture to reduce transport distances are effective strategies for improving the environmental sustainability of grain trade.

In terms of social sustainability, grain trade must also address potential inequalities that may arise in the trade process, ensuring fair distribution of benefits between grain producing and consuming countries (Sotelo, 2020). In particular, in developing countries, the expansion of grain trade should benefit small farmers and vulnerable groups locally, contributing to socially inclusive development. Fair trade mechanisms can ensure that grain producers receive more reasonable income, improving their production conditions and living standards (Kathiresan et al., 2020). Furthermore, governments and NGOs can support small farmers by providing financial assistance, technical training, and market access, helping them better participate in the international grain market, improving their income levels, and reducing poverty (Bendinelli et al., 2020). Future grain trade policies should focus on achieving a balanced coordination of economic benefits, environmental protection, and social fairness.

Lastly, the development of grain trade faces unpredictable challenges, such as extreme weather due to global warming, supply chain disruptions caused by political conflicts, and logistical issues related to pandemics. Addressing these challenges requires joint efforts from governments, international organizations, businesses, and academia (Maiyar & Thakkar, 2019). Future research should delve deeper into risk management in grain trade, such as establishing an international grain risk management platform to monitor and assess global supply chain risks in real time, thereby formulating effective response strategies (Kabo-Bah & Bannor, 2024). Predictive data analysis can also be used to forecast potential supply chain disruptions and develop contingency plans in advance, ensuring the stability and continuity of grain trade.

In conclusion, the future development pathways of grain trade require coordinated efforts across multiple dimensions, including policy support, technological innovation, international cooperation, supply chain management, and sustainability. Based on this development trend, further analysis reveals that appropriate policies and technological advancements can significantly enhance the efficiency and sustainability of the grain trade system, thereby contributing to global grain security. Thus, it can be seen that in this process, academia and policymakers must continue to integrate research and practice, driving the role of grain trade in addressing environmental, economic, and social sustainability challenges. This integration provides practical and effective solutions to future global grain crises. From this perspective, it becomes clear that the sustainable development of grain trade is not only a pursuit of economic benefits but also a reflection of global shared welfare. Future research should continue to focus on the comprehensive development of grain trade, striving to achieve genuine global grain security.

5. Conclusion and Research Outlook

Grain trade plays a vital role in global food security and economic development. By systematically reviewing the theories, influencing factors, developmental characteristics, and future trajectories of grain trade, we can better understand its complexity and the profound impact it has on the agriculture and economies of various countries. With the deepening of globalization, grain trade has become not only an exchange of economic interests but also an

essential tool for achieving food security strategies. Future research and policy formulation should further deepen our understanding of the multifaceted factors influencing grain trade to establish a more sustainable and equitable global grain system.

From a conclusive perspective, the development of grain trade is influenced by various factors such as climate change, policy adjustments, technological advancements, international cooperation, and supply chain management. Traditional international trade theories, including comparative advantage theory, the Heckscher-Ohlin model, as well as new trade theory and new-new trade theory, provide theoretical foundations for explaining the drivers and evolution of grain trade. By optimizing resource allocation and facilitating the international flow of production factors, grain trade has effectively alleviated the imbalances in global grain supply and demand (Savary et al., 2020). However, with the continuous evolution of the external environment, grain trade now faces new challenges. Climate change has increased the uncertainty surrounding grain production, while protectionist policies adopted by various governments have exacerbated global grain supply instability (Liverpool-Tasie & Parkhi, 2021). Moreover, the fragility of international cooperation and market monopolies held by multinational corporations have become significant barriers to the development of grain trade.

Looking forward, the development of grain trade requires advancement across multiple dimensions. First and foremost is policy support. Governments must promote the liberalization and facilitation of international grain trade while ensuring domestic grain security (T.-T. Sun et al., 2021). This includes reducing trade barriers, increasing market access, and regulating trade behavior through international agreements to foster fair competition (Falkendal et al., 2021). Simultaneously, the application of technological innovations is critical to improving the efficiency of grain production and distribution. The adoption of emerging technologies such as precision agriculture, the Internet of Things (IoT), and blockchain can not only enhance production efficiency but also ensure transparency and traceability in the grain supply chain, reducing losses during the supply chain process and safeguarding global food security (Balié & Valera, 2020).

International cooperation's importance in the future development of grain trade cannot be overstated. Global food security is a transnational issue requiring collective action through international organizations, bilateral, and multilateral agreements (D. Sun et al., 2021). For instance, organizations like the Food and Agriculture Organization (FAO) and the World Food Programme (WFP) are playing an increasingly important role in the global food security system. By fostering cooperation and information-sharing among countries and establishing international grain reserves, these organizations can effectively mitigate the risks to grain supply posed by climate change and natural disasters (Hoffmann et al., 2021). Regional cooperation, such as ASEAN's grain security reserve mechanisms and the European Union's Common Agricultural Policy, also plays a crucial role in ensuring regional food security (Ortega-Beltran & Bandyopadhyay, 2021).

The optimization of supply chain management is another core element for the sustainable development of grain trade. The grain supply chain in the context of globalization is becoming increasingly complex, with interconnected stages where any disruption in one link can have significant repercussions for the entire supply chain (Liverpool-Tasie & Parkhi, 2021). Therefore, future research should focus on improving the resilience of the supply chain, including optimizing logistics networks, expanding cold chain facilities, and establishing information-sharing platforms (Grabs & Carodenuto, 2021). Intelligent management of supply chain stages can effectively reduce grain losses, improving efficiency and stability across the entire supply chain (Reardon et al., 2021).

While advancing grain trade, environmental and social sustainability must be prioritized. Carbon emissions from grain production and transportation are major contributors to global climate change. Future efforts should focus on adopting renewable energy sources and low-carbon transportation methods, alongside the development of green trade (Harris, 1996). Moreover, grain trade must consider social equity, particularly in terms of protecting the rights of smallholder farmers in developing countries. By establishing fair trade mechanisms, increasing

financial support, and providing technical training to small farmers, their standing in the international market can be enhanced, allowing them to benefit from global grain trade and facilitating more inclusive trade development (Kabo-Bah & Bannor, 2024; Maiyar & Thakkar, 2019).

We believe that future research should focus on the following key areas: First, the dynamic relationship between climate change and grain trade. Studies should explore how climate change impacts global grain production and trade, and how policy measures can help countries adapt. Combining climate models with grain trade models can predict future shifts in supply and demand, offering valuable guidance for policymakers. Second, the role of technological innovation in advancing grain trade. Researchers should assess the applications of IoT, blockchain, and artificial intelligence in production, storage, and transportation, focusing on their impact on efficiency, cost reduction, and transparency. Further exploration of automation, drone monitoring, and genetic modification technologies could reveal their potential in increasing grain yields and ensuring food security.

Third, optimizing international cooperation and trade regulations. In a globalized context, food security is a shared global challenge. Research should examine how multilateral cooperation, trade agreements, and international organizations can reduce uncertainties in grain trade, promote fair distribution, and address global food security gaps. Fourth, enhancing resilience and risk management in the grain supply chain. Globalization introduces complexities that require robust supply chain resilience. Future studies should explore flexible and adaptive systems to mitigate risks from natural disasters, climate change, and geopolitical conflicts. Early-warning systems and reserve mechanisms are also crucial for ensuring global grain market stability.

Finally, social equity and inclusive development. Research should address fairness and inclusivity, particularly for developing countries and smallholder farmers. Emphasis should be placed on distributing the economic benefits of grain trade more equitably, using policies and aid to enhance market competitiveness for vulnerable groups. This approach can reduce global food insecurity and promote a more equitable and sustainable trajectory for grain trade.

In conclusion, grain trade is a complex system, influenced by a combination of economic, political, social, and environmental factors. Thus, it can be seen that addressing these challenges requires a holistic understanding of their interactions. Future research should aim at achieving global food security and sustainable development by comprehensively considering the interplay of these factors. Based on this development trend, further analysis reveals that a multi-level, multi-dimensional approach is essential for in-depth exploration. Only through effective integration of policy innovation, technological advancements, international cooperation, and supply chain management can we address the challenges facing global grain trade. This integration is vital for achieving sustainable and inclusive development while ensuring global food security and social stability. Building on this perspective, it becomes evident that ongoing research and practice are critical for actively contributing to global food security in an ever-changing global environment. The sustainable development of grain trade is not only a demand for economic growth and food security but also a crucial path toward maintaining global social equity and environmental health. By synthesizing these insights, we conclude that future research on grain trade must continue to advance both theoretically and practically, offering effective solutions to global food challenges. Ultimately, this approach aligns with the overarching goal of achieving true global food security and sustainable development.

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